MICROFICHE REFERENCE LIBRARY

A project of Volunteers in Asia

Rice: Postharvest Technology

by: E.V. Araullo, D.B. De Padua and Michael
Graham, eds.

Published by:
International Development Research Centre
60 Queen Street
P.O. Box 8500
Ottawa, Canada K1G 3H9

Paper copies are $20.00; free to local groups in
developing countries.

Available from:
International Development Research Centre
60 Queen Street
P.O. Box 8500
Ottawa, Canada K1G 3H9

Reproduced by permission of the International
Development Research Centre.

RICE
postharvest technology

Editors: E. V. Araullo, D. B. de Padua, and Michael Graham

RICE
Postharvest Technology

Edited by   E. V. ARAULLO
   International Development Research Centre
   Singapore

D. B. DE PADUA
   University of the Philippines at Los Baños

MICHAEL GRAHAM
   International Development Research Centre
   Ottawa

Foreword

The contents of this publication represent an immense amount of thoughtful and valuable work. It is indeed encouraging to observe how much attention and investment is being devoted to increasing the yield potential of the rice plant and to the development and demonstration of improved systems of rice production in South and Southeast Asia. On the other hand much less effort has been devoted to the postharvest rice system: the continuum of activities that begins with the harvest and ends when the rice grain is eaten and its by-products are efficiently used.
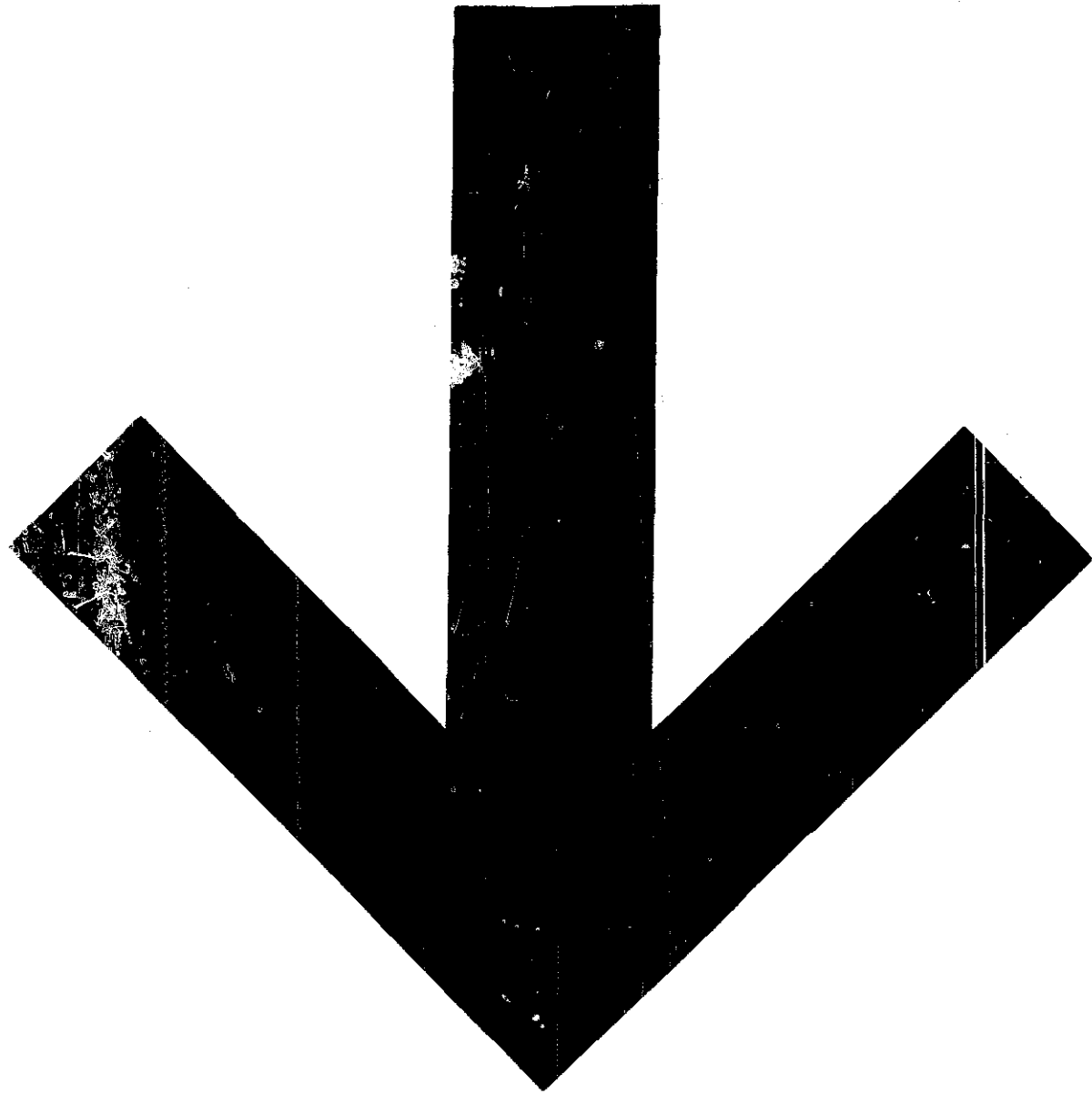
This training manual, which is the outcome of a regional training course presented at the University of the Philippines at Los Baños, provides a wealth of useful information and advice to all who are directly concerned with rice production, protection, processing, marketing, distribution, and use. The contributors, together with all those who took part in organizing and presenting the course, and in the design, compilation, and editing of this publication are to be warmly congratulated upon the service they have rendered to international food and agricultural development.

JOSEPH H. HULSE
Program Director
Agriculture, Food and Nutrition Sciences
International Development Research Centre
Ottawa, Canada

Contributors

John Rawnsley   Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines

Bienvenido O. Juliano   Department of Agricultural Chemistry, International Rice Research Institute, Los Baños, Laguna, Philippines

Noel G. Mamicipic   Department of Agronomy, University of the Philippines at Los Baños, College, Laguna, Philippines

U Thet Zin   Food and Agriculture Organization of the United Nations, Regional Office, Bangkok, Thailand

Harry van Ruiten   Department of Agricultural Engineering, University of the Philippines at Los Baños, College, Laguna, Philippines

M. B. de Ramos   College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines

Amir U. Khan   Department of Agricultural Engineering, International Rice Research Institute, Los Baños, Laguna, Philippines

James M. Beck   Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines

D. B. de Padua   Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines

Florendo C. Quebral   Department of Plant Pathology, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines

Nawab Ali   Agricultural Engineering Department, Indian Institute of Technology, Kharagpur-721302 W.B., India

T. P. Ojha   Agricultural Engineering Department, Indian Institute of Technology, Kharagpur-721302 W.B., India

James Wimberly   IRRI – Ford Foundation Sri Lanka, Rice Processing Project, Colombo, Sri Lanka

Nora C. Quebral   Department of Development Communications, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines

Bart Duff   Department of Agricultural Engineering, International Rice Research Institute, Los Baños, Laguna, Philippines

Ida Estioko   Department of Agricultural Engineering, International Rice Research Institute, Los Baños, Laguna, Philippines

J. D. Drilon   Southeast Asian Regional Centre for Graduate Study and Research in Agriculture, College, Laguna, Philippines

Vicente U. Quintana   Agricultural Credit and Cooperative Institute, University of the Philippines at Los Baños, College, Laguna, Philippines

Manuel B. Villar, Jr. University of the Philippines at Los Baños, College, Laguna, Philippines

Jose C. Lapus University of the Philippines at Los Baños, College, Laguna, Philippines

R. Chandrasekaran Paddy Processing Research Centre, M. R. Mill, Tiruvarur, S. India

P. Pillaiyar Paddy Processing Research Centre, M. R. Mill, Tiruvarur, S. India

Sjuhinar Bustami Rice Mill "Sinar Kongsi," 58 Diponegoro, Padang, W. Sumatra, Indonesia

Kong Samol Agriculture Department, Phnom Penh, Khmer Republic

Chhieu Nam Agriculture Department, Phnom Penh, Khmer Republic

Thao Sommai Department of Agriculture, Vientiane Province, Laos

Luang Baccam Department of Agriculture, Vientiane Province, Laos

Ahmad Annuar bin Mohd. Ibrahim National Padi and Rice Board, Tingkat 20-21, Bangunan UMBC, 4 Jalan Sulaiman, Kuala Lumpur, Malaysia

Abdul Rahman bin Mohd. Dalib National Padi and Rice Board, Tingkat 20-21, Bangunan UMBC, 4 Jalan Sulaiman, Kuala Lumpur, Malaysia

Salim bin Abdul Hamid National Padi and Rice Board, Tingkat 20-21, Bangunan UMBC, 4 Jalan Sulaiman, Kuala Lumpur, Malaysia

T. B. Karki Ministry of Food, Agriculture, and Irrigation, Department of Food, Agriculture, and Marketing Services, Shri Mahal, Kathmandu, Nepal

Ernesto Tubon Technical Research and Services Division, National Grains Authority, Quezon Boulevard Extension, Quezon City, Philippines

Javier Lozada, Jr. Technical Research and Services Division, National Grains Authority, Quezon Boulevard Extension, Quezon City, Philippines

B. D. E. M. Pereira Paddy Marketing Board, P.O. Box 205, Colombo 5, Sri Lanka

F. S. Y. Samuel Paddy Marketing Board, P.O. Box 205, Colombo 5, Sri Lanka

Chaw Suvansatit 516/19 Larnluang Road, Bangkok, Thailand

Prayoon Sawangsak College of Agriculture, Kasetsart University, Bangkok 9, Thailand

C. L. Intong, Jr. Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines

RICE
Postharvest Technology

Introduction

A cooperative research program in postharvest rice technology was initiated by a working group of food scientists and technologists from Asia that met first in Singapore in March 1972. One of the priorities identified by this group was the need for short courses, training sessions, and seminars dealing with postharvest systems. Training sessions were specifically needed to provide intensive training for development managers, technicians, and engineers so that they could return to their countries to rehabilitate old facilities, to manage and operate new and existing complexes, and to serve as extension engineers.

This manual is derived from material prepared for one such training course in postharvest technology that took place at the University of the Philippines in April 1973 and was sponsored, in response to the working group's recommendation, by the IDRC and the Canada Plus One Project in cooperation with the Southeast Asian Centre for Agriculture and the United Nations Development Program Grain Industries Project (RP/UNDP SF/PHI-70 534).

The introductory sections describe some of the anatomical and biochemical properties of the rice grain in relation to postharvest processing problems. By examining the mechanical and thermal stresses that are applied during processing operations in conjunction with the anatomy of the rice grain, insight is obtained into the causes of breakage during various processing operations. Biochemical studies are correlated to variations in milling and cooking quality to identify the critical factors for consumer preference and to examine the effect of grain hardness on milling quality.

The importance of the seed to the viability of the whole grain industry is stressed in Standards, and two methods of maintaining seed quality, the limited generation system of seed multiplication and seed certification, are presented. In order to establish quality standards it is essential that grain should be graded. The advantages and disadvantages of various grading machines and their operational principles are examined. However, to ensure the accuracy of both grading and laboratory analyses, it is essential that proper experimental design and sampling techniques be used. These subjects are reviewed and a model grading system and the Philippine rice grading specifications are included as practical examples.

Suitable harvesting and threshing methods are required to achieve the optimum benefit from improved production techniques. Harvesting and Threshing covers the gradual changeover, from labour-intensive manual operations to mechanization, that is occurring in the tropical regions of the world. The constraints affecting farmers, farms, crops, and equipment are stressed,

and the methods for harvesting and threshing and their influence on grain yield and quality are reviewed.

A review of the principles of psychrometry and some examples of the practical application of the psychrometric chart are included in Drying since a knowledge of the properties of air is essential for an understanding of the processes involved in grain drying and storage. The significance, representation, and determination of the moisture content of the grain are stressed since moisture content is one of the most important indices for timing the harvest and for ensuring safe storage and maximum milling recovery. Because the rice grain is a living, respiring biological product, its respiration rate must be reduced for safe storage by decreasing its moisture content to 14% or less on a dry weight basis. The principles and practices used for reducing the moisture content are outlined and several systems are described.

The climatic conditions of Southeast Asia are very favourable to rapid insect and microbial growth, and in general create unique problems for grain storage. Therefore, careful consideration must be given to the methods of construction of storage facilities. In Storage the biological and physical constraints governing safe storage and the problems associated with infestations of moulds, insects, and other storage pests are discussed. Recommendations are given for the prevention of infestations and for other design parameters of storage facilities, such as methods of temperature and relative humidity control especially suited to the tropics.

Many premilling techniques have been devised to increase the milling, nutritional, cooking, and eating quality of rice. The latest and most widely used of these treatments is parboiling. Parboiling technology has evolved from simple methods to complex industrial ones, and several methods and their advantages and disadvantages are described. The basic principles of parboiling and their effect on chemical, biological, and eating quality are outlined. Costs analyses of both a traditional and a modern parboiling plant are presented to point out differences in the cost of parboiling and drying one tonne of paddy.

Regardless of whether or not the rice is parboiled, it must be hulled and milled efficiently. However, maximum efficiency and yield can only be ensured by correct adjustment and operation of the milling machinery. The machines are described in great detail in Milling, affording insight into their operation, and providing a firm basis for an understanding of the principles of their operation. By combining the description of their operation with the preceding information on the characteristics of the rice grain, precautions and recommendations for precleaning, hulling, husk and paddy separation, whitening, polishing, and glazing are obtained. The comparative performance of different rice mills is also illustrated.

The methods and systems of moving both bulk and sacked grain are discussed in Handling and Conveying. Several conveying systems are shown and the uses and advantages of each system are discussed.

The section on Implementation is devoted to the software necessary for the successful development of the grain industries. The importance of effective communication of the improvements in processing technology are outlined, and the necessity of establishing design criteria that meet the needs of developing countries are explained. Agribusiness management concepts and cooperatives are reviewed to furnish ideas for effective organization and col-

laboration for the benefit of both the individual farmer and the whole processing industry. In addition, two case studies are presented.

In Processing Methods the practices and special problems related to the rice processing industries in various Southeast Asian countries are examined, and suggestions for improvements and modifications to increase the efficiency of individual systems are explained.

An Appendix includes the results of drying and milling tests and the labour and power requirements for various harvesting and processing operations and provides a basis for some general comparisons between different systems and procedures. In addition, biological and physical properties of both the rice plant and the grain are given.

By virtue of its broad coverage, the manual is designed to be both a teaching aid for future training sessions and a convenient reference for those engaged in improved methods of rice technology.

To all those people who contributed directly or indirectly to the success of the training course that formed the basis for this manual, and in particular to the staff of the University of the Philippines at Los Baños, I wish to express my sincere thanks.

E. V. ARAULLO
Senior Program Officer
Agriculture, Food and Nutrition Sciences
International Development Research Centre
Asia Regional Office
Singapore

BIOLOGY

Anatomical
Studies

An understanding of the gross anatomy of the rice grain will: (1) clarify the reason rice kernels break so easily on mechanical impact during the physical operations of threshing and milling and under thermal stress during drying; (2) give a fairly precise visual determination of the degree of milling and, consequently, the period of whitening that will produce a particular combination of the required recovery, nutrition, and palatability; (3) indicate a means of visually examining the effects of different hulling methods on the surface tissue of the grain kernel and the importance of this in storage; (4) demonstrate the importance of the correct adjustment of hulling machines to take advantage of the structure of the grain in preventing breakage; and (5) present the possibilities in certain circumstances of benefitting from the much greater bulk density of brown rice compared with paddy and, therefore, economizing on storage volume.

Anatomy of the Rice Grain

The outermost tissue of the grain is commonly known as the husk and is formed from two specialized leaves, the lemma covering the dorsal part of the seed and the palea covering the ventral portion. The palea and lemma are very loosely joined together longitudinally by means of an interlocking fold on each side of the seed, and they are consequently very easily separated. The husk is formed mostly of cellulosic and fibrous tissue and is covered with very hard glass-like spines. In the dry seed there is a distinct space between the husk and the caryopsis (kernel).

The outermost layer of tissue of the caryop-sis is a thin sheet of fibrous cells, the pericarp. This is sometimes called the silver skin because of its very flimsy and fibrous appearance when it is dissected from the grain. The thin pericarp layer is a very hard tissue that is highly impermeable to the movement of oxygen, carbon dioxide, and water vapour. When it is intact it provides very good protection against mould attack and oxidative and enzymatic deterioration of the underlying tissues. Beneath the pericarp is the tegmen, which is a layer several cells in thickness. These cells are also a part of the seedcoat but are less fibrous than the pericarp layer. They are rich in oil and protein but contain little starch. Beneath the tegmen is a layer of tissue several cells in thickness commonly known as the aleurone layer or bran. This layer of cells is very rich in protein, oil, and vitamins with a relatively small amount of starch. The shape of the cells is somewhat hexagonal to spherical. The innermost tissue of the caryopsis is the starchy endosperm, which contains only a very small percentage of protein. In the central core of the grain the starchy cells are somewhat hexagonal in shape, but between the centre and the outside they are elongated with the long walls radiating outwards from the centre. It is the radial walls of the starchy cells that form thousands of potential cleavage planes that may result in breakage of the grain as a result of mechanical impact or thermal or moisture stress during processing.

In cross section the total caryopsis has an undulating shape, the undulations corresponding with those of the husk. The undulating form is important in the whitening process because the bran layer can only be removed entirely when the undulations have been completely levelled.

Significance of Grain Anatomy in
Processing and Handling

The paddy grain, which is very fibrous and covered with hard spines, is very abrasive and easily causes wear and tear in mild steel conveying ducts. For this reason, chain, flight, and belt conveyors are often used.

The distinct space between the husk and

the caryopsis in dried grain allows the grain to be dehusked without any or with very little abrasion to the pericarp. Provided the clearance between the shearing surfaces of the hulling machinery is very critically adjusted, the palea and the lemma can be separated from the caryopsis with only a minimal mechanical stress against the surface of the caryopsis. Dehusking between rubber rollers can be effective without scratching the pericarp. On the other hand, with the emery disc type of hulling, even if very well adjusted, it is difficult to avoid at least some abrasion of the pericarp. When such abrasion does occur, it usually results in damage to the oily layers beneath the pericarp that release lipase enzyme, which results in enzymatic hydrolysis of the oil to produce free fatty acids, that are commonly manifested as rancidity. If the grain is to be stored in the form of brown rice, it is extremely important that the pericarp of the caryopsis is not damaged during the dehusking process. There are a number of advantages to be gained from storing the grain as brown rice, principally the fact that brown rice occupies about half the volume of an equivalent quantity of paddy. It may also be useful to store the grain as brown rice in large milling centrals because they are equipped to dispose of the large quantities of husk created.

The radiating configuration of the outer starchy cells of the endosperm makes breakage very easy in the grain. The risk of such breakage is quite clearly much greater when impact is exerted along the side of the grain rather than at the end. It has been observed that breakage during the manual beating of grain, even at a moisture content of about 20%, is much greater than in certain types of mechanical threshing where the force is applied to the ends of the grain. The alignment of the longitudinal walls of the starch cells across the body of the grain makes it very friable during the drying process and when the temperature of the grain reaches 48 °C, thermal stress is likely to cause breakage. Further mechanical stress may be the cause of grain breakage during conveying and milling.

It is very important to avoid breakage of the rice because in the whitening stage of the milling process, the surface area of the grain exposed to abrasion is much greater, and much more than bran is lost. This results in a low total recovery and a low recovery of whole grain.

Some Staining Techniques that Reveal the Action of Milling Machinery

It has been mentioned that in rubber roll hulling the husk may be removed without damage to the pericarp layer of the caryopsis. This is particularly important in storage, because the pericarp layer is highly impervious to gaseous exchange, and protects the bran oil from oxidation and hydrolysis. On the other hand, it is difficult to avoid at least some abrasion of the pericarp during emery disc type hulling. This effect can be observed with the naked eye by staining the grain with a standard solution of iodine in alcohol and water. Where the pericarp is damaged the exposed starchy cells below take on an almost black colour, and the pericarp and bran cells are not affected.[1] With rubber roll hulling there may be no starchy endosperm exposed, but almost invariably emery disc hulling leaves the pericarp extensively pitted, resulting in the corresponding pattern of black stains with iodine. Such abrasion of the pericarp tissue may also be accompanied by grain breakage or cracking as a result of mechanical stress.

Iodine staining may also be used to determine at what point during the whitening cycle the bran is removed completely. During whitening the pericarp may be removed during the first 15 s, leaving the starchy endosperm virtually untouched and covered with most of the bran. At this point the fibrous tissue, which is usually regarded as objectionable from the eating point of view, is already removed completely. Most of the soft bran tissue is removed during the next 1.5–2 min, leaving only a small amount of bran with most of the starchy endosperm exposed. Continued whitening usually results in the removal of the ridges of the caryopsis only, still leaving the strips of bran in the depressions between the ridges. Com-

---

[1]Details of the chemical composition of the rice grain are found in "Biochemical Studies."

plete whitening, with removal of almost all the bran, may only be achieved by polishing, following 4–6 min of whitening.

The grain might be considered as quite palatable after only 1.5–2 min of whitening and if this were the case, it would fortunately coincide with high recovery and high nutritional value because most of the protein and vitamins, in addition to oil, are in the bran layer.

The removal of the bran may also be demonstrated by staining the progressively whitened rice with a standard solution of Sudan 4 in alcohol and water. This stain causes a red coloration in oily tissue, and consequently the bran and the germ are very clearly stained. This staining produces a pattern, which is the reciprocal of the iodine staining.

The staining techniques described above cannot be universally standardized because they are useful only to describe what happens in a particular set of rice machinery. The removal of the bran, with the same rice variety, has a different rate in, for example, cone-type whitening, abrasive disc-type whitening, and horizontal steel cylinder whitening. — JOHN RAWNSLEY. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Biochemical Studies

The rice grain consists of the edible portion, brown rice, enclosed by the hull or husk. Starch is the major constituent of rice and is present in the endosperm as compound granules 3–10 μm in size. Protein is the next major constituent and exists in the endosperm as bodies 1–4 μm in size. The concentration of nonstarch constituents is higher in the bran and germ fractions than in the endosperm.

Starch and protein accumulation in the grain is essentially complete 3 weeks after flowering. Opaque portions in nonwaxy or nong   ous grains contribute to high grain breakage during milling. Cooking time is affected directly by the gelatinization temperature of the starch and by the protein content. The amylose/amylopectin ratio is the major factor influencing water absorption and volume expansion during cooking, as well as the texture and gloss of boiled milled rice. However, varieties of similar amylose content are known to differ in eating quality due to differences in starch gel consistency and viscosity. Aging through storage results in higher total and head rice yields, greater water absorption and volume expansion during boiling, a more flaky boiled rice, and reduced solubility of starch and protein in water.

Gross Composition and Properties of Brown Rice

Proximate Analysis

The edible portion of rough rice, the brown rice, consists of about 8% protein, 75% carbohydrates, and small amounts of fat, fibre, and ash at 14% moisture (Table 1). Milled rice (endosperm) has 7% protein and 78% carbohydrates (mainly starch). These nutrients are unevenly distributed in the rice seed. The nonstarchy constituents, particularly fat, fibre, minerals (ash), and vitamins, are concentrated in the aleurone layers and germ; whereas, starch is found mainly in the endosperm. Protein distribution in the grain cross section becomes more even as protein content increases.

Properties of Starch and Protein

Starch and protein are the major constituents of milled rice. Starch is present in the form of compound granules 3–5 μm in size. These starch granules are polyhedral due to their close packing in the endosperm cells of the mature grain. The protein in the endosperm exists in the form of discrete particles (protein bodies) 1–4 μm in size.

TABLE 1. Caloric and nutrient contents of brown and milled rices and the losses during milling.

	Brown rice (Pinawa)	Milled rice (Bigas)	Loss during milling (%)[a]
Moisture	14.0	14.0	10
Food energy (Kcal/100 g)	352	354	10
Protein (g/ 100g)	8.3	7.1	23
Fat (g/100 g)	1.9	0.5	76
Total carbohydrate (g/100 g)	74.9	77.8	6
Fibre (g/100 g)	0.7	0.4	49
Ash (g/100 g)	1.1	0.6	51
Calcium (mg/100 g)	9	8	20
Phosphorus (mg/100 g)	183	104	49
Iron (mg/100 g)	1.6	1.2	32
Thiamine (mg/100 g)	0.29	0.10	69
Riboflavin (mg/100 g)	0.07	0.05	36
Niacin (mg/100 g)	3.9	2.3	47

[a]Based on 10% bran removal and on the total nutrient content of brown rice.

Starch molecules in the granule occur in an orderly arrangement giving crystallinity to the granule in both waxy and nonwaxy rices. One characteristic physical property of the starch is its gelatinization temperature, the temperature range in which the starch granules start to swell irreversibly in hot water with loss of crystallinity. The range of final gelatinization temperature of rice starch is 56–59 °C. Gelatinization temperature is measured by the extent of disintegration of milled rice in the alkali test.

Starch granules are fairly hygroscopic; therefore, the moisture content of the rice grain readily changes with a change in storage temperature or relative humidity. Its moisture content is about 14% at 75% relative humidity (27–32 °C).

Starch is made up of glucose units and occurs as two distinct fractions – a branched fraction amylopectin and a linear fraction amylose. Starch may be classified as waxy or glutinous (mainly amylopectin or less than 2% amylose), or nonwaxy or nonglutinous (containing more than 5% amylose). Waxy starch stains reddish brown with iodine; nonwaxy starch stains purple blue with iodine; and amylose stains blue with iodine. This amylose-iodine blue colour is the basis for the analysis of the amylose content of nonwaxy starch. Amylose content of nonwaxy milled rice

ranges from 7 to 33%. This corresponds to 9–37% amylose in the starch and to 63–91% amylopectin in the starch. Amylose content is, therefore, an index of amylose/amylopectin ratio. Amylose/amylopectin ratio and gelatinization temperature are generally independent properties of rice starch.

Rice protein is mainly water-insoluble. It is usually determined from Kjeldahl nitrogen multiplied by 5.95, based on the mean nitrogen content of 16.8% of rice protein. Like starch granules, the protein bodies show in cross section an orderly arrangement of alternating electron-dense and electron-thin concentric rings.

Changes During Seed Development

Dry matter production is essentially complete 3 weeks after flowering at which time wet weight is maximum. Starch granules are first observed by 4 days after flowering and protein bodies by 7 days after flowering. In Los Baños, Philippines, maximum head rice yield is obtained between 4 and 6 weeks after flowering in the wet season (20–24% moisture) and between 4 and 5 weeks after flowering in the dry season (18–20% moisture). In a less humid climate, as in California, USA, optimum head rice yield is obtained at higher

moisture contents of 22–30% probably because of the greater stress on the grain during drying in the panicle.

Grain Dormancy

Most tropical rice varieties possess some degree of dormancy. The seeds will not germinate completely immediately after harvest and require an after-ripening period of 3–6 weeks at ambient temperature for complete germination. Dormancy in rice is not due to embryo dormancy since the excised embryo is capable of germination. The structures covering the embryo act as barriers to germination since dehulling partially breaks dormancy. Pricking the dehulled rice (brown rice) near the embryo (and not elsewhere) completely breaks dormancy. The covering structures probably reduce the diffusion of oxygen to the embryo in the dormant seeds, because dormancy may be broken by placing the grains in an oxygen atmosphere and dormant and nondormant grains have the same respiration rate during steeping in water. Hence, the causes of grain dormancy are probably biochemical.

When grains have to be planted after harvest, dormancy may be broken quickly by heat treatment up to 55 °C in open containers or by treatment with acid. The degree of dormancy is relatively less in the dry season than in the wet season due to the relatively higher temperature during the dry season.

Milling Quality

Opacity of waxy rice endosperm is due to the presence of micropores within the starch granules. Opacity of portions of nonwaxy rice grains, such as the white belly of IR8, is due to air spaces between the starch granules. Opaque portions in nonwaxy rice result in a softer grain that breaks more easily during milling than grains that are completely translucent. The endosperm of waxy rice, on the other hand, is just as hard as the endosperm of nonwaxy rice.

Studies on grain hardness are difficult to evaluate because head rice yield is affected by environmental conditions such as moisture content at harvest, conditioning and drying after harvest, and by aging during storage. In addition, coarse-grain varieties, which have more aleurone cell layers, usually require more pressure to mill to the same degree in a McGill mill than slender fine-grain varieties. Such differences in grain size and shape contribute to the difficulty in developing methods for estimating endosperm hardness.

Endosperm hardness may also be related to the packing density of the starch and grain, as reflected in the gelatinization temperature of the starch granules. Gelatinization temperature correlates with the resistance of the granule to corrosion by acid or starch hydrolyzing enzymes and to enzymic hydrolysis during early germination. However, most of the coarse grain *japonica* rices have a low gelatinization temperature, and most tropical rice varieties have an intermediate gelatinization temperature.

Cooking Quality

Rice is chiefly eaten as boiled milled rice. Cooking time is directly affected by the gelatinization temperature of the starch and by protein content. However, water absorption and volume expansion during cooking are directly affected by amylose content. Waxy or glutinous rice expands the least during cooking and its cooked grain has the heaviest bulk density.

Some rices, like Basmati D25-4 and certain Iranian varieties, show extreme elongation when presoaked grain is cooked. The nature of this property is not well understood. These samples tend to have a gelatinization temperature below 74 °C and an amylose content below 25%, but not all varieties with this combination of properties show extreme elongation.

Water soluble vitamins, such as thiamine, riboflavin and niacin, may be partially lost during washing of the milled rice before boiling and in the cooking process, particularly if the rice is cooked in excess water and the cooling gruel is discarded. Protein loss is minimal since it is essentially insoluble in water.

Eating Quality

Amylose/Amylopectin Ratio and Gel Consistency

The ratio of amylose to amylopectin in starch, as indexed by amylose content, is the chief influence on eating quality. It correlates negatively with taste panel scores for cohesiveness, tenderness, and gloss of the boiled rice. Cooked waxy rice is very sticky, tender, moist, and glossy. It retains these properties even after storage for a few hours up to a few days. It is the staple food in parts of Laos and northern Thailand. The texture of freshly boiled waxy rice is not affected by differences in gelatinization temperature; however, cooked samples with a high gelatinization temperature (74–78 °C) of the starch tend to harden faster on storage, due to the higher molecular weight of their amylopectin.

Most tropical nonwaxy varieties have amylose contents of 20% or higher, although a few, such as Khao Dawk Mali from Thailand, Chhuthana in Khmer, and IR24 in the Philip-

pines, have lower amylose contents (14–18%). Most of these varieties have a gelatinization temperature between 70 and 74 °C. Amylose content may be classified as low (below 20%), intermediate (20–25%), and high (above 25%).

Low amylose rice is preferred in Japan and South Korea for its stickiness, tenderness, gloss, and taste (Table 2). It is more sensitive to overcooking than rices with over 20% amylose and its cooked grains disintegrate when soaked overnight. Most *japonica* varieties have a low gelatinization temperature.

Filipinos and Indonesians prefer intermediate amylose rice, because it remains soft even when stored overnight. This kind of rice has between 20 and 25% amylose.

High amylose rices differ widely in the rate of hardening of cooked rice. A gel consistency test, based on the tendency of cooled rice gel (100 mg flour in 2 ml 0.2 N KOH) to flow, readily classifies high amylose varieties into those with hard (26–35 mm), medium (36–50 mm), or soft (51–100 mm) gel consistency. In most of Asia, high amylose rice with

TABLE 2. Ranges of amylose content, gel consistency, and BEPT types of milled rices obtained from rice producing countries.

Country	Varieties	Amylose content range (% dry basis)	Gel consistency types[a]	BEPT types[b]
Bangladesh	20	15–26	S > MH	I > L
Burma	10	20–31	—	I
China	5	22–32	S > MH	LI
India (Hyderabad)	24	15–27	S > MH	LI
India (Maharashtra)	14	18–26	MH > S	LI
Indonesia	10	18–23	S > M	I > LH
Japan	12	12–17	S	L
Khmer Republic	6	13–26	S > H	I > L
Laos	8	waxy, 16–24	—	LI > H
Malaysia	19	10–28	SM > H	I > LH
Nepal	16	18–25	SH	L > I
Pakistan	7	21–29	HMS	LI
Philippines	18	22–30	S > MH	L > I
Sri Lanka	10	24–28	H > M	I
Taiwan	10	15–26	S > H	L > I
Thailand	12	waxy, 10–28	S > MH	L > I
South Korea	10	16–21	S	L
South Vietnam	10	18–29	S	I

[a]S = soft; M = medium; H = hard; > greater than.
[b]L = low; I = intermediate; H = high; > greater than.

a soft gel consistency is preferred over rice with a hard gel consistency. Cooked rice with a hard consistency hardens faster during cooling, shows a higher amylograph setback, a higher gel viscosity, and has a lower level of water-soluble amylose at 100 °C than rice with a soft consistency. Differences in the gel viscosity of starches of similar amylose content, including waxy starches, are due mainly to differences in the viscosity of the amylopectin fraction of starch. In Sri Lanka where most varieties have high amylose content, "samba" varieties (small- and short-grained) are preferred to bold, long-grained varieties because of their greater resistance to splitting during boiling.

Such high correlation ($r = 0.8$) between texture of cooked rice and amylose content limits the extent to which any one variety can universally meet the different eating quality preferences in various countries. Texture differences in boiled rice, rather than actual differences in flavour level, may contribute to the reported flat taste of IR8 (high amylose content) in Indonesia as compared to intermediate amylose rice like Bengawan. However, a high amylose rice with medium to soft gel consistency like IR20 and IR26 may find wider acceptability in tropical Asia than an intermediate type such as C4-63G or a high type with hard gel consistency such as IR8 and IR22. Varietal differences in eating quality within the same amylose class are common, because amylose accounts for at most 65% of the differences in eating quality.

Other Factors

Protein content is a secondary factor affecting texture. It is important in countries where the amylose range of the rice varieties is narrow. Protein is the major quality factor in Spain, although the preferred variety is higher in both protein and amylose levels than the other varieties. Differences of two percentage points in the protein content among samples of a variety have no significant effect on the colour score of cooked milled rice.

Aromatic varieties are preferred in many countries, but the preferred aroma may differ from region to region. The exact nature of the aroma has not been studied, but varieties differ in the character of the aroma. Climatic factors have a marked effect on the intensity of the aroma because it is volatile.

Aging

The rice grain changes in some properties during the first 4–6 months of storage, particularly above 15 °C, regardless of whether it is stored in rough, brown, or milled form. The brown rice becomes progressively more resistant to milling and total and head rice yields increase. Volume expansion and water absorption of milled rice during cooking increase. The starch and protein become less soluble in the cooking water. In addition, except for waxy rice, the cooked rice becomes more flaky. Aroma is lost and seed viability decreases progressively during storage. Aging probably starts in the grain in the field prior to harvest and is accelerated by heat treatment during drying. In fact aging may be accelerated by treatment of the grain with dry or wet heat.

Parboiling probably originated with aging as its primary purpose. It consists of steaming presoaked grains and slowly drying them. The changes are mainly physical and the process results in a harder and more translucent grain. Milled parboiled rice is reported to have a higher content of water-soluble vitamins than milled raw rice because, during steaming, these vitamins diffuse into the endosperm. A more likely explanation is that parboiled rice is undermilled compared to raw rice under the same milling conditions and contains more vitamin-rich bran polish.

High temperature drying of moist grain may result in parboiling of the grain, as in hot-sand drying or infrared heat drying of rough rice. The parboiling effect during drying is more evident in the wet-season crop than in the dry-season crop.

Processed Rice

Varieties in the same amylose class may differ in the quality of processed rice. In

processed rice, including parboiled rice, which is not consumed immediately after processing, factors other than the amylose/amylopectin ratio may provide information on factors that are also important in boiled rice quality. Most of these differences are related to differences in the gel consistency and viscosity of the starch.

Waxy rices are used mainly for sweets, pudding, desserts, cakes, and sauces. In Japan, waxy rices that differ in cake quality also differ in gelatinization temperature and molecular weight of amylopectin. Philippine waxy parboiled flaked rices also differ in tenderness on reconstitution with water, especially after storage. Generally, waxy rices with a high gelatinization temperature (74–78 °C) give cooked products that are less sticky and harden faster than rice with a low gelatinization temperature.

Low amylose rices are preferred for breakfast cereals and baby foods because, among the nonwaxy rices, their gel has the least tendency to harden during storage. Puffed rice and popped rice manufacturers prefer waxy and low amylose rices for their greater puffed volume, which probably results from their higher equilibrium water content during steeping in water prior to parboiling. The higher water content results in a greater degree of parboiling, which directly affects puffed volume.

Intermediate amylose rices are used in canned soups in the USA. In preparing Philippine fermented rice cakes, varieties of intermediate amylose content with soft gel consistency are used because of their soft texture and optimum volume expansion on steaming.

High amylose rices, particularly those of hard gel consistency, are ideal for rice noodle manufacture, because of their greater stability and resistance to disintegration on overcooking. — BIENVENIDO O. JULIANO. *Department of Agricultural Chemistry, International Rice Research Institute, Los Baños, Laguna, Philippines.*

STANDARDS

Seed Multiplication

The seed as a component of the production phase in the grain industry can be considered as a 'mini-industry' that requires integration of production, processing, storage, and marketing, in addition to that part involving milling. Although only a small part of the total system, the seed has a strong influence on the viability of the industry because, as the most basic input, the seed sets the upper limits of productivity, product quality, and consequently price. The linkage of seed in the grain industry is illustrated in Fig. 1. The seed program in the grain industry, therefore, deserves full recognition in systems planning and implementation.

Systems of Seed Multiplication and Certification

In seed production, quality control has a central role. All phases from seed multiplication, processing, and storage to distribution and marketing should be subject to quality control either by seed testing, inspection, regulation, or certification. Therefore, the seed laboratory is essential to the quality control program (Fig. 2).

A system of seed production to provide the needed quantity of seeds with a given quality is illustrated in Fig. 3. In this system of seed production, there are two schemes for quality control, namely, the limited generation system of multiplication and seed certification.

In the limited generation scheme of seed multiplication, control of genetic or varietal purity is attained by limiting the number of generations that the seed may be increased from the original or breeder seed. In rice, under this system, the third generation is usu-
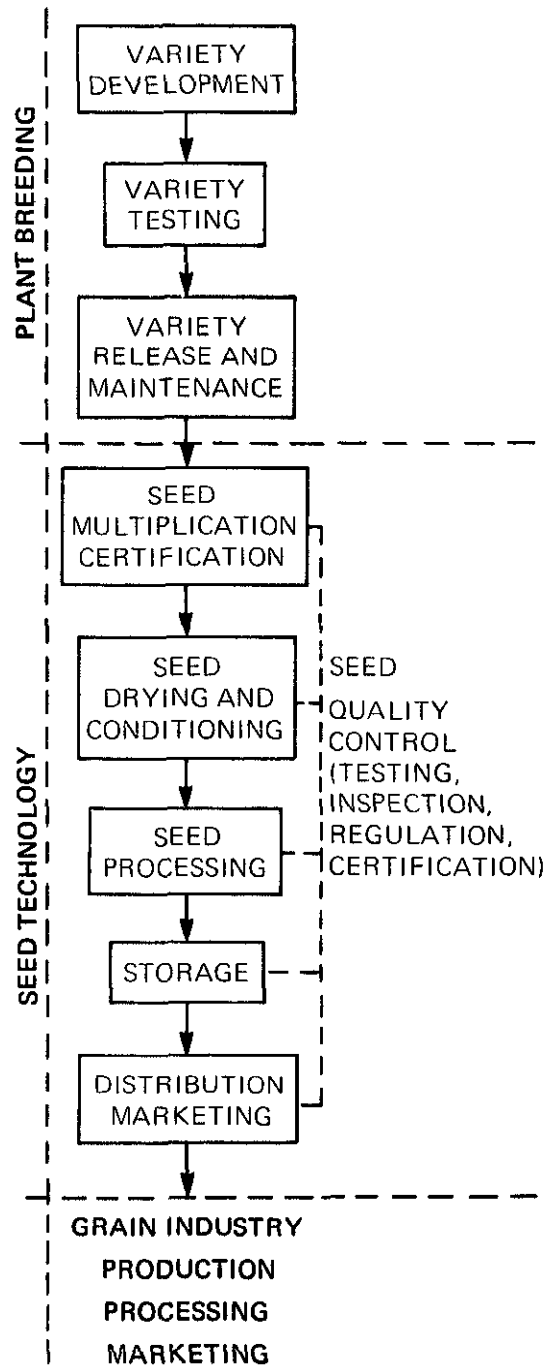

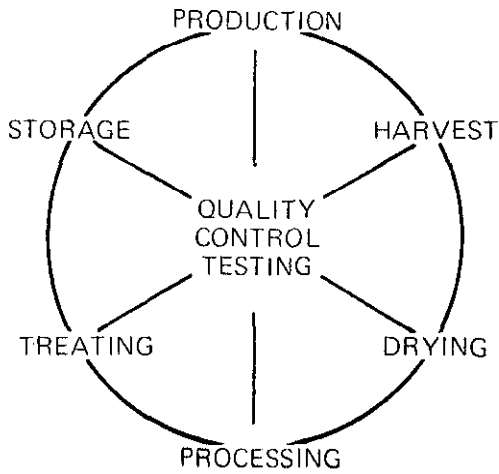Fig. 1. Linkage of the seed in the grain industry (Gregg et al. 1970).

FIG. 2. The seed laboratory as the hub of seed quality control (Grabe 1968).

ally the seed intended for commercial crop production. Thus, this system recognizes the following classes of seed:

	No. of generations from breeder seed
Breeder	0
Foundation	1
Registered	2
Certified	3

The seed-class nomenclature may change from country to country, but what is essential is an understanding of the number of generations involved in seed multiplication. The concept is that the farther away the seed progeny is from the breeder seed, in terms of filial generation, the greater the chances of variation from the original purity.

In addition to quality control by means of the limited generation system of multiplication, seed certification is required in the production of the different classes of seed mentioned above to ensure that certain field and laboratory seed standards are satisfied. The process of certification consists of two successive phases: (1) field inspection; and (2) laboratory inspection or seed testing and analysis.

Certification presumes the existence of standards for inspecting seed fields and examining seed lots. In general, field standards provide for proper field isolation and tolerance for field mixtures; whereas, seedlot standards set tolerance limits for varietal and physical purity, percentage germination, and moisture content. Seed certification, therefore, focuses its evaluation on: (1) genetic or varietal purity; (2) physical purity; and (3) germination or planting value.

In field inspection, the main problem is sampling because it is impossible or impractical to examine every single plant in the seed field or every single portion of the field. In-field visits must be carefully planned for efficiency and reliability of inspection. Figures 4–7 are examples of field inspection route patterns for a rectangular field, showing the comparative efficiency and accuracy of each pattern.

Assuming that the field meets established standards of isolation and crop stand, the seed crop is gathered from the field. The field inspector draws a sample from the seed harvest and forwards it to the seed laboratory for the next phase in certification, which is seed examination. The seed sample is subjected to a series of tests and the results are matched with established seed quality standards to determine if the seed lot qualifies for the certification. If certified, a tag containing all the information on the seed lot pertinent to the quality factors
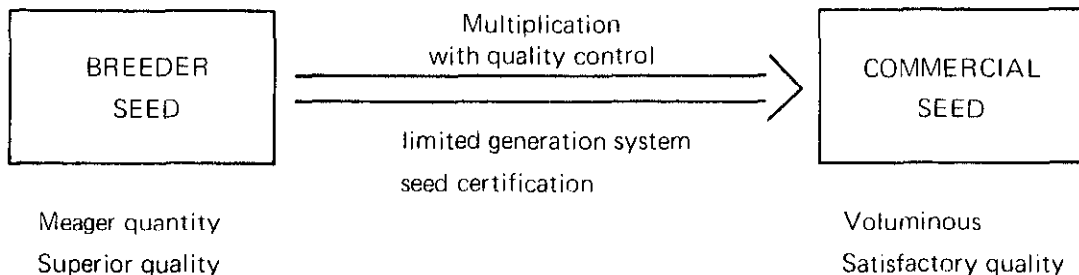

FIG. 3. Meeting seed quality and quantity needs by proper multiplication.
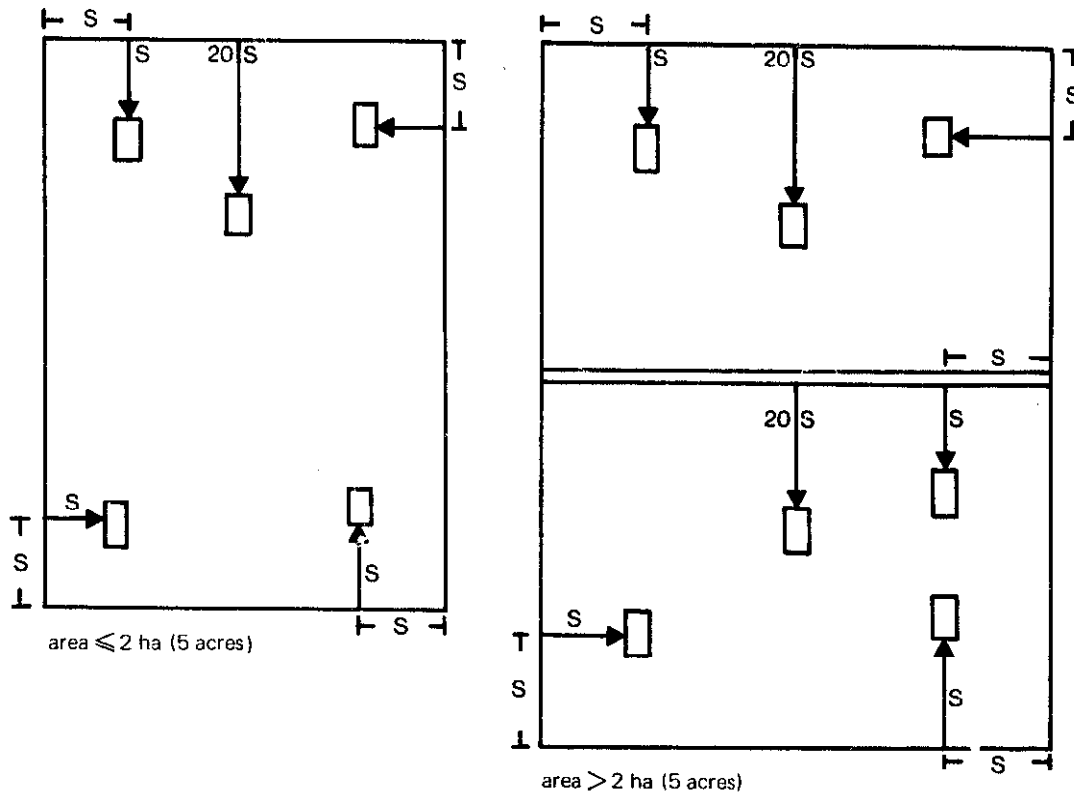
FIG. 4. Techniques of inspecting paddy fields (Seed Processing, Storage, and Distribution). Procedure: (1) inspector decides how many steps (s) he will take from corners and into the field before making count; (2) counts from centre of field at least 20 steps from edge.

is attached to each bag. Figure 8 shows the series of tests for ascertaining seed lot quality in rice.

The importance of proper sampling technique cannot be overemphasized because so much depends on the sample. However, as shown by field experience proper sampling is easier said than done. As a guiding principle, sampling should be done from as many positions within each seed bag and from as many bags as possible because the sources of sample differences are within-bag and between-bag variations.

Seed Processing Principles

In the broadest sense, seed processing encompasses all the steps involved in the preparation of harvested seed for marketing. These include handling, threshing, preconditioning, drying, cleaning, size-grading, upgrading, treating, and packaging. More commonly, however, seed processing refers only to preconditioning, cleaning, size-grading, and upgrading of seeds. The steps involved are similar to those in grain processing, except that the processed seed is intended for planting.

In seed processing a seed lot is conceived as a mixture of good seeds, undesirable seeds, and other types of materials. The removal of these undesirable materials from the good seeds (Fig. 9) converts a seed harvest into a marketable grade of seed. Obviously there are many steps involved (see Fig. 10).

The first step is receiving seeds at the processing plant in containers or in bulk. From the receiving station, seeds go into bulk storage for later processing, or to conditioning and precleaning, which includes removal of trash,
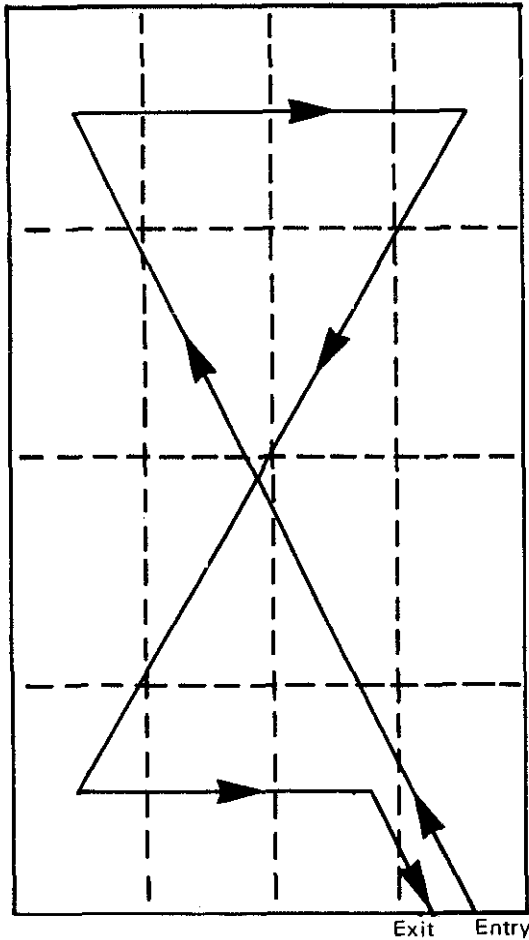
FIG. 5. Techniques for inspecting paddy fields (Revier and Young). Area 40 ha (100 acres), (805 × 503 m, 880 × 550 yards); travel 2605 m (2850 yards); coverage ¾ of field; centre covered twice; outer portion of mid-field not covered; remotest part from inspector 183 m (200 yards).
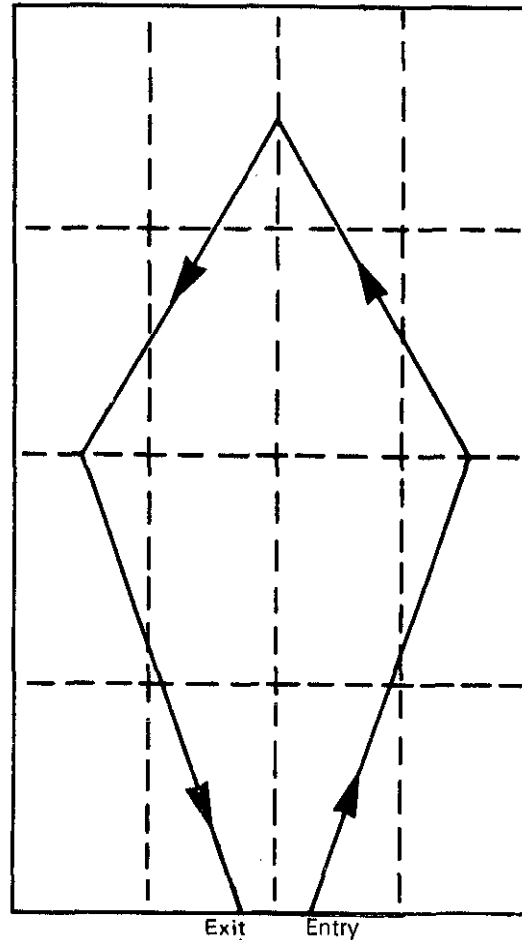
FIG. 6. Techniques foi inspect.ng paddy fields (Revier and Young). Area 40 ha (100 acres), (805 × 503 m, 880 × 550 yards); travel 1737 m (1900 yards); coverage less than ½ of field; remotest part from inspector 365 m (400 yards).

debearding, etc. to make the next step, basic cleaning, more efficient. Basic cleaning is the first actual cleaning and/or upgrading step, and the air-screen cleaner is the most commonly used machine. If needed, the seed may go through more special separating or upgrading machines to remove specific mixtures. Then the seeds are ready for bagging, although chemical seed treatment against seed pests and disease organisms may be done before bagging. Finally, the seed is shipped or held in storage until needed.

Regardless of the type of machinery used for seed processing the basic interests of the processor are: (1) complete separation — removal of undesirable materials from the seed; (2) minimum seed loss— some good seeds are removed along with contaminants in almost every processing operation, but this loss must be kept at a minimum; (3) upgrading quality — improvement not only of purity, but also removal of rotten, cracked, broken, insect-damaged, injured, or low quality crop seed; (4) efficiency — the highest capacity
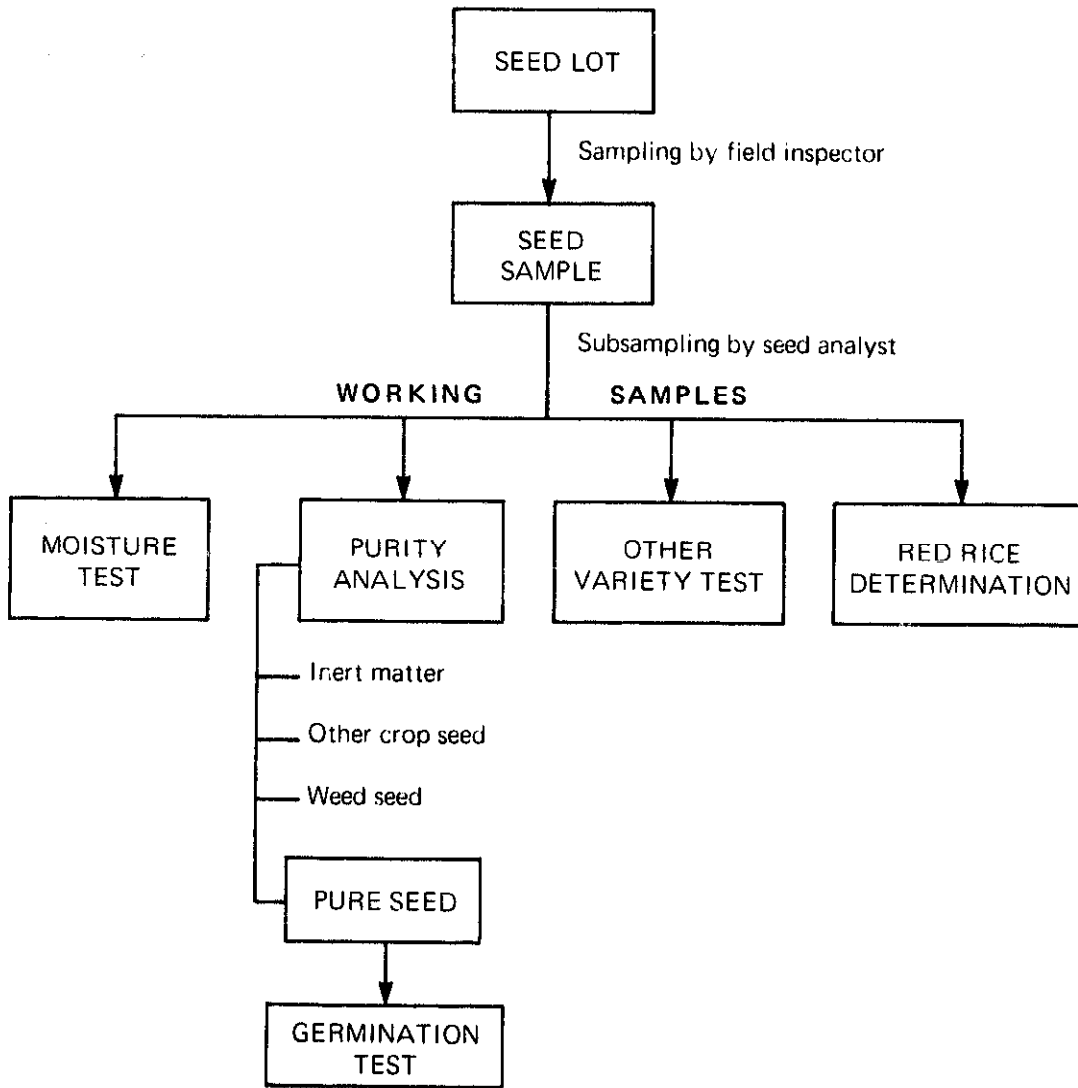
FIG. 7. Techniques for inspecting paddy fields (Revier and Young). Area 40 ha (100 acres), (805 × 503 m, 880 × 550 yards); travel 2432 m (2650 yards); coverage ⅞ of field; remotest part from inspector 91 m (100 yards).

consistent with effective separation; and (5) minimum labour — labour is a direct operating cost and cannot be recovered.

Seed processing equipment effects seed cleaning and separation on the basis of physical differences among seeds and between seeds and other materials in the seedlot. The principles of separation of some of the more common seed processing equipment are: (1) air-screen cleaner (Fig. 11 and 12) — makes separation based on seed size and weight differences; (2) gravity separator (Fig. 13 and 14) — based on seed weight, specific gravity, or relative density; (3) disc and cylinder separators (Fig. 15) — based on seed length difference; (4) graders, sizers (Fig. 16) — based on width and thickness; (5) incline draper (Fig. 17), spiral separator — based on shape of seed; (6) roll mill (Fig. 18), magnetic separator (Fig. 19), incline draper (Fig. 17), Buckhorn machine (Fig. 20) — based on differences in surface texture; and (7) electrostatic separator (Fig. 21 and 22), electric colour sorter — based on electrical property of the seed. — NOEL G. MAMICIPIC. *Department of Agronomy, University of the Philippines at Los Baños, College, Laguna, Philippines.*

FIG. 8. Laboratory tests for rice seed certification.

HARVESTED SEED
- threshed
- shelled
- dried

Inert material → ← Common weed seed

Noxious weed seed → ← Other crop seed

Deteriorated seed → ← Other variety seed

Damaged seed → ← Off-size seed

MARKETABLE SEED
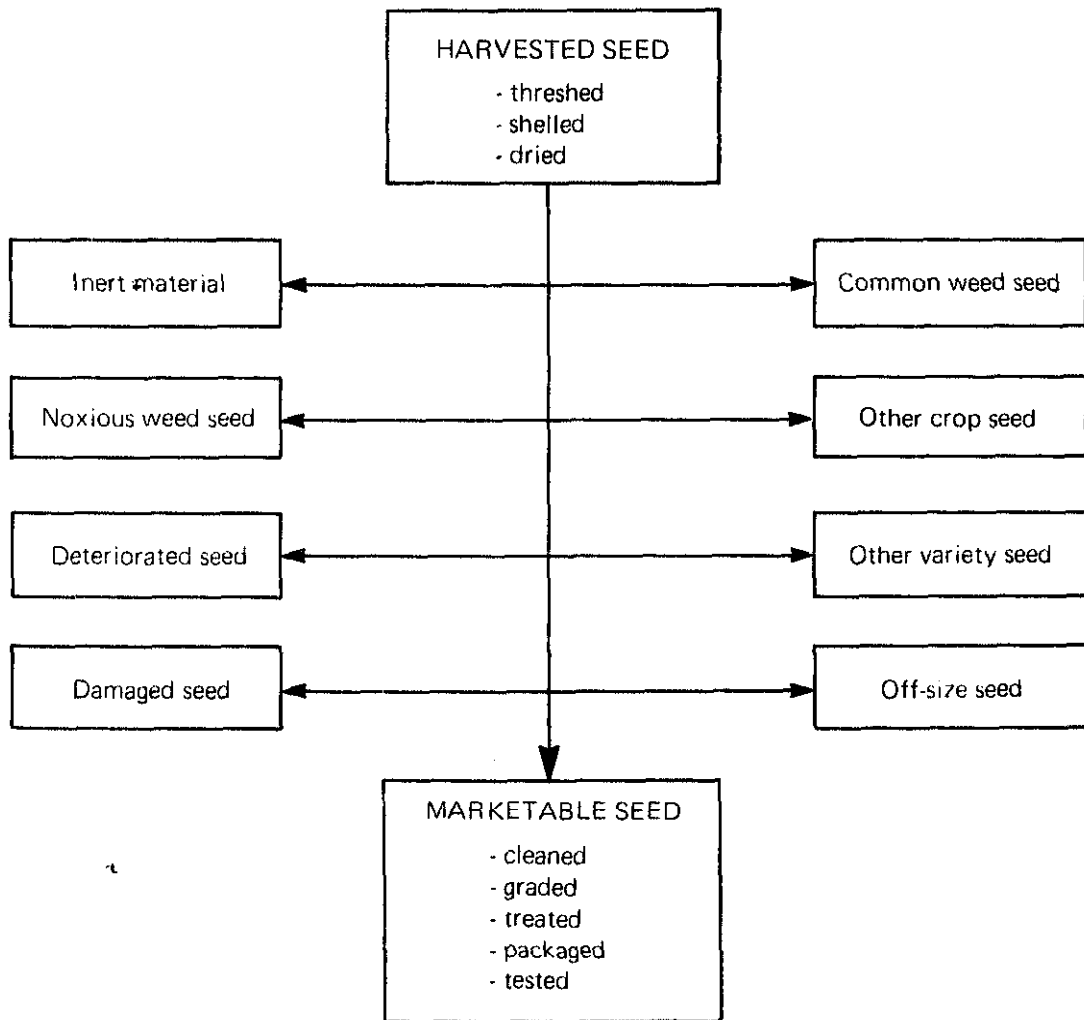- cleaned
- graded
- treated
- packaged
- tested

FIG. 9. Types of materials removed from seedlots during processing (Gregg et al. 1970).
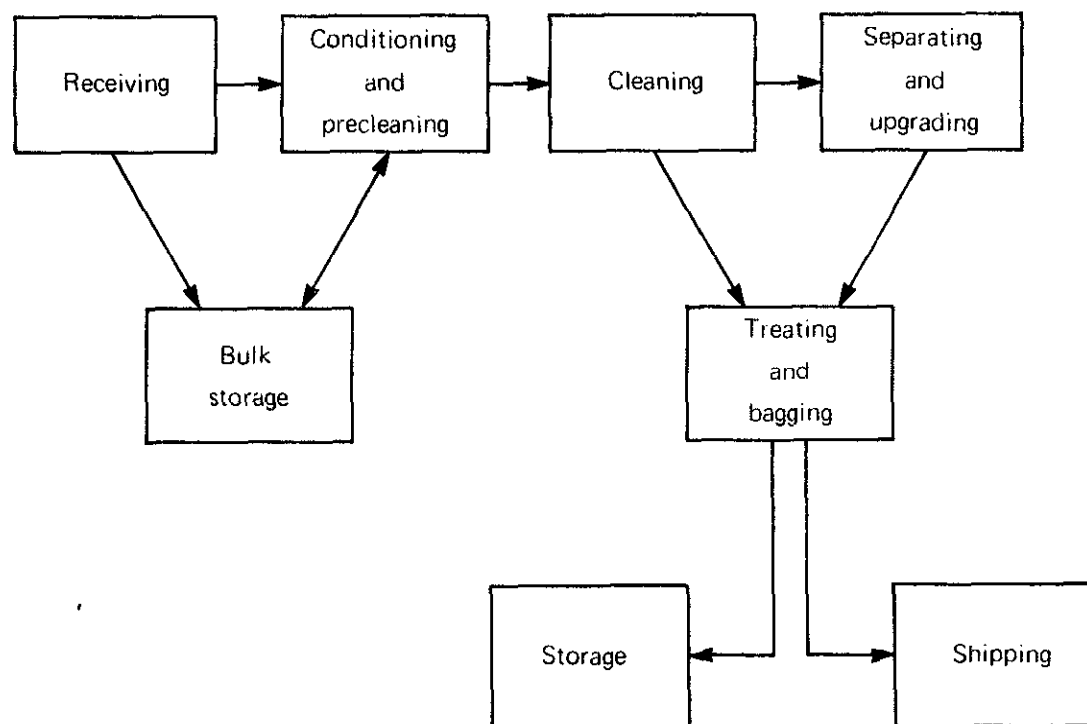
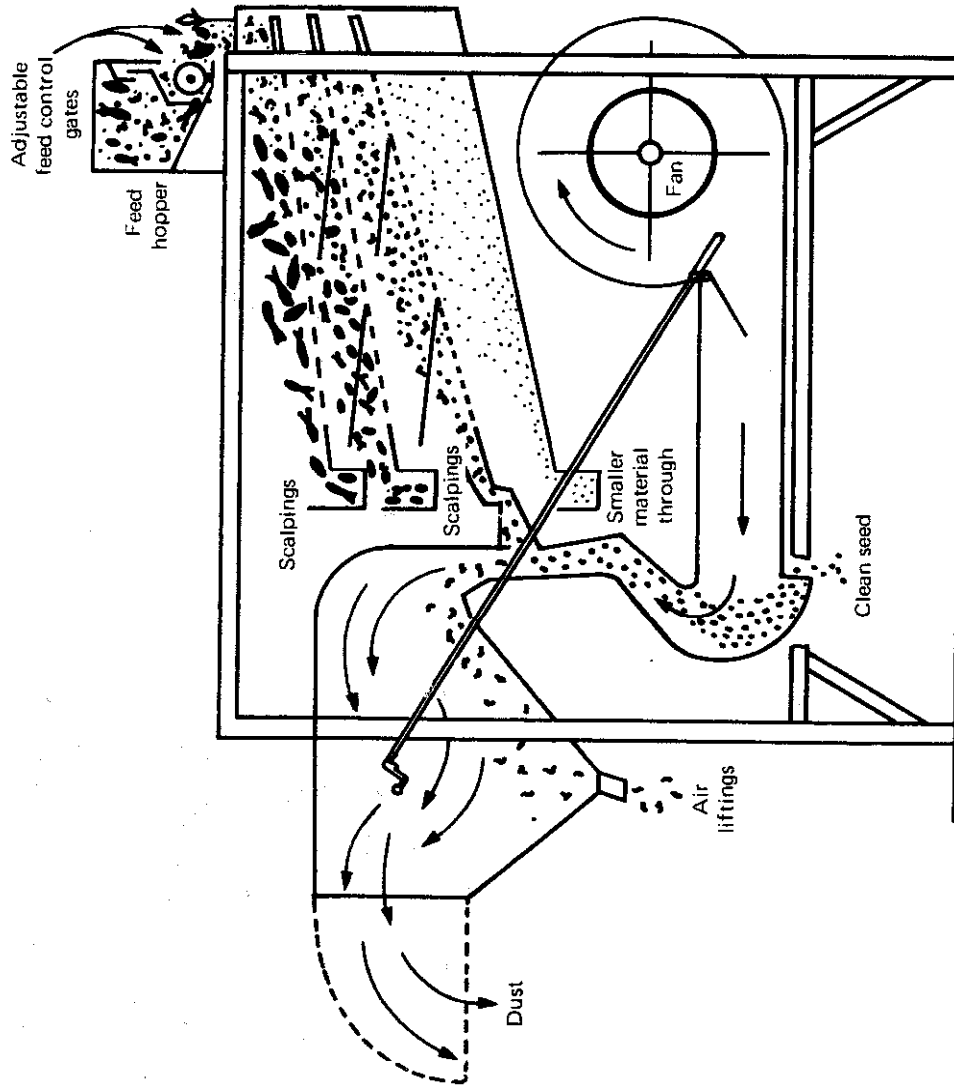FIG. 10. Basic flow and essential steps in seed processing (Vaughan et al. 1968).

Fig. 11. Flow diagram of Crippen A-334 air-screen cleaner (Vaughan et al. 1968).

OBLONG HOLES

3/64 x 5/16   8 x 3/4

ROUND HOLES

1/25   10/64

TRIANGLE HOLES

9/64 or 5-1/2V   11/64 or 6-1/2V

WIRE MESH

3 x 14   18 x 18
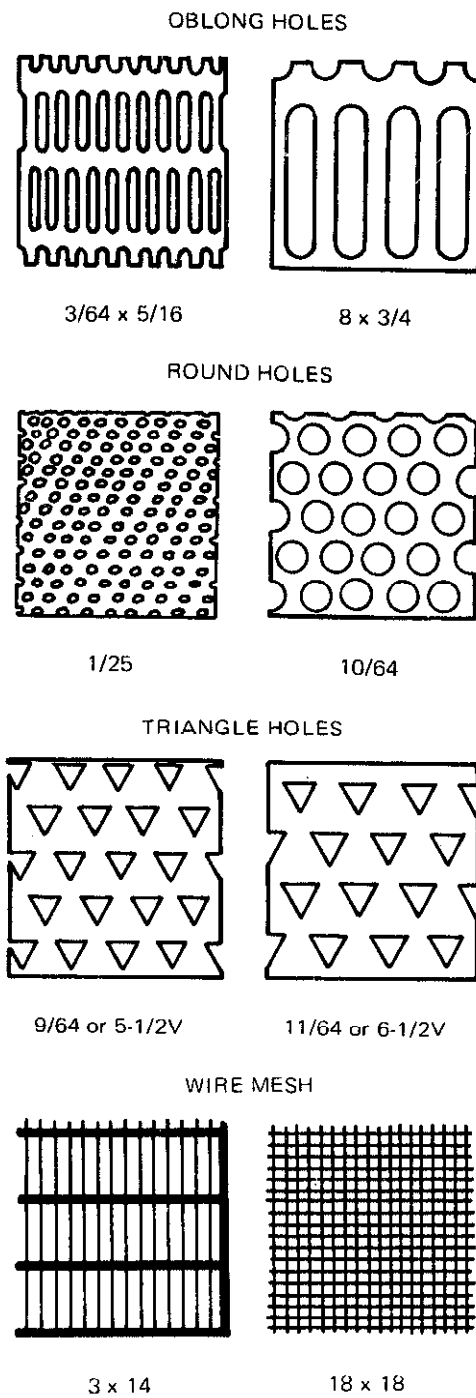
FIG. 12. Types of screens and perforations used in cleaning seeds (Vaughan et al. 1968).
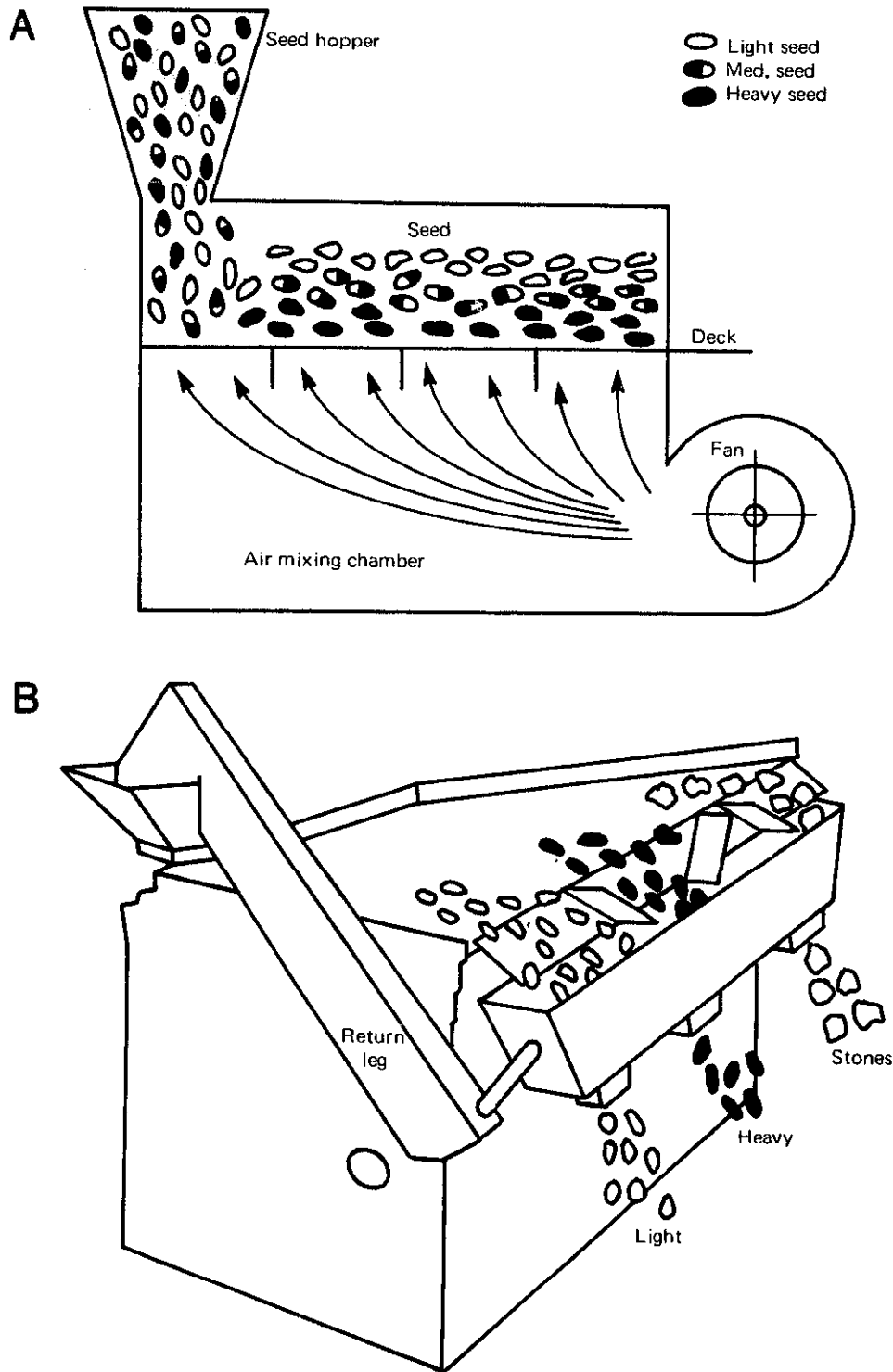
FIG. 13. (A) Diagram of the airflow through seeds on the deck of a specific gravity separator. Seeds are stratified into vertical zones by weight. (B) Diagram of gravity separator showing seed flow across the deck (Vaughan et al. 1968).

A

Feed
box

Angle of
gravity flow

Direction of
conveyance

Light waste

Rocks
metal, etc.

Discharge edge

B

Air

Trash

Weevil
eaten
beans

Clean
beans

Stones
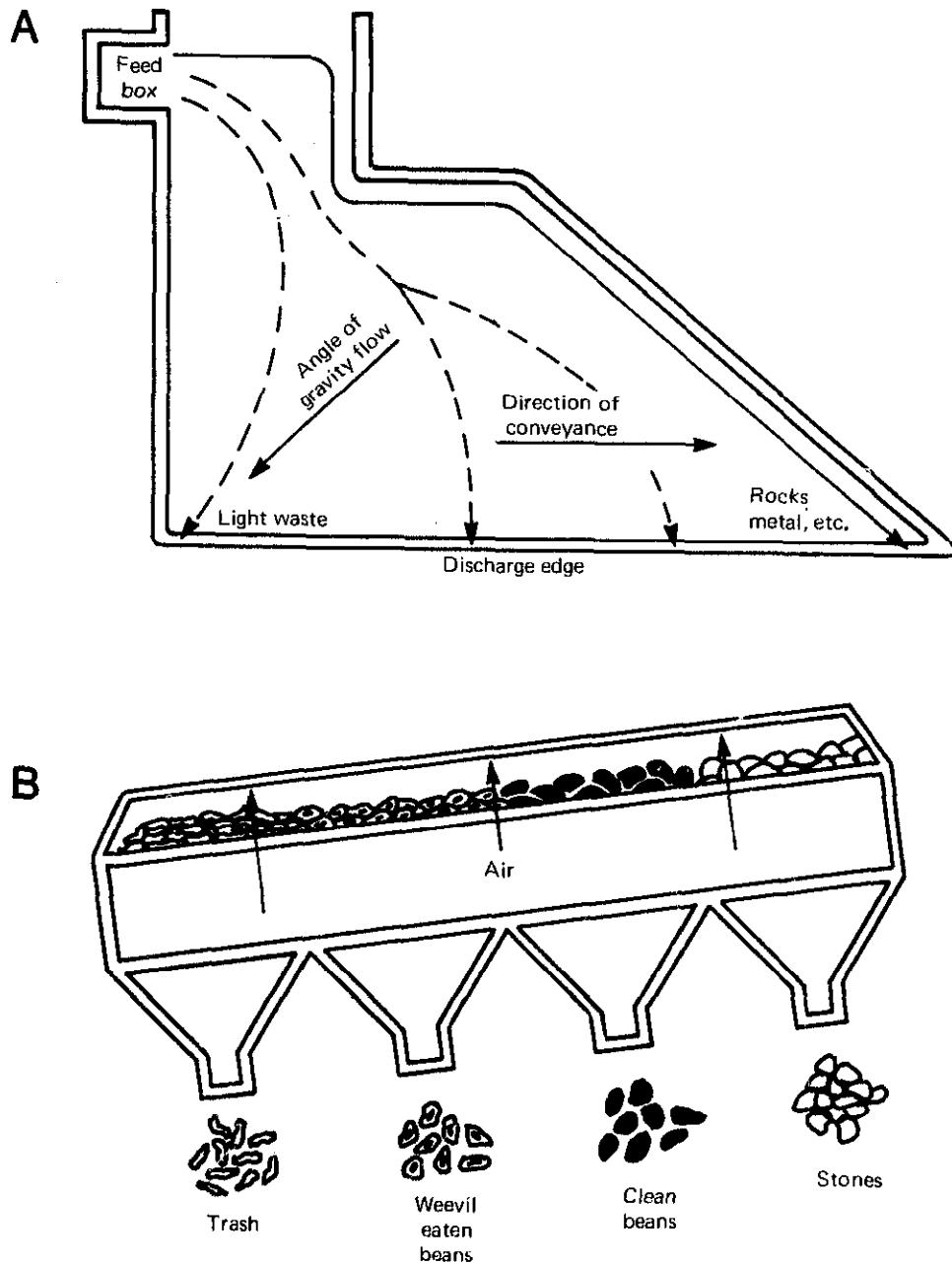
FIG. 14. (A) Flow pattern of seeds across deck of a gravity separator. (B) Discharge of separates along the edge of the gravity deck in a typical bean separation (Vaughan et al. 1968).
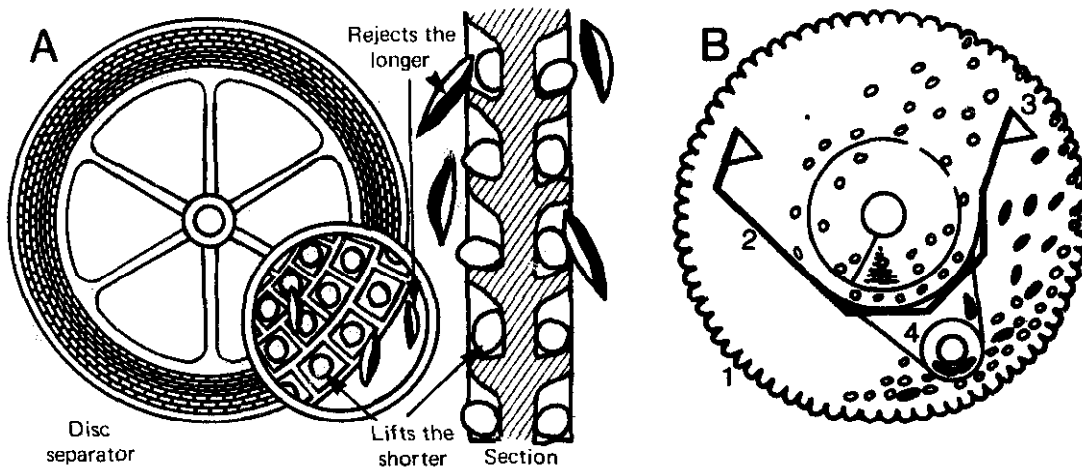
FIG. 15. (A) Face and cross section of a single disc. (B) Cross section of a cylinder length separator. (1) the cylinder wall with indents stamped on it; (2) the adjustable trough catching short lifted seed; (3) the separating edge of the adjustable trough; and (4) the auger conveyor at the bottom of the cylinder that conveys long rejected material out of the cylinder (Vaughan et al. 1968).
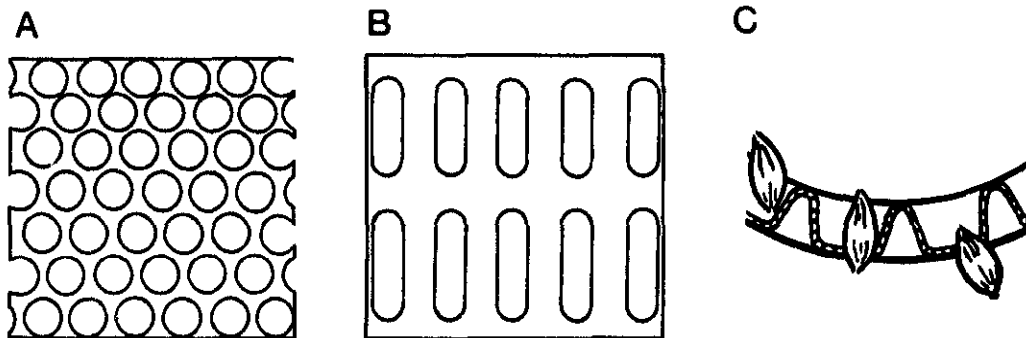

FIG. 16. (A), (B) Types of screens used in width and thickness sizing; round hole for width sizing and oblong opening for thickness sizing. (C) Sketch showing how separation is made (Vaughan et al. 1968).
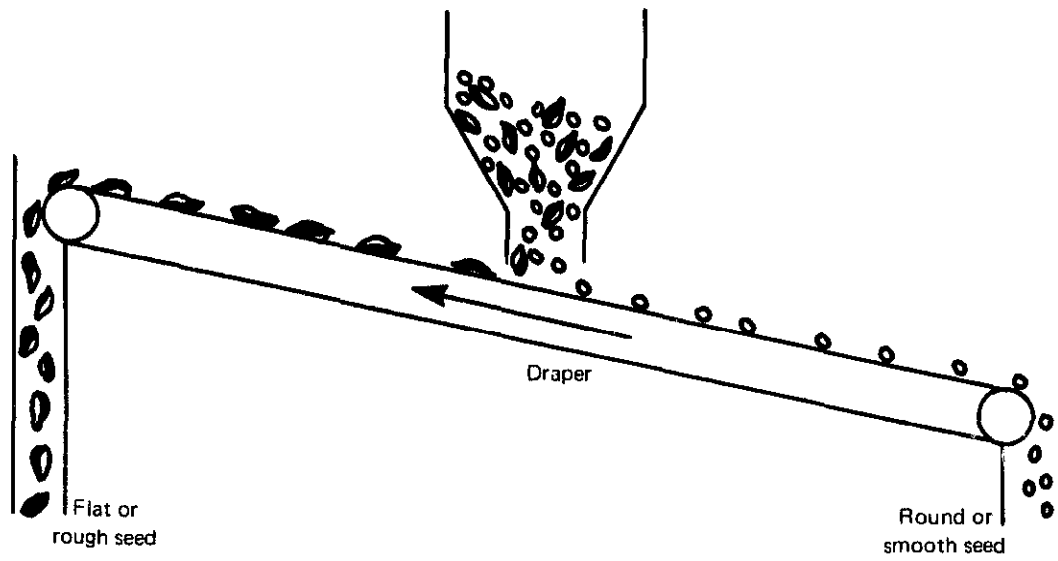
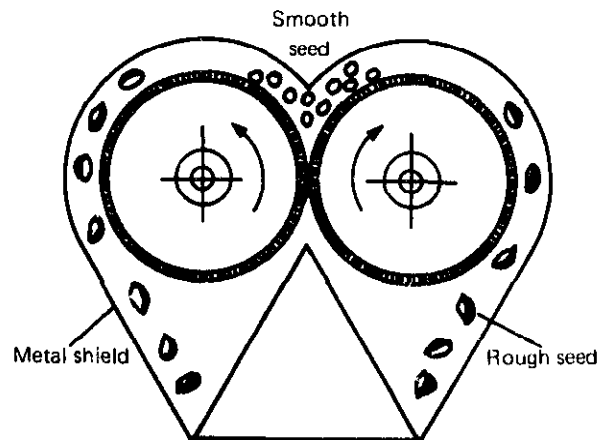Fig. 17. Incline draper (Vaughan et al. 1968).

Fig. 18. Cross section of a pair of rollers illustrating movement of rough seed over rollers (Vaughan et al. 1968).
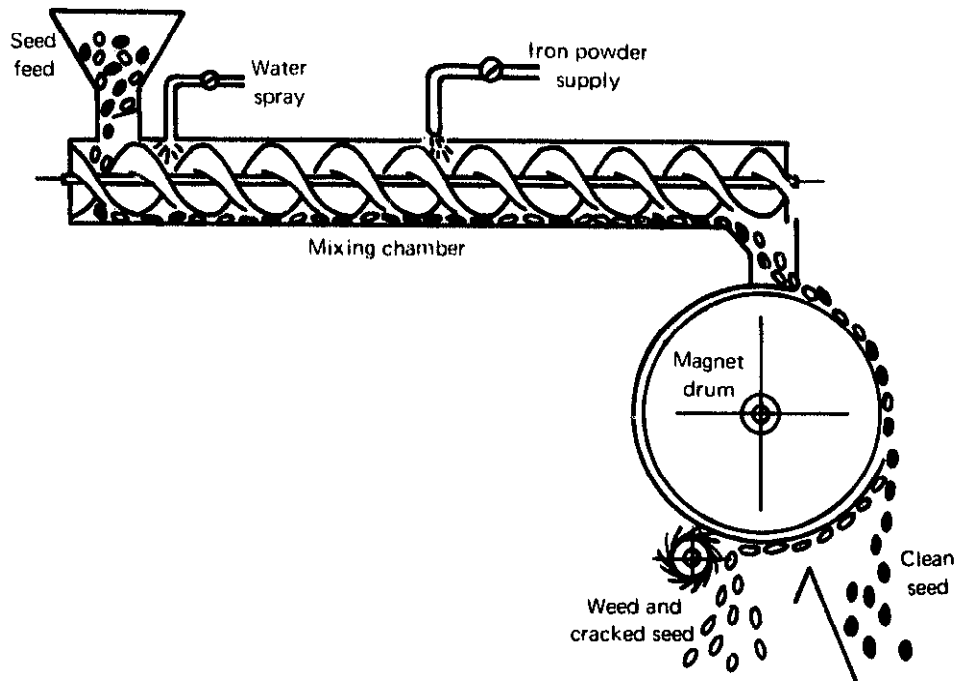
FIG. 19. Diagram of a drum-type magnetic seed separator (Vaughan et al. 1968).
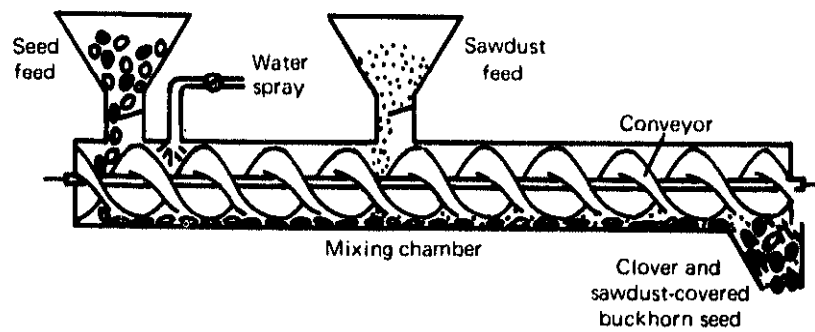

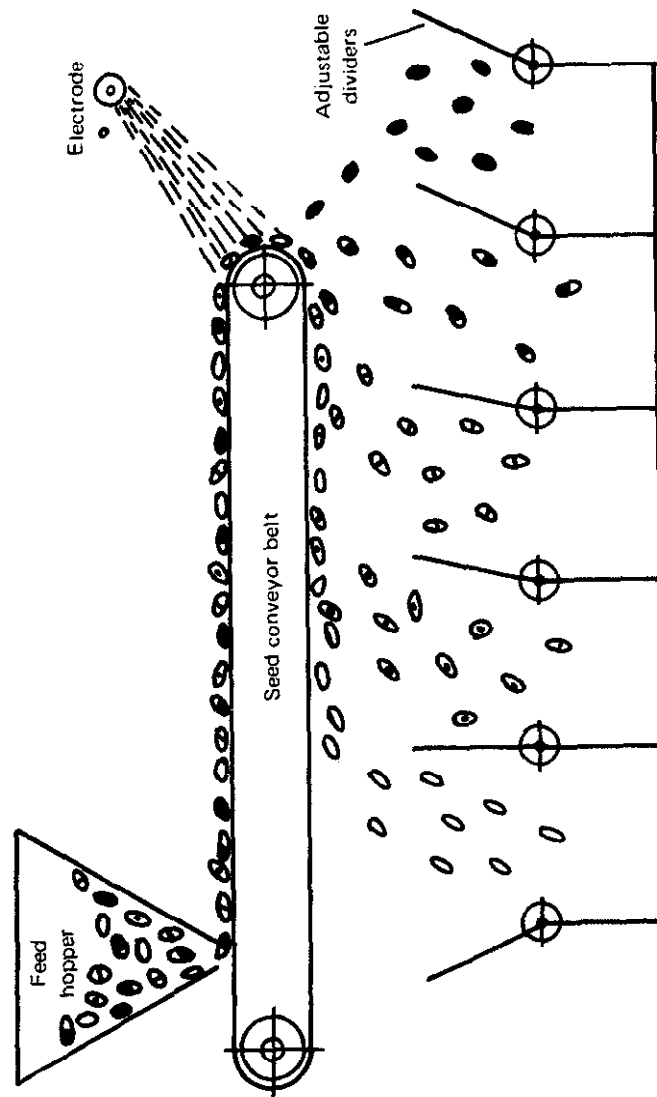FIG. 20. Section view of buckhorn machine (Vaughan et al. 1968).

Fig. 21. Schematic drawing of a belt-type electrostatic seed separator (Vaughan et al. 1968).
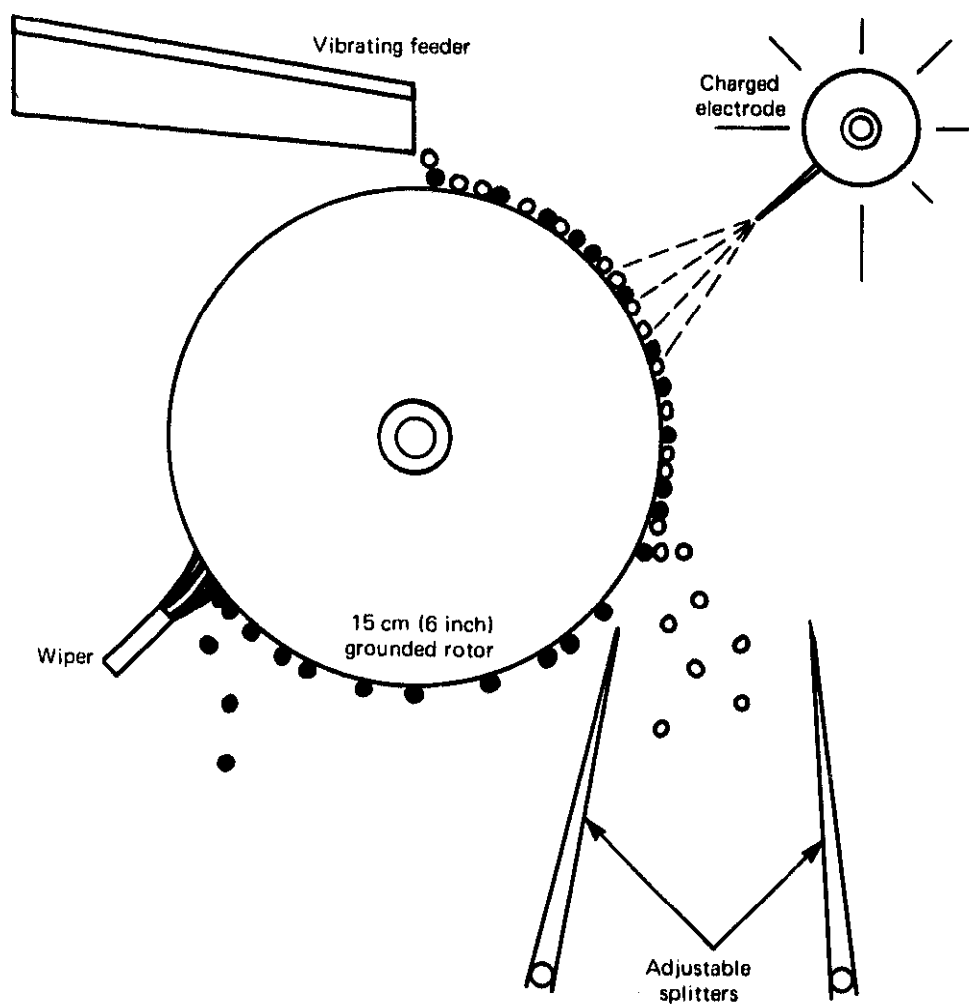
FIG. 22. Schematic diagram of an electrostatic separator set up to produce a discharging, high capacity field. Seeds that are poor conductors are pinned to the rotor; whereas, good conductors are pinned only momentarily, then continue to free fall (Vaughan et al. 1968).

tion of quality rice. The only answer to the problem is the enforcement of standards and grades and the introduction of a grading system on an objective basis.

Inspection

Grain grading has been neglected in agricultural teaching although it is necessary for assessment of the value of the grains. Too frequently, farmers market their grain without any idea of the grade of their grain. The producer or farmer should be vitally interested in getting the best grade and price for the quality of the product he o fers.

The development of grain grading is essential for the establishment of standards so that the producer may be paid for the quality of the products that he produces. Even a small amount of knowledge and experience in grain grading helps the producer to secure proper payment for the grain he sells. Standardization mainly aids orderly marketing and efficient buying and selling.

Official standards are important in the marketing process because they furnish the means of describing variations in quantity and condition. They also provide a basis for merchandizing contracts, for quoting prices, for loans on products in storage, and for sorting or blending by producers to meet market requirements. They also offer an incentive to farmers to produce better crops because farmers have the assurance that their return is based on the quality of the grains produced.

Quality has become one of the dominant factors for consideration in the expansion of the rice milling industry. The first step towards achievement of quality rice is grading. Setting up modern processing units cannot solve the quality problem completely. Good milling results can only be obtained from graded paddy; therefore, as long as the producers do not differentiate between low and high quality paddy and are not paid for producing the best paddy, but are penalized for low quality, no substantial progress can be made in the produc-

Representative Sample

The sample for examination or analysis should be representive of the lot from which the sample was taken. If the sample is not representative, no amount of care in making the determinations for the grading factors will assure proper grading of the rice. For quality inspection it is essential that the sample be: (1) large enough to permit the required tests to be performed; (2) properly identified, and (3) preserved in its original condition from the time it is taken until the grade or quality factors are determined.

Bulk Paddy in Trucks, Wagons, and Small Boats

The sample should be taken with a double-tube compartmented bulk grain probe. The grain should be probed in as many places as possible. Insert the probe or trier into the rice at an angle of about 10° from the vertical, with the slots closed. The slots should face up when the probe is opened. While the slots are open, give the probe two or more slight up-and-down motions so that all the openings are filled. Close the slots, withdraw the probe, and place the contents of the probe full length on a sampling cloth or tray.

Bulk Paddy in Flat-Storage and in Bin Silos

A long probe can be used to sample bulk paddy in flat-storage at a depth of 3–4.3 m (10–14 ft); however, extra hand pressure is required to probe deep into the stack. Sampling from bin silo storage is extremely difficult. Proper sampling can only be done when the grain is running into or out of the bin. Mechanical samplers can be installed to draw samples at regular and frequent intervals to obtain a representative sample.

Sacked Paddy and Rice

Samples from sacked paddy or rice can be taken with a sampling trier or a small probe of sufficient length to reach to the centre of the sack. The rice should be probed in as many places as possible to obtain representative samples. The usual commercial practice is to draw samples from 10% of the bags in a lot, provided that there is no significant variance in the grade or quantity. One hundred percent sampling is, however, necessary if the quality between sacks is not uniform.

The presence of live or dead insects, insect webbing, and odour would not be very noticeable from the sampled rice drawn with probes. In such cases, portions of the rice should be examined by opening the sacks.

If sacked rice is stacked so that not all the sacks are accessible for sampling, samples should be drawn from randomly selected sacks from the top, sides, and ends of the lot to enable the sampler to secure a representative sample from the accessible sacks. On the sample slip, the number of sacks in the stack and the number accessible for sampling should be noted.

Pooling the Sample

When all individual portions of a sample are found to be of one uniform quality, they should be pooled to form the sample of the lot. If any part of the lot is found to be of distinctly different quality than the balance of the lot, the samples from this part should be pooled separately.

Inspection and Grading

The important factors determining quality are: variety, moisture, dockage, milling yield, condition of grain, purity, and palatability.

Variety

Owing to the large number of rice varieties, grouping of varieties under slender and bold groups is made in certain countries; whereas, some countries have classified their varieties as fine, medium, and coarse for the purpose of grading. In the world market, much emphasis is placed on grain length as a criterion of quality. Although the combination of various shape factors such as length, width, and general contour of the grain has an important bearing on consumer preference, the palatability characteristics (appearance, cohesiveness, tenderness, and flavour) also constitute an important factor in quality grading.

The classification of paddy varieties should be made on the basis of kernel length and shape. Kernel length and breadth of both paddy and rice grains, are determined by measuring (in millimetres) whole grains selected at random and then calculating mean values. Uniformity in the size of the kernels is a good indication of varietal purity.

Moisture

High moisture directly reduces the grade of the rice; if the grain moulds or spoils, the grade is lowered even more. The moisture content has a bearing on: (1) keeping properties of grain during storage; (2) storage loss; (3) milling return; and (4) quality of milled rice. Moisture should be determined by the use of equipment and procedures prescribed by the government or its agency. The air-oven method is the basic method for determining the moisture content of paddy.

Accuracy with rapidity is an important point in determining moisture content. It is, therefore, necessary to use quick testing methods even if they are not 100% accurate, provided the error is constant. For calibration purposes, thermostatic ovens for the conventional determination of moisture content are essential to check the rapid-type moisture testers and work out correction factors.

Impurities and Foreign Matter

All material other than paddy or rice kernels is called foreign matter or impurities. This includes soil, stones, weed seeds, fragments of rice stalk, dust, husks, weevilled webs, and dead insects. The separation of impurities and foreign matter is made with the use of appropriate sieves and aspirator cleaning devices.

Hand sorting should be done wherever necessary.

Round perforations in a screen are measured by the diameter of the openings. Perforations of 6/64 inch and larger are measured in 64ths of an inch and are commonly stocked by manufacturers in sizes ranging to 80/64 inch. These screen sizes are commonly designated by using the numerator of the fraction, i.e. 6, 7, . . . , 64, 72, or 80. Round openings of 5.5/64 inch and smaller in diameter are measured in fractions of an inch and are so designated, i.e. 1/12, 1/13, 1/14, . . . , 1/25. Sizes ranging from 1/12th to 1/25th of an inch are readily available from most manufacturers.

Perforated metal screens with oblong or slotted openings are measured in two dimensions: the width and length of the opening. As was the case with round hole screens, openings of 6/64ths of an inch and larger in width are measured in 64ths of an inch; openings less than 6/64ths of an inch are expressed in fractions of an inch. Oblong openings are usually 1/4, 5/16, 1/2, or 3/4 inch in length. When designating these screens, it is common practice to give the width dimension first and the length dimension last, i.e. 5 1/2 × 3/4, 6 × 3/4, or 1/22 × 1/2, in cases where fractions of an inch denote the width.

Generally, the direction of the slot is the same as the direction of the flow of seeds on the screen. In large screen sizes, however, the slots can be across the direction of the flow of seed. These cross-slot screens are particularly useful for separating spilt seeds from varieties having a relatively thin shape. Also, among the small size slotted screens, there is a 1/22 × 1/2 diagonal screen that has its slots turned at a 45° angle from the usual direction of seed flow. This screen is useful for separating relatively short seeds from slightly longer seeds. Manufacturers commonly stock over 50 different oblong hole screens of assorted sizes, ranging from 1/24th × 1/2 to 32/64ths × 1 inch.

Test Weight per Bushel

The test weight is used as an indicator of good quality grain, and it is particularly useful when paddy is measured on a volume basis. In some countries the test weight is used for computing the quantity of paddy in the bins.

The determination of the test weight per bushel should be made on a 1.3–1.4 litre (1.1–1.3 quart) representative portion of the original sample. To determine the test weight per bushel of rough rice on the approved apparatus, the following procedure should be followed: (1) enough rough rice should be used to cause overflow on all sides of the kettle; (2) the filling and stroking of the kettle should be accomplished without jarring the apparatus; and (3) the stroking should be done cleanly with three full-length zigzag motions with the standard stroker held lightly on the kettle; the flat sides of the stroker should be in a vertical position. The accuracy of the kettle, the beam readings, and the sensitiveness of the beam should be tested periodically.

Milling Quality of Rice

After reexamining the foreign matter and ascertaining the moisture content and test weight per bushel, the potential milling properties are determined. Many factors influence the value of paddy and they require an expert for their identification, but even he is not infallible and his opinion cannot be precisely checked. Therefore, to avoid an empirical or biased verdict, a sample of the rice should be milled. The main objectives of sample milling are to ascertain: (1) the total milled yield, i.e. the total quantity of whole and broken grains recovered from the sample; (2) the head rice yield, which is the quantity of whole grains recovered from the sample; and (3) the quality of milled products.

The degree of hardness is strictly related to milling-breakage resistance. Chalky and defective kernels, being more brittle, reduce both total and head rice milling yield.

Assessing the milling quality calls for a testing device capable of simulating, in the smallest space and in the shortest time, the main processes that are carried out in a commercial mill. In all milling tests, it is extremely important that the degree of milling be constant.

Grading Factors

The following factors are used to grade paddy and rice.

Paddy: (1) moisture; (2) impurities and foreign matter; (3) seeds and foreign matter in test milled rice; (4) red grains and red streaks in test milled rice; (5) chalky and immature grains in test milled rice; (6) damaged grains in test milled rice; (7) foreign grains in test milled rice; (8) milling yield (total) in test milled rice; and (9) milling yield (head rice) in test milled rice.

Rice: (1) moisture; (2) head rice; (3) big brokens; (4) brokens; (5) chalky and immature grains; (6) damaged grains; (7) foreign grains; (8) red grains and thick red streaks; (9) paddy seeds; and (10) seeds and foreign matter.

Certification

As a practical example of the certification of rice, a sample certificate is reproduced below:

Paddy Inspection Certificate

This is to certify that the following described lot of paddy was inspected by the Institution. The inspection results are as stated below:

1. Date of inspection: *24/9/1969*
2. Sampled at: *Hock Chuan Aun*
   R. M. Butterworth
3. Sample code No.: *7-4-020*
4. Quantity: *2000 pikuls*
5. Variety/Class: *"Bahagia" long grain slender*
6. Grade: *Grade 1*
7. Moisture (paddy): *12.3%*
8. Milling yield: *Total rice 68.7%*
   Head rice 91.7%
9. Impurities (paddy): *0.30%*
10. Red grains: —
11. Seeds/Foreign matter: —
12. Chalky/Immature grains: *0.60%*
13. Foreign grains: *0.05%*
14. Damaged grains: *0.07%*
15. Remarks: —
Dated *1/12/1969*

....

Signature of Inspector

The grade of the paddy is designated on the basis of the results of analyses and observations, and on a comparison with the requirements of the standards.

The quality certificate is an important document particularly for commercial purposes. Rice inspection certificates are issued for: (1) lot inspection; (2) sample inspection; and (3) inspection of origin. A lot inspection certificate shows the results of the inspection of an identified lot. It cannot be issued as representing an identified lot unless the entire lot is accessible for examination and a representative sample is obtained. Sample inspection certificates are issued only for samples presented to the inspection agency and apply only to the sample described. In most cases, these samples are unofficial. Certificates of origin are generally issued for lot inspections. This certificate is issued primarily to certify that an identified lot of rice is the product of the soil and industry of a country (the name of the country to be given). — U THET ZIN. *Food and Agriculture Organization of the United Nations, Regional Office, Bangkok, Thailand.*

Grading

Normally paddy is not graded prior to milling, but under certain circumstances the grading of paddy is desirable or even necessary. Grading has several advantages: (1) immature grains are separated; (2) a more precise adjustment of the huller is possible, which minimizes breakages; and (3) independent milling of graded lots is possible.

In grading paddy, use is made of differences in the thickness or length of different varieties. Paddy grains having the same length but different thicknesses are graded by rotating graders; whereas, grains with the same thickness but different lengths, are separated by trieurs. If the mixture consists of grains having different thicknesses and lengths, separation is completed by both the rotating graders

and the trieurs. However, if the paddy consists of a mixture of varieties with about the same length and thickness, paddy grading is practically impossible.

Grading of milled rice refers to the separation of brokens from the head rice and the further classification of brokens into a prefixed selection of grades. In the Philippines, normally only the very small brokens and points are separated, leaving as the main product a mixture of small brokens, large brokens, and head rice. This mixture can be sold easily on the Philippine market because traditionally domestic production is not sufficient and rather high living costs dictate the purchase of this cheaper ungraded rice.

The introduction of the new high-yielding varieties (HYV's) and the fact that these HYV's, in general, are classified under "special varieties" provides bright prospects for export of this rice to quality conscious markets. This means the Philippines will have to export a product that meets the requirements of the customer. In the international trade of rice, in general, and of quality rice, in particular, the specification of these requirements always refers to the range and percentages of brokens that will be accepted. Consequently, the rice miller producing rice for export will have to grade his rice. The local demand for graded quality rice is also increasing; therefore, the grading of rice is becoming more and more important.

A milled rice grain is classified with respect to its length: 1/1 head rice; 7/8 head rice; 6/8 large broken; 5/8 large broken; 4/8 large broken; 3/8 small broken; 2/8 small broken; 1/8 small broken (points). When the specification of the rice to be produced requires: 70% head rice; 10% large brokens 6/8; 10% large brokens 5/8; 5% large brokens 4/8; and 5% small brokens 2/8–3/8, the rice miller will have to grade his rice first, then mix in accordance with the requirements. There is no other way to meet the customer's specification. When grading, use is made of differences in both the length and thickness of the particles (Fig. 23A,B).

In general the full range of rice grades can be produced by trieurs, which separate on the basis of differences in length. However, trieurs
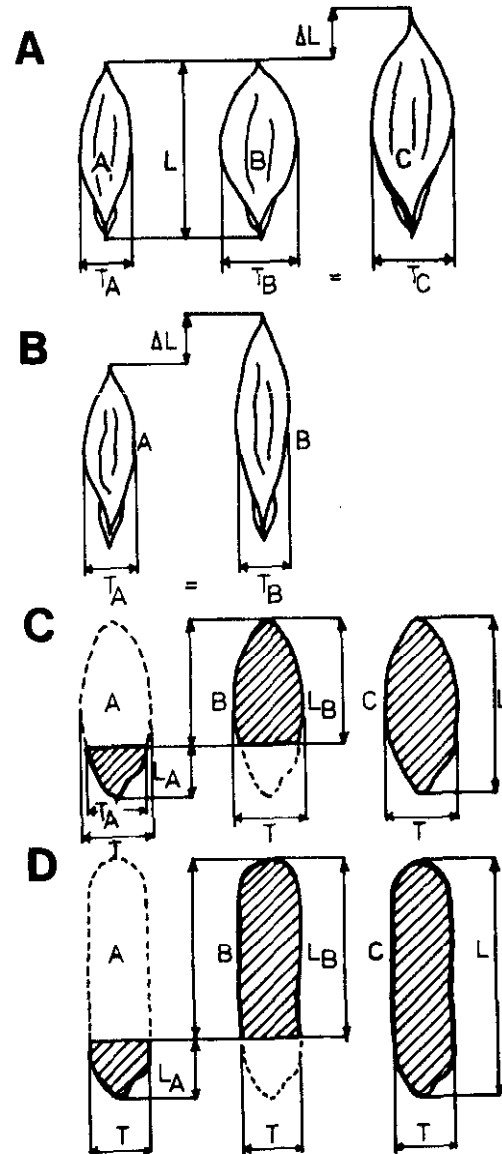

Fig. 23. Characteristics used for grading paddy and rice. (A) Grain A can be separated from B by thickness; A from C by thickness or length; B from C by length. (B) Grain A can be separated from B by length; (C) Grain A can be separated from either B or C by thickness or length; B from C by length. (D) Grain A can be separated from either B or C by length; B from C by length.

are more expensive than sieves and, where possible, sieves are used instead of trieurs.

Small brokens produced by a short medium but rounded variety of rice are thinner than the large brokens (Fig. 23C). Consequently, it is possible to separate these brokens by sieving. The large brokens, however, have the same thickness as the head rice so separation by sieves is impossible. A different situation exists with medium or long grain varieties that have long parallel sides (Fig. 23D). In this case the small brokens are the same width as the large brokens and head rice, and only grading, by length, in trieurs is possible. Points, however, can always be separated through sieves.

The machines involved in grading of paddy and rice are: (1) rotating graders (paddy); (2) trieurs (paddy and rice); (3) sieves (rice); and (4) volumetric mixers (rice).

Rotating Graders

These machines are also called "grading reels." Different designs have been made for thickness grading through these grading reels and basically three methods are used: (1) adjustable wire coil reels; (2) perforated sheets with slot perforations; and (3) wire screen reels.

Adjustable Wire Coil Reel (Fig. 24)

The operation of this rotating reel is based on the following principles. A coil spring always has a uniform clearance between the coils; however, when the spring is compressed, the uniform clearance between the coils is reduced (Fig. 24A,B). If a compressed spring contained a selection of steel balls of different sizes, only the small balls having a diameter equal to or smaller than the coil clearance would fall through. However, if the pressure on the spring was released, larger balls would fall through when the clearance was equal to the ball diameter.

The adjustable wire coil reel operates on this principle. One, two, or sometimes three adjustable wire coils are held by the rotating frame of the reel. The clearance of the first

coil is made smaller than that of the second coil. A mixture of thin, normal, and thick paddy is fed into the machine and is slowly moved through the machine by a spiralled scoop. The thin paddy grains fall through the first wire coil, the normal sized paddy is discharged by the second coil, and the thick grains leave the reel as its overflow. When three coils are installed, the first coil normally separates the immature grains, the second coil separates the thin grains, the third coil grades the normal sized paddy, and the thick grains are discharged through the overflow (Fig. 24C,D).

The reels of this type of machine, as well as the other rotating graders, are continuously cleaned by a rotating brush (Fig. 24D, no. 1) installed on top of the reels and driven directly from the main shaft of the machine.

Grader With Perforated Sheets (Slots) (Fig. 25)

Instead of the adjustable wire coil reel, a fixed clearance can be used. In this case the lining of the rotating reel consists of perforated sheets with a slot-perforation of preselected mesh (Fig. 25A, no. 1). The length of these slots normally is about 20 mm, the width varies between 2 and 3.5 mm. The range of slot widths to be installed and kept in stock depends on the varieties of paddy grown in the country concerned. For instance, for IR20 a slot mesh of 2.2 mm will hold the paddy and a mesh of 2.4 mm will let the paddy through. Immature grains are then graded with a 2 or 2.1 mm slot mesh, the main product with a 2.4 mm slot mesh, and the thicker grains are discharged as the overflow of the machine. The machine operates the same way as the adjustable wire coil reel, the only difference being that when other slot meshes are required, the sheets must be changed (Fig. 25B).

Grader With Wire Screen Reels (Fig. 26)

Instead of perforated sheets a wire screen of preselected mesh can be used. These screens consist of steel wire welded at prefixed equal distances on a crossbar that is normally a steel wire too (Fig. 25A, no. 2). The distance be-
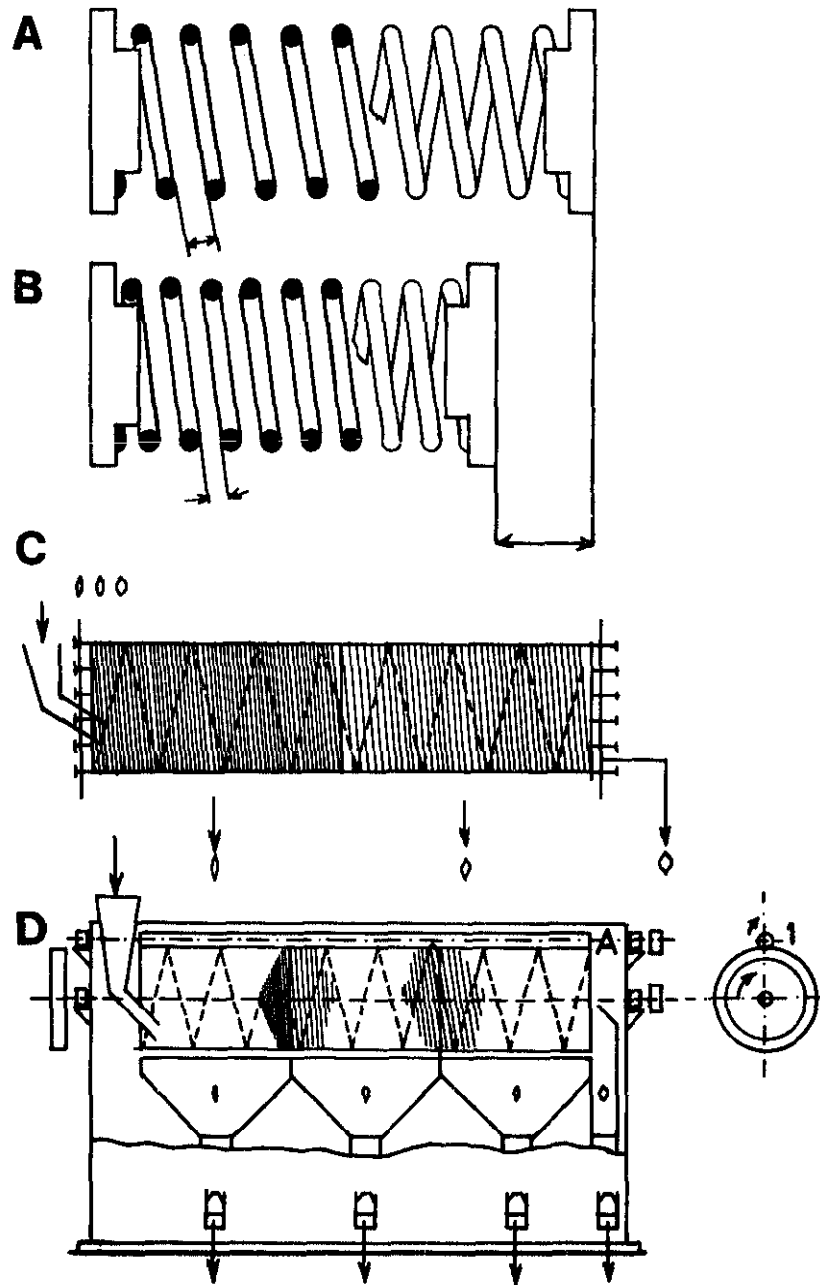
FIG. 24. Paddy grading with an adjustable wire coil reel. (A) The clearance between the coils of a spring is always equal. (B) When the spring is compressed the spacing between the coils is reduced equally. (C) A reel with two different sized adjustable coils separates thin paddy through the first coil, normal paddy through the second, and the overflow is thick paddy. (D) Using three coils the first separates immature paddy, the second thin paddy, the third normal paddy, and the overflow is thick paddy.
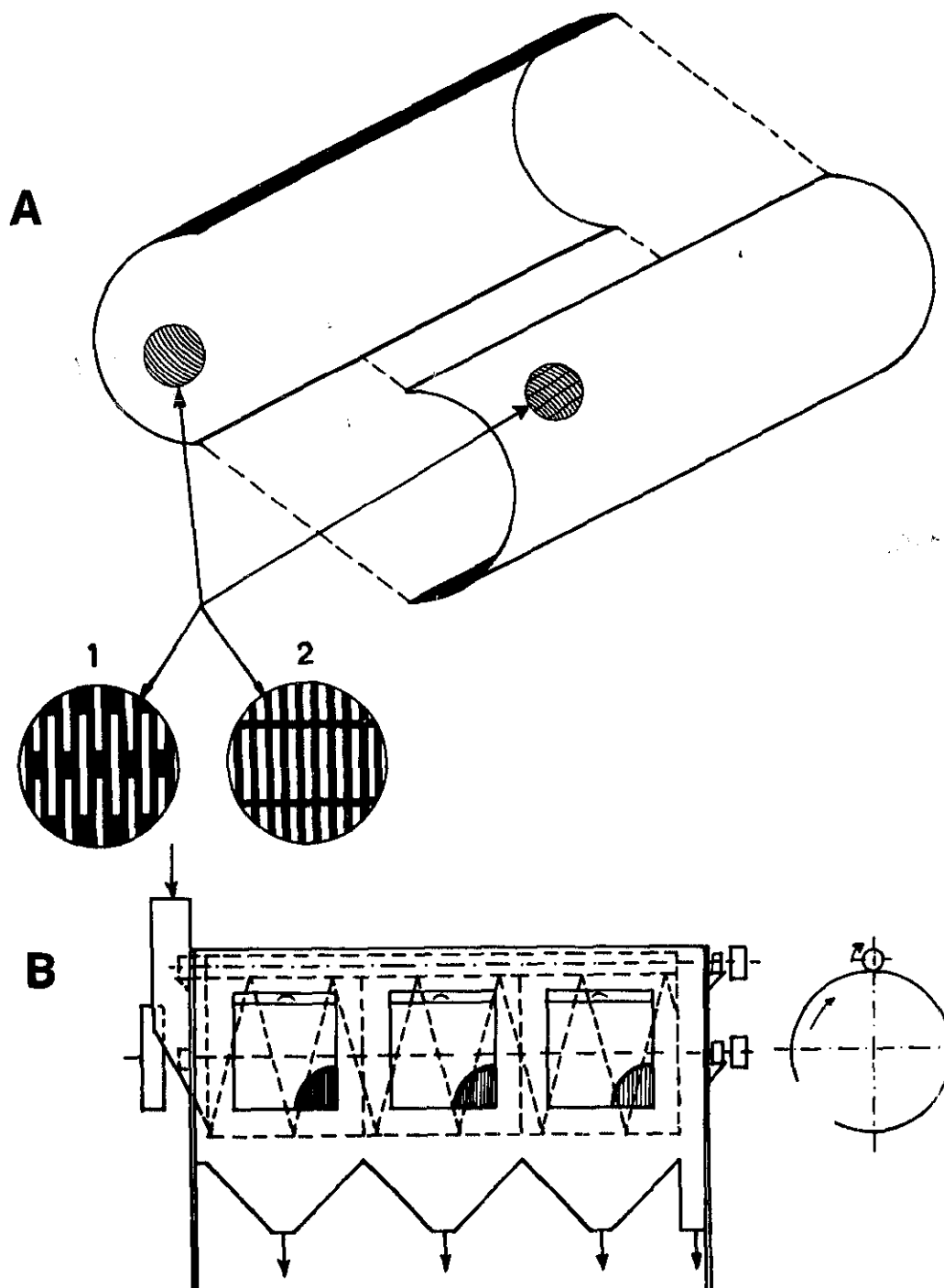
FIG. 25. Rotating grader. (A) The rotating cylinder can be a perforated sheet (1) or a wire screen (2). (B) The operation of this machine is the same as the wire coil reel except that when other slot-meshes are required the cylinders must be changed.
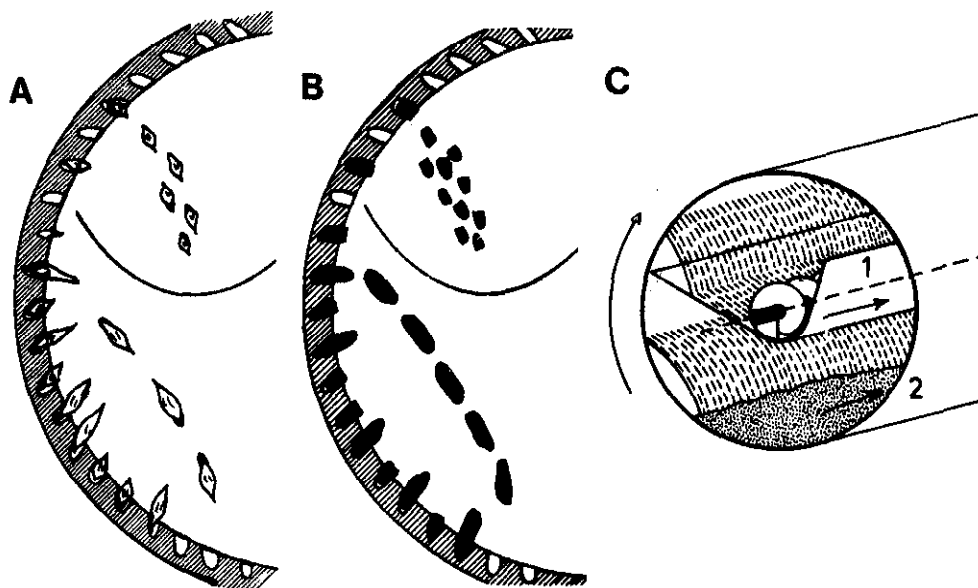
FIG. 26. Principle of grading using a trieur. (A) As the drum is rotated both long and short paddy grains
are lifted in the indents; however, the short grains are held longer and fall into an adjustable
collector plate. (B) Grading of white rice is identical except the size of the indents is different.
(C) A screw conveyor (1) discharges the short grain at the centre of the lower end of the trieur,
the overflow (2) is the long grain.

tween the wires represents the mesh of the
screen and varies, for paddy separation, be-
tween 2 and 3.5 mm. A selection of screen
meshes must also be available to meet variable
requirements. The grading performance and
operation of this machine are identical to the
other two types of rotating graders.

The Trieur (Rotating Indented Steel Cylinder)

For both paddy and white rice grading,
trieurs are used when grading by length is
desired or is necessary. A trieur mainly con-
sists of a slightly inclined rotating steel sheet
cylinder that has thousands of pocket-like in-
dents pressed in the steel at a slight angle. The
diameter of these pockets varies from 2 to
8 mm. The size of the indents depends on the
projected function of the trieur and the kind
of product the trieur will have to process. For
small brokens the indents are small, they be-
come larger as the grade of the brokens in-

creases, and are largest when large brokens
must be separated. For paddy the size of the
indent depends on the size (length) of the
short grain that must be separated from the
longer variety.

The mixed paddy, short and long, is un-
loaded into the trieur cylinder at the elevated
end. The cylinder rotates slowly (about 50
rpm) and each pocket (indent) lifts either
one long or one short paddy grain. At a cer-
tain point in their rotation the indents can no
longer hold the long grains and they fall out
of the indents. The short grains, however, are
held in the pockets and fall out at a much
higher point (Fig. 26A). The small paddy
grains are caught by an adjustable collector-
plate fixed inside the cylinder, and a screw
conveyor discharges these grains at the centre
of the lower end of the trieur (Fig. 26C, no.
1). The longer grains slowly move downwards
over the lower part of the inclined cylinder,
and are continuously lifted and released as
explained above. The cylinder overflow repre-
sents the longer paddy variety (Fig. 26C, no.

2). When grading white rice the operation of the trieur is exactly the same; however, the size of the indents is different (Fig. 26B). In the case of white rice grading, the shorter rice particles are discharged at the centre and the longer particles (or the head rice) are discharged as the overflow of the trieur.

From this explanation it is clear that a trieur separates the short grains from the long grains and does *not* separate the long grains from the short ones, and that a trieur separates the small brokens from the large brokens and *not* the large brokens from the small ones. This aspect is very important since it concerns the capacity and performance of the machine.

Because a trieur is normally ordered for a given capacity and specified function, a sample of the product to be separated should be included with the order. If a trieur is ordered that has a throughput capacity of 1000 kg/h and can remove 15% large brokens (5/8–6/8) from the head rice it must not be overloaded. For example, if the rice to be graded contains 30% large brokens (5/8–6/8) the machine will not be able to remove them all and the overflow will be a mixture of head rice and large brokens. The same will happen if the rice holds 15% large brokens (5/8–6/8) and is fed at the rate of 1500 kg/h instead of 1000 kg/h. In the first case not all brokens can be removed because the number of indents is insufficient. In the second case not enough pockets are available to lift the brokens because too many of the pockets are filled with head rice grains, and consequently, not all the brokens can be separated.

Examples of Paddy Grading

With rotating reels and trieurs perfect paddy grading can be achieved. A large number of combinations are possible although sometimes one pass through a single machine will do. Since the grain flow through the grading equipment depends on the condition of the product to be graded, the grain flow should be made flexible and, consequently, it should be made possible to bypass certain machines.

(1) Using one trieur (Fig. 27A) the paddy can be graded into long grains (LG) and short grains (SG).

(2) Using one grading reel with two compartments the paddy can be graded into immature grains, thin grains, and thick grains.

(3) Using one single compartment grading reel and one trieur (Fig. 27B) the paddy can be graded into thin short grains (TS), thin long grains (TL), and thick grains.

(4) Using one single compartment grading reel and two trieurs in series (Fig. 27C) the paddy can be graded into thin short grains (TS), thin medium grains (TM), thin long grains (TL), and thick grains.

(5) Using one double compartment grading reel and two trieurs in series (Fig. 28) the paddy can be graded into immature (dead) grains, thin short grains (TS), thin medium grains (TM), thin long grains (TL), and thick grains.

(6) Using one triple compartment grading reel and two trieurs in parallel (Fig. 29) the paddy can be graded into immature (dead) grains, thin short grains (TS), thin long grains (TL), thick short grains (THS), thick long grains (THL), and round grains.

The Oscillating Grading Sieve

Oscillating grading sieves are commonly used in the Philippines as paddy precleaners for the processing of both huller and whitening-cone discharge. Only the latter process actually refers to a white rice grading function. An oscillating sieve is a slightly inclined sieve, supported by flexible wooden or steel bars, that is moved back and forth by a vertical eccentric drive from a transmission shaft. The frequency of the stroke varies between 200 and 400 cycles per minute.

The actual sieve is a perforated steel sheet with preselected round perforations or a wire screen with preselected mesh. For perfect performance the sieve should be self-cleaning; however, this is not normally the case in rice mills made locally in the Philippines. The oscillating sieves can be of the single or double layer type. In the Philippines the rice discharged from the whitening cone is passed through a double layer type sieve. The rice
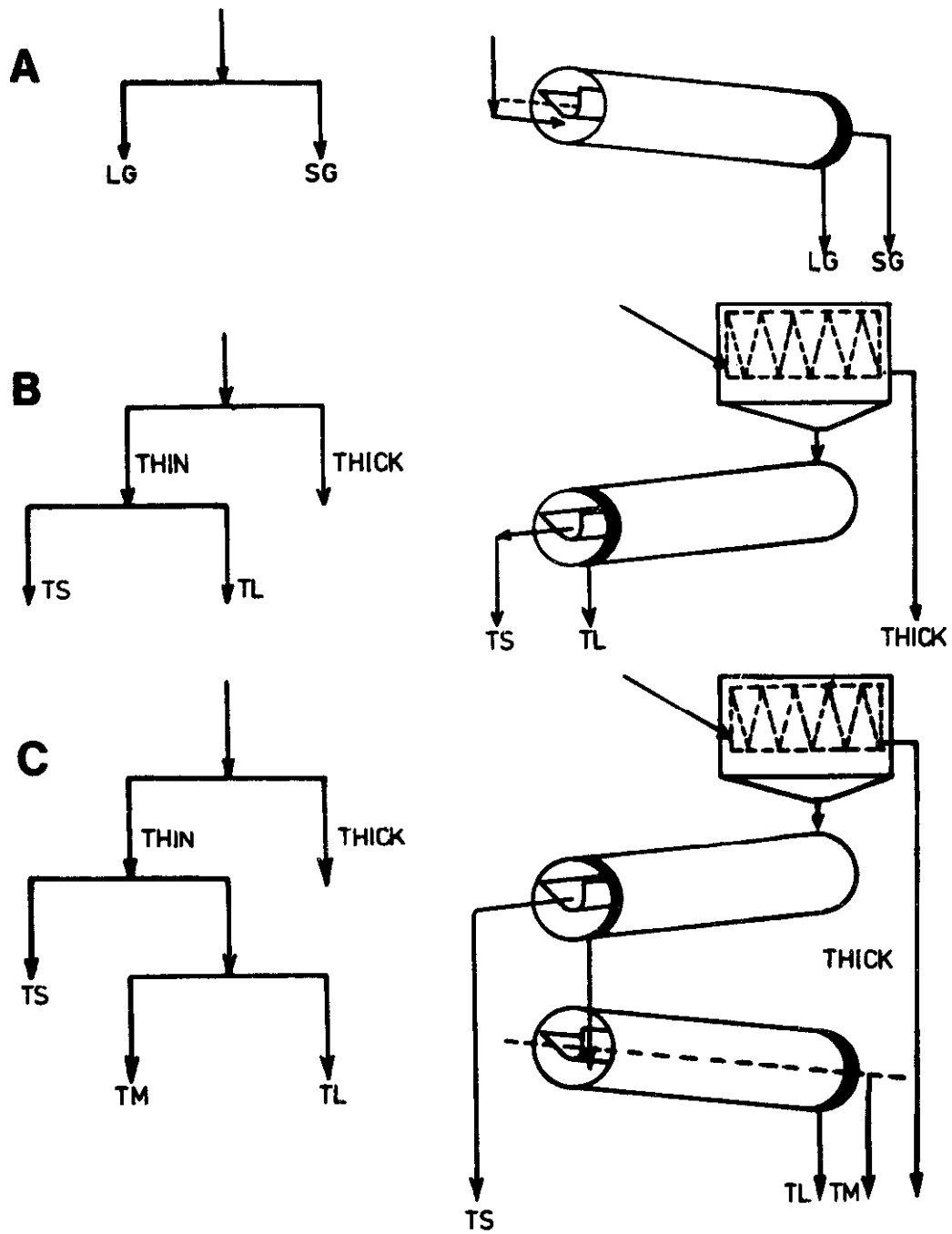
FIG. 27. Examples of paddy grading. (A) One trieur. (B) One grading reel with two compartments. (C) A single compartment grading reel and one trieur.
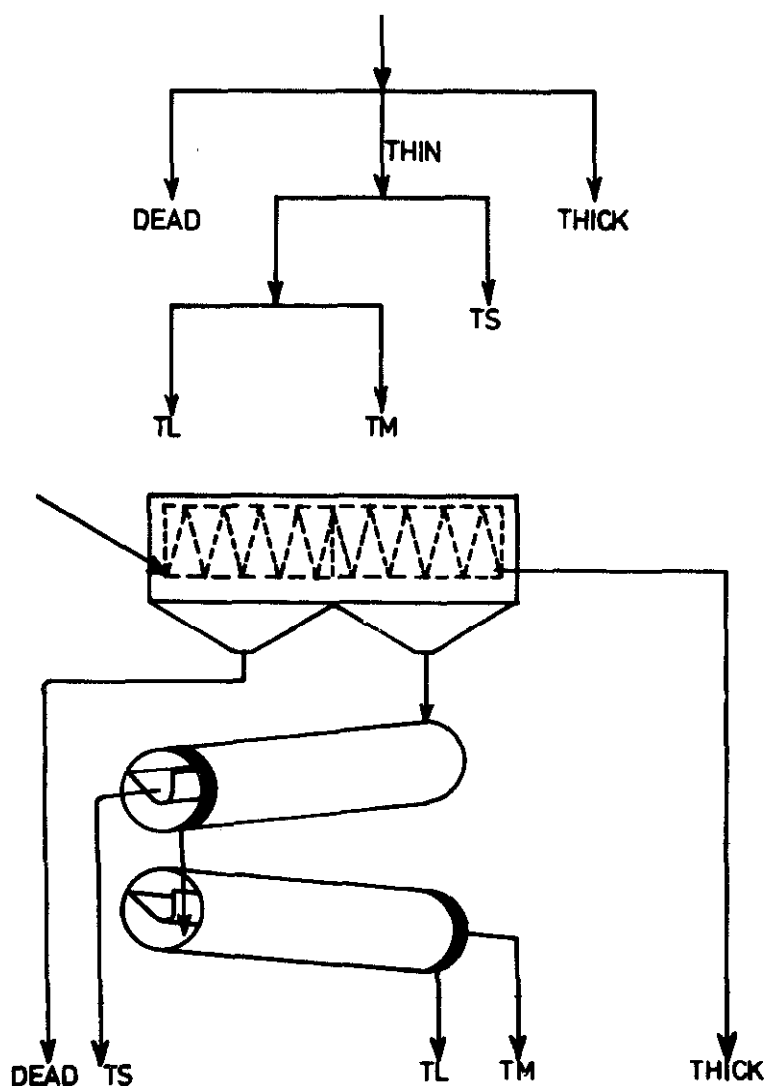
Fig. 28. Grading of paddy using one double compartment grading reel and two trieurs in series.

passes the first tray when unloaded by the first cone, and the second tray when discharged by the second cone. Actually this machine is a combination of two single tray sieves because the perforations in the sheets of both trays are the same. Their function is to remove the points, germs, and very small brokens from the rice, which is a grading function. However, single and double layer oscillating sieves can be exclusively used for the grading of fully whitened and polished rice.

If a single tray sieve is used (Fig. 30A) small brokens (1/8–2/8) (SB) can be sepa-rated from the large brokens (LB) and head rice (HR). A double tray sieve that has two different sizes of perforations can separate small brokens (1/8), small brokens (2/8), and large brokens and head rice (Fig. 30B). The same separation performance is obtained if two single tray sieves are used (Fig. 30C).

The grading capacity per square foot is rather low since, at the end of each stroke, the movement of the grain is brought to a full stop to change the direction of movement of the grain. The grains, therefore, are continuously accelerating and decelerating between
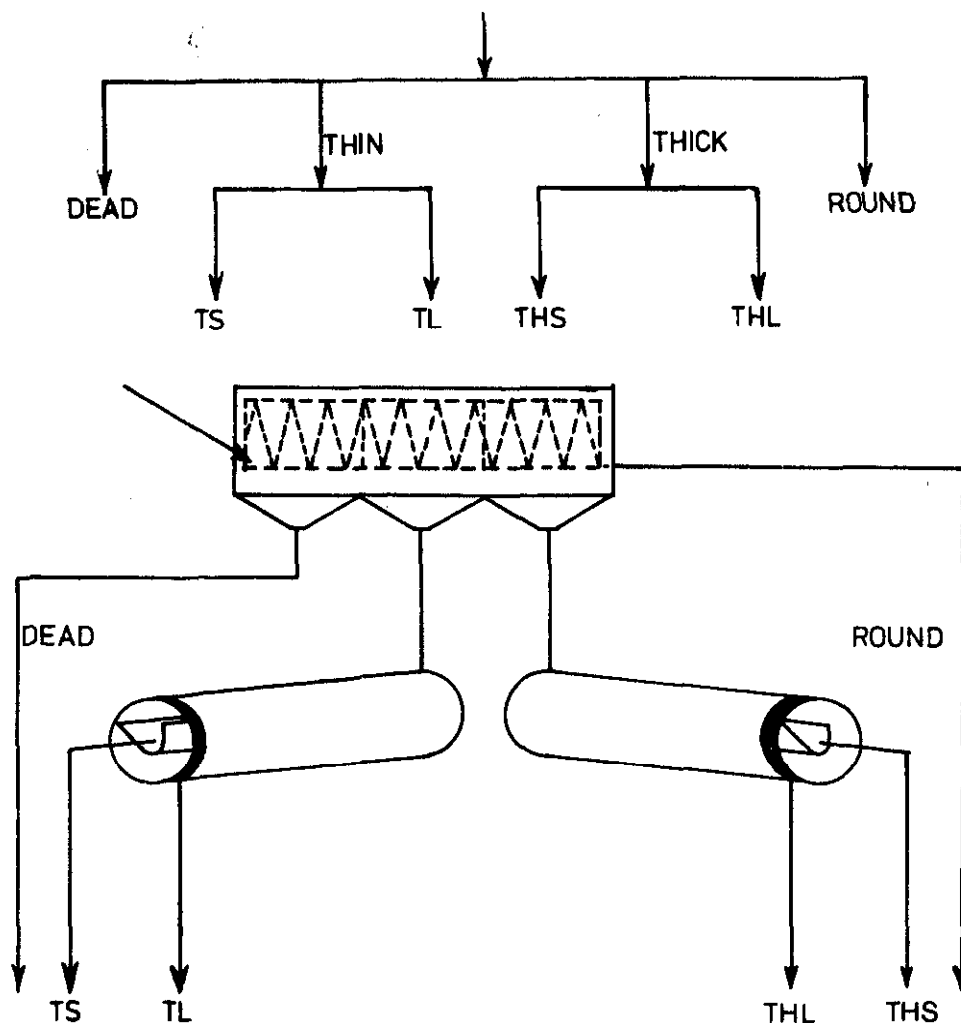
FIG. 29. Grading of paddy using one triple compartment grading reel and two trieurs in parallel.

the limits of zero and maximum. When there is practically no movement of the grain over the tray, the separation efficiency is very low. Since the grain movement over the trays is very variable, the separation of the small brokens will also be very irregular. This problem does not exist when the movement of the grains over the tray is constant. This is the case with so-called swing sieves or plansifters.

The Plansifter (Swing Sieve)

The plansifter, in general, is a single layer sieve hanging on four steel cables (Fig. 31A). The tray is directly or indirectly driven by a horizontal eccentric that makes the tray swing around in its hanging position, following the movement of an eccentric drive (Fig. 31B). The perforated sieve of the tray can be uniform in its perforations, in which case the plansifter is only separating one product, normally small brokens and points. However, the sieve can be divided into two sheets with different perforations, in which case two grades of brokens can be separated from the main product (Fig. 32A). This single layer plansifter can be driven by an electric motor through a V-belt transmission mounted on a drive assembly under the sieve (Fig. 31A), or by a flat-belt transmission that is normally mounted over the machine (Fig. 32A).
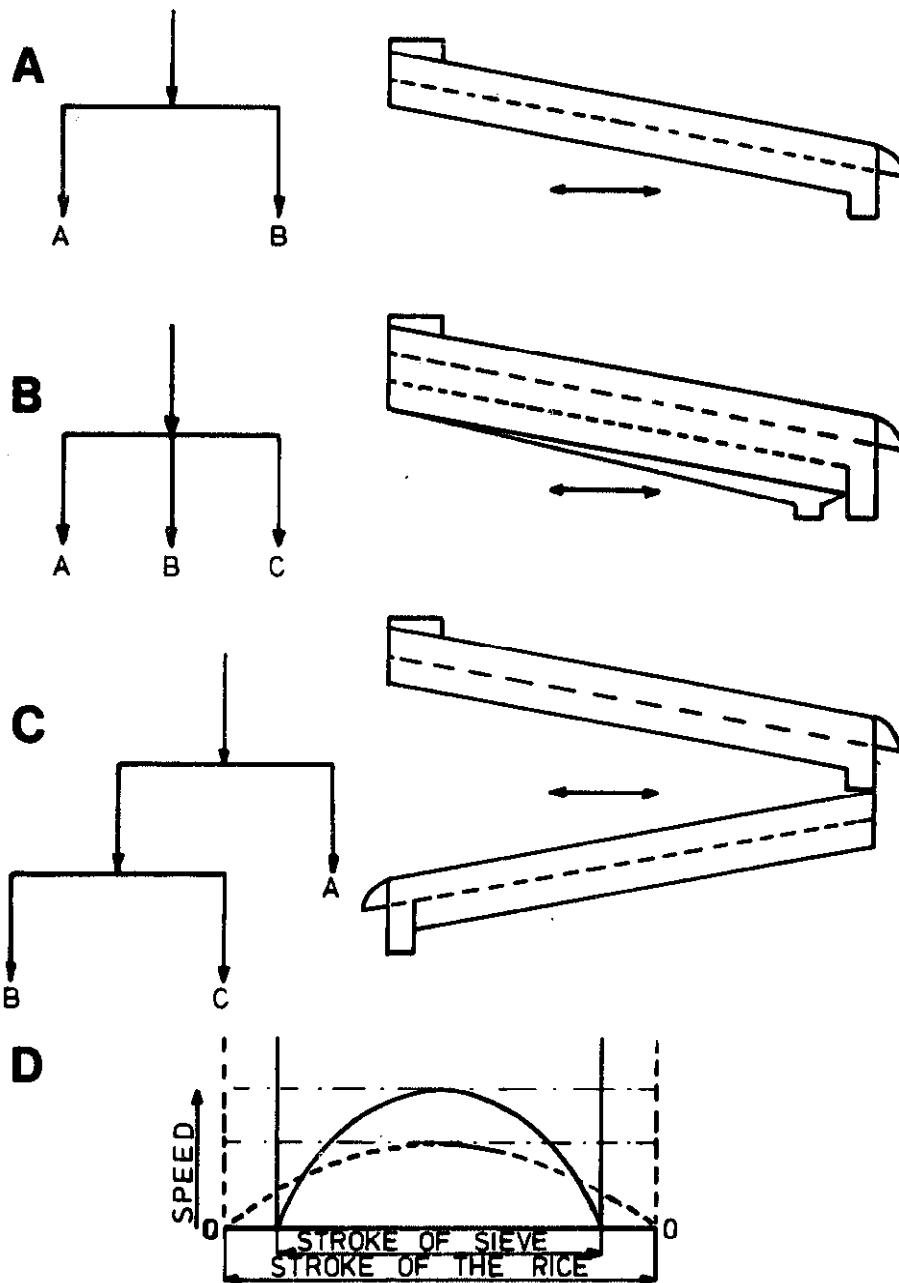
FIG. 30. Grading of white rice by oscillating grading sieves. (A) A single tray sieve. (B) A double tray sieve (C) Two single tray sieves used in series. (D) During the operation of the sieve the grains are continuously accelerated and decelerated and separation efficiency is reduced.

The movement of the grain over the swinging tray is nonstop, slowly downwards, and in a spiral-like direction over the perforated sheet. The movement is nonstop because the tray does not accelerate and decelerate in its movement (Fig. 31C) and is downwards because of the tray inclination. The movement is spiral-like and not fully circular because the grain direction is the result of the peripheral speed of the eccentric and the centri-
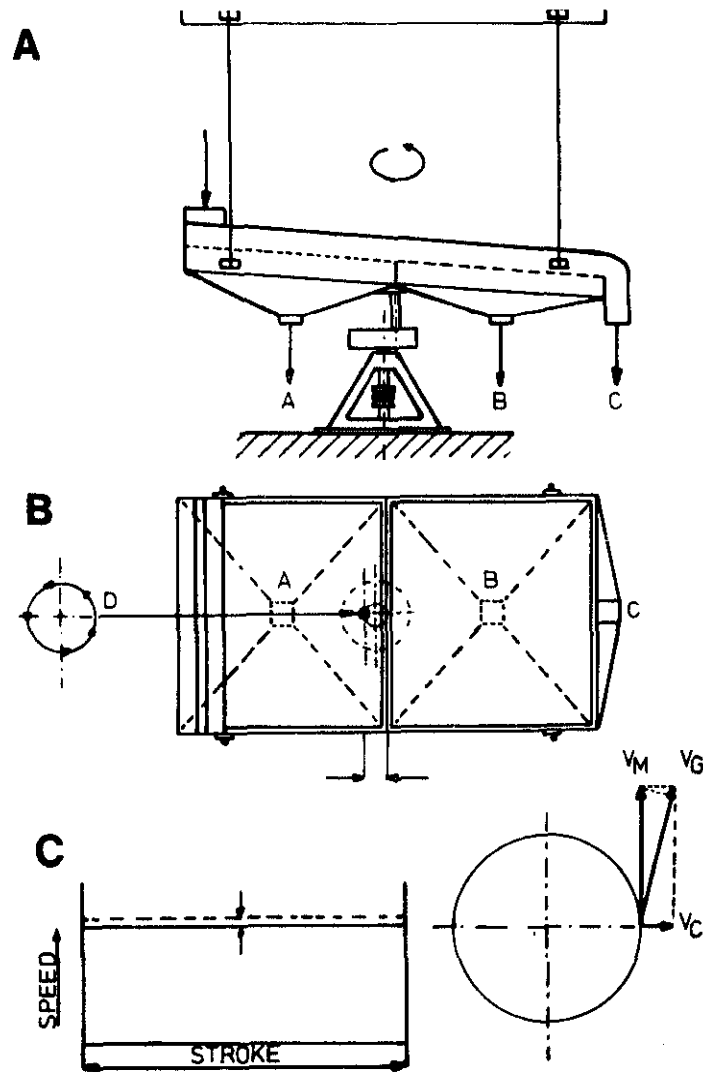
Fig. 31. The plansifter is a single layer sieve hanging on four cables. (A) The screen has uniform perforations for the separation of a single product. (B) The tray is driven by a horizontal eccentric that makes the tray swing around following the movement of the eccentric drive. (C) The movement of the grain over the tray is constant; therefore, the separation performance is more regular and efficient than the oscillating sieve.

fugal speed of the tray. Consequently, the grains always move slowly to the sides of the sieve trays.

Plansifters can also be made with two or more trays, each tray having a different perforation: the largest perforations for the top tray; the smallest perforations for the bottom tray. These plansifters are more compact and can be made as self-supported machines by

hanging the plansifter in the steel frame that supports the electric motor drive and eccentric. One of these machines was constructed by a German manufacturer, it is totally enclosed and incorporates a bran aspiration system (Fig. 32B). This machine produces two grades of rice (2,3) with a mixture of brokens and head rice (4) as its overflow. Other combinations are always possible by changing the
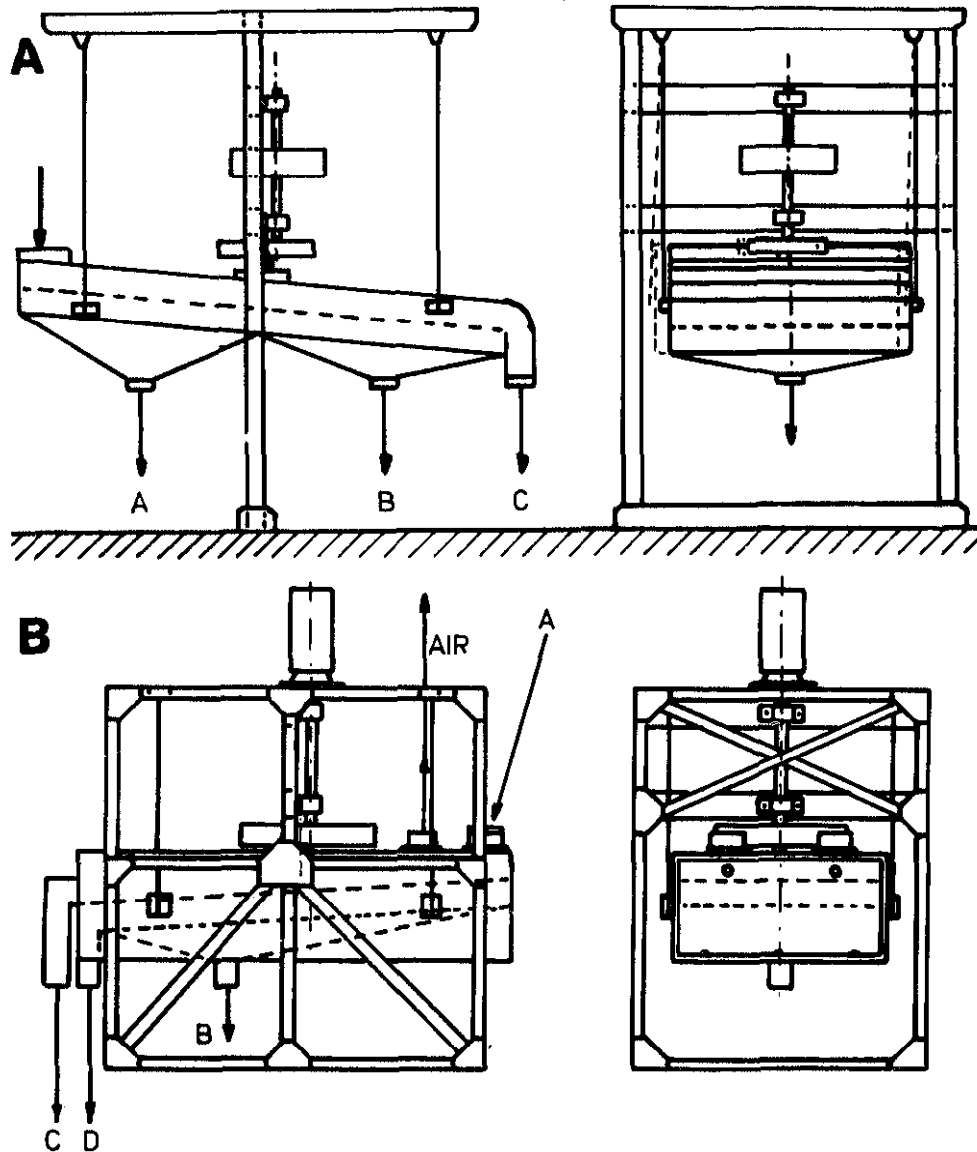
FIG. 32. Plansifters. (A) Sieve divided into two sheets with different sized perforations for the separation of two grades of brokens. (B) The "compact" Schule plansifter that incorporates a bran aspiration system.

mesh of the screens.

In large capacity rice mills so-called high capacity plansifters are used. These very compact machines consist of two, four, six, or eight rectangular steel boxes or sections that hold a large number of trays that have different mesh wire screen sieves (Fig. 33A). The trays are specially designed and follow a fixed pattern for grain overflow and screen discharge. The number of trays per section varies between eight and twelve depending on the capacity and product to be graded. Because of the multi-tray design and the repetition of grading functions, it is possible to separate as many as four grades in one pass. These machines are used in rice mills, corn mills, flour mills, and feed mills. The eccentric drive with counterweights is located in the

centre of the machine and always divides the number of sections into two equal parts (Fig. 33B).

The sections are framed together making one compact block. This swinging block of plansifter sections hangs on a large number of rattan bars that are solidly fixed in the top section of the supporting frame. Each section has five outlet spouts, four for the separated grades and one for the main overflow. Through a spout system these grades are fed into bins or to machines for further processing.

In some of the rice mills and corn mills in the Philippines these high capacity plansifters have already been installed. Their horsepower consumption is very low, their flexibility in grading performance is unlimited, and their worn screens can be replaced with practically no loss of time. Simply open a door, remove the damaged tray, replace it with a new one, close the door, and continue operations.

Rice grading plants can be very simple or they can be very complicated and offer a large program of alternative grain flows. Some examples of white rice grading units using plansifters (or oscillating sieves) and trieurs are given below.

(1) Using one single layer sifter and two trieurs in series (Fig. 34A) the paddy can be graded into points and very small brokens (P), small brokens (SB), large brokens (LB), and head rice (HR).

(2) Using one double layer sifter and two trieurs in parallel (Fig. 34B) the paddy can be graded into points (P), small brokens 1/8–2/8 (SB), large small brokens 3/8 (LSB), large brokens (LB), and head rice (HR).

(3) Using one double layer sifter and three trieurs in series (Fig. 34C) the paddy can be graded into points (P), small brokens 1/8–2/8 (SB), small large brokens 3/8–4/8 (SLB), large brokens 5/8–6/8 (LB), and head rice (HR).

(4) Using one double layer sifter, and five trieurs operating in parallel or in series, including change valves (Fig. 35), the grading results are flexible and the paddy can be graded into points (P), small brokens 2/8 (SB 2), small brokens 3/8 (SB 1), large

brokens 4/8 (LB 2), large brokens 5/8 (LB 1), and head rice 6/8–7/8–1/1 (HR) or combinations of brokens and/or head rice.

Volumetric Mixers

Volumetric mixers are used in rice mills where export markets require the rice to be mixed in accordance with preset programs after it has been graded. There are volumetric mixers of different designs but basically they follow the same principle.

Grain is loaded into a rotating compartment drum (Fig. 36A, no. 1) and is unloaded through an opening in the drum housing (Fig. 36A, no. 2) that can be partly closed to set the volume of grain to be discharged (Fig. 36A, no. 3). This controls the discharge volume per rotation and because the shaft speed of the compartment drum is made variable, a wide range of capacities can be obtained. There are provisions for inspection of the operation (Fig. 36A, no. 4) and sampling of the discharged product (Fig. 36A, no. 5). At the same time it is possible to bypass the mixer for free discharge of the bin in question (Fig. 36A, no. 6). The setting of the sleeve, which partly closes the opening of the drum housing, can be adjusted manually by a handle (Fig. 36B, no. 1), which can easily be locked (Fig. 36B, no. 2). These volumetric mixers are mounted under the bins holding the graded rice.

A simple installation for the grading of milled rice (Fig. 37) into points, small brokens, large brokens, and head rice followed by mixing consists of: (1) a bin holding the ungraded rice; (2) a single layer plansifter for the separation of points; (3) an elevator to lift the rice; (4) a trieur for the separation of the small brokens; (5) a bin for small brokens; (6) a second trieur for the separation of the large brokens and head rice; (7) a bin for large brokens; (8) a bin for head rice; (9) volumetric mixers; (10) a belt conveyor; (11) an elevator; and (12) a bin for bagging.

These sample installations are made for rice mills with a capacity of 2000 or more kilograms of paddy intake per hour (525 cavens/12 h) and can already be made in the
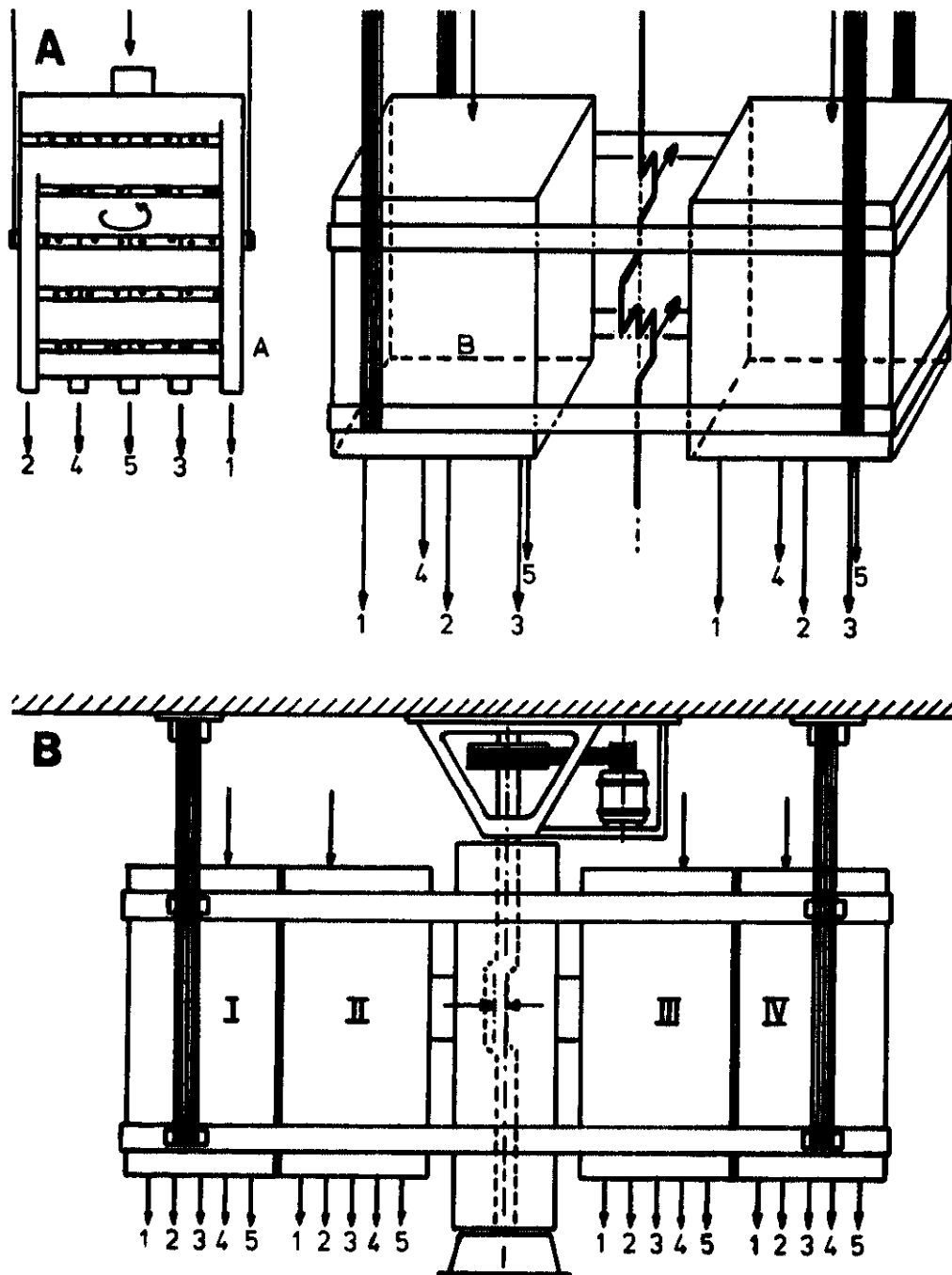
FIG. 33. (A) High capacity plansifters consist of rectangular steel boxes that hold a variety of sieves. (B) The eccentric drive divides the number of sections into equal parts. Each section has five outlet spouts, four for the separated grades and one for the main overflow.
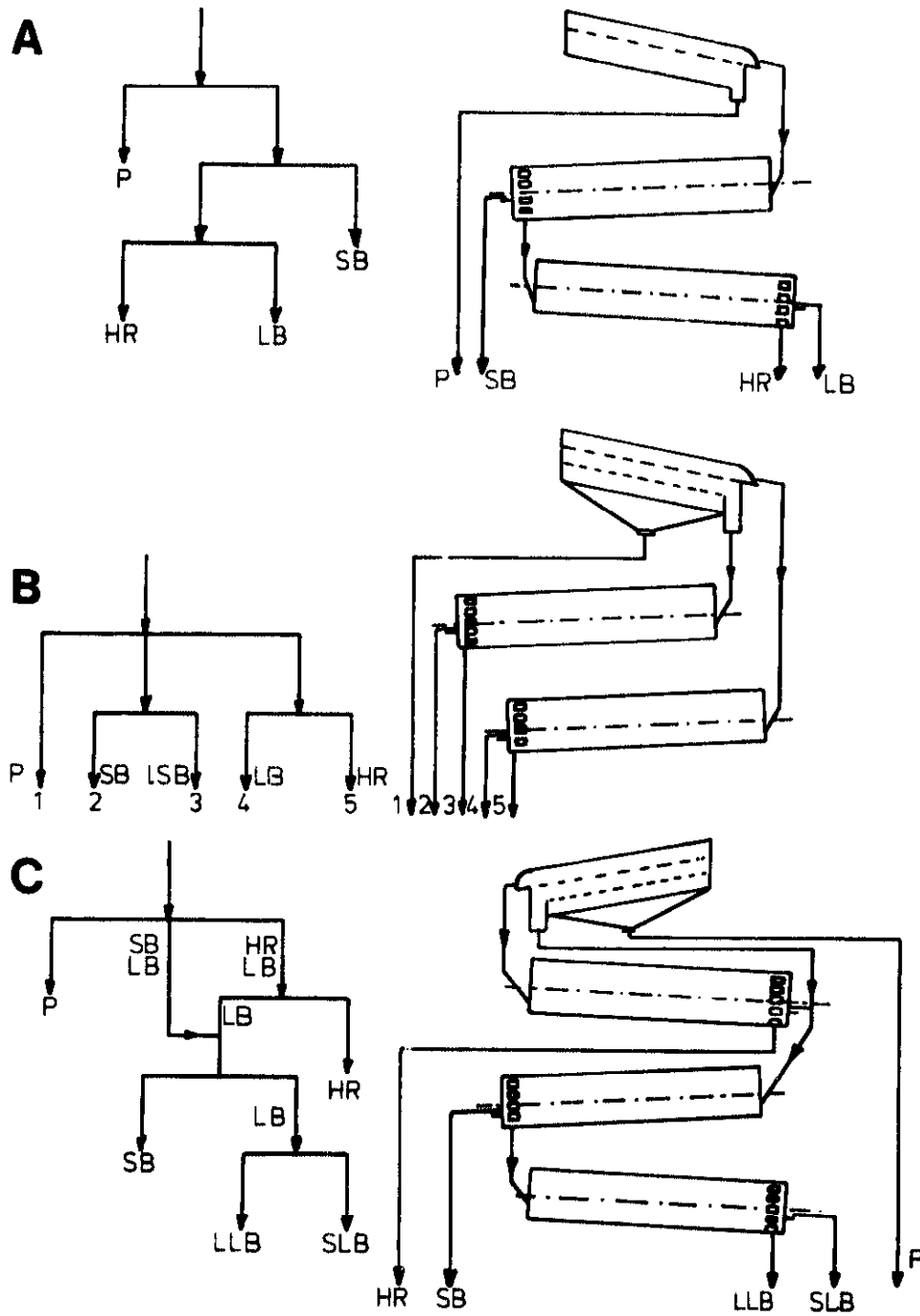
FIG. 34. Examples of white rice grading. (A) One single layer sifter and two trieurs in series. (B) One double layer sieve and two trieurs in parallel. (C) One double layer sifter and three trieurs in series.
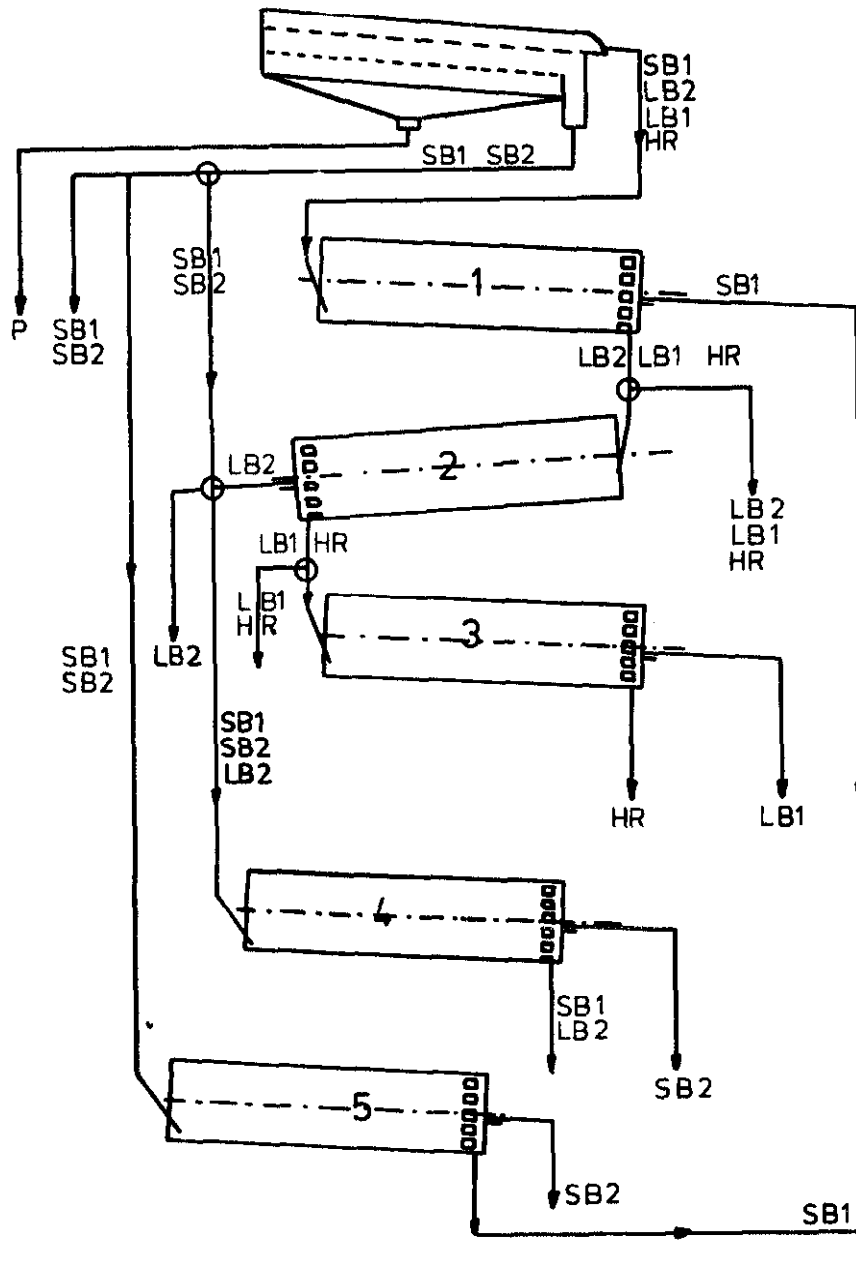
FIG. 35. Flexible grading of white rice is obtained by using one double layer sifter and five trieurs operating in parallel or in series.

Philippines. Their use, however, depends on the market situation and requires a study of their feasibility in relation to the market requirements. — HARRY VAN RUITEN. *Depart-* *ment of Agricultural Engineering, University of the Philippines at Los Baños, College, Laguna, Philippines.*
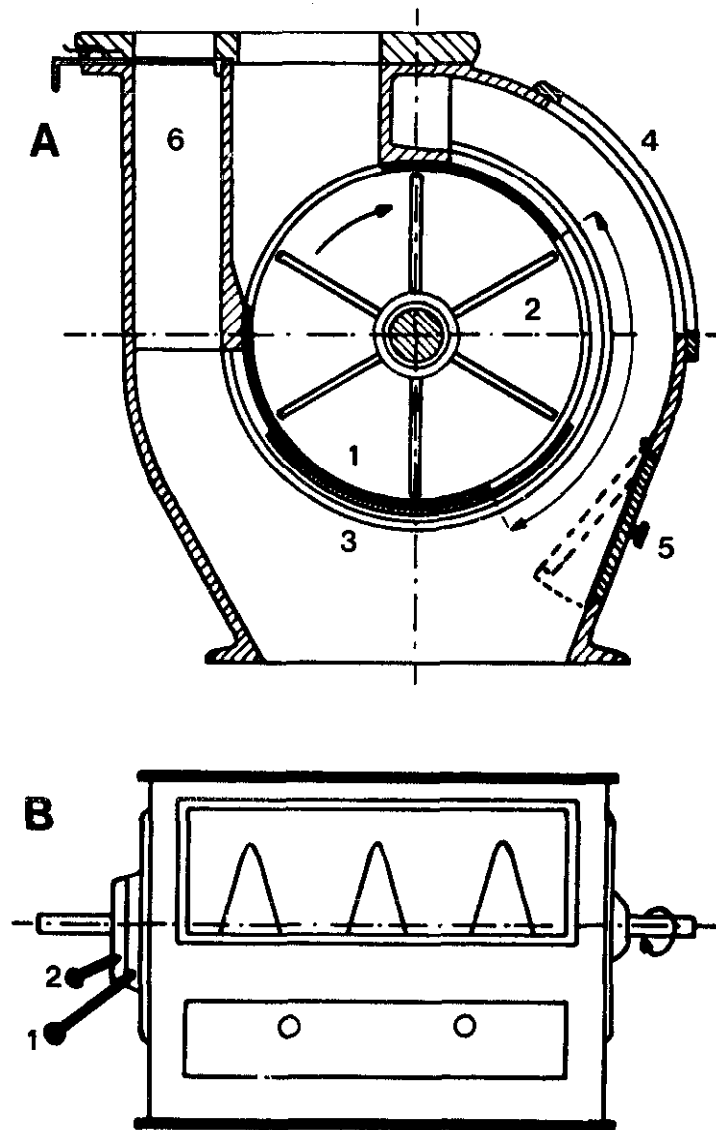
Fig. 36. Volumetric mixer. (A) The volume of grain released from the rotating compartment drum is con-
trolled by a sleeve (2) that adjusts the amount of discharge per rotation. (B) The adjustment of
this sleeve is controlled by an external handle (1) that can be locked in position (2).
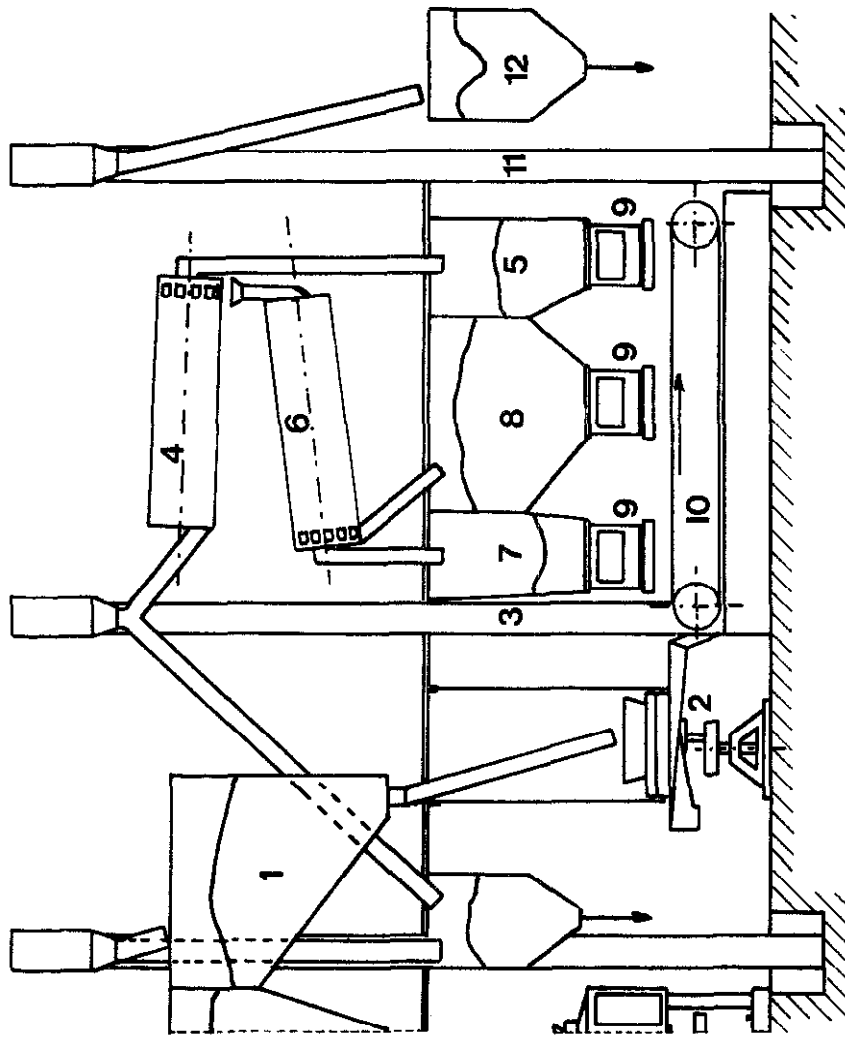
FIG. 37. Simple installation for the grading of milled rice into points, small brokens, large brokens, and head rice followed by mixing: (1) holding bin (ungraded rice); (2) single layer plansifter; (3) elevator; (4) trieur; (5) holding bin (small brokens); (6) trieur; (7) holding bin (large brokens); (8) holding bin (head rice); (9) volumetric mixers; (10) belt conveyor; (11) elevator; and (12) bin for bagging.

Experimental Design

Measurement

In statistics we recognize four levels of measurement: (1) nominal scale; (2) ordinal scale; (3) interval scale; and (4) ratio scale. The following illustration will clarify these various scales.

Three rice samples, denoted by the letters A, B, and C are to be examined according to the following objectives: (1) to identify the varieties by a symbol or number; (2) to rank the samples according to texture; (3) to determine the temperature setting in drying the sample to 14% MC in 5 h drying time; and (4) to determine the protein content. The results of the examination are given in Table 3.

Concept of Random Variables and Their Distributions

The observations that we make in our experiments may employ one or more of the four levels of measurement. The measurements that we observed are in general governed by the laws of chance, hence, they are generally called random variables. Each possible outcome in an experiment is also said to have its own probability of occurrence. The two examples given below illustrate these concepts.

Example 1

A 100-grain sample of milled rice is examined and each grain is classified as either "whole" or "not whole." The following measure is adopted: $x = 0$ if the grain is not whole and $x = 1$ if the grain is whole. The results are given in Table 4.

From these results we can say that a grain selected at random has a probability of 0.30 of being not whole or a probability of 0.70 of being whole. This is an example of a binomial random variable and binomial probability distribution.

The Bernoulli probability function is an example of a binomial population with probability function

$$f(x) = \theta^x(1 - \theta)^{1-x}, x = 0,1$$

where: $\theta = P_r$ (whole) and

$$1 - \theta = P_r \text{ (not whole)}$$

Example 2

The percentage protein content, x, of 100 samples of clean rice is determined. The summary of the data is shown in Table 5.

This experiment is a typical example wherein the random variable is in the ratio scale (continuous). The probabilities under this type of distribution are defined only between interval

TABLE 4. Results for grain classification.

Random variable (x)	Number corresponding to x ($N_{(x)}$)	Relative frequency of probability ($P_r(x) = N_{(x)}/N$)
0	$N_{(0)} = 30$	$30/100 = 0.30$
1	$N_{(1)} = 70$	$70/100 = 0.70$
Sum:	$N = 100$	1

TABLE 3. Results of the examination of three rice samples.

Purpose of measurement	Sample			Level of measurement (scale)
	A	B	C	
(1) Identification	BPI-76	IR8	C4	Nominal
(2) Texture ranking	2	1	3	Ordinal
(3) Temperature setting (°F)	210	215	205	Interval
(4) Protein content (%)	10.1	12.1	9.8	Ratio

values. Thus from the table we have $P_r(11.75 \leq x \leq 17.94) = 0.25$ and $P_r(x > 12.34) = 0.05$.

The normal distribution is an example of a theoretical frequency function of a continuous random variable x. The function is:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-1/2[(x-\mu)^2/\sigma]}, \text{ for } -\infty < x < \infty$$

The graph of a normal curve is:
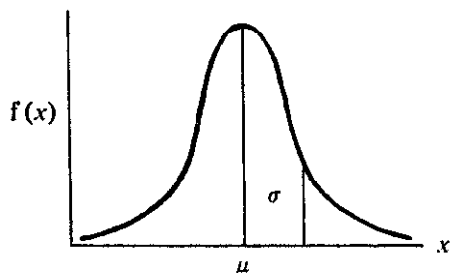
The curve is symmetric, bell-shaped, and asymptotic to the x-axis. The parameters of the distribution are μ, which is the mean (a measure of average) and σ, which is the standard deviation (a measure of spread or variability).

Sampling, Estimation, Testing Hypotheses, and Sample Size

The two main purposes of sampling are: (1) to estimate the population parameters such as μ and σ; and (2) to test hypotheses concerning population parameters. A random mechanism such as the use of a table of random numbers must be employed so that the tests of the hypotheses will be valid.

Table 6 shows a summary of the estimation

TABLE 5. Percentage protein content of 100 samples.

Interval values of x	Midpoint values of x	Frequency (f)	Relative frequency (rf)
11.15–11.34	11.245	7	0.07
11.35–11.54	11.445	14	0.14
11.55–11.74	11.645	19	0.19
11.75–11.94	11.845	25	0.25
11.95–12.14	12.045	18	0.18
12.15–12.34	12.245	12	0.12
12.35–12.54	12.445	5	0.05
Sum	—	$N = 100$	1.00

and testing hypotheses procedures under the normal and binomial populations. Using σ levels of significance the critical values for the test statistics are:

for t_c: $t_{tab} = t_{\alpha/2, n-1}$

for χ^2_c: $\chi^2_{tab} = \chi^2_{\alpha/2, n-1}$ or $\chi^2_{(1-\alpha/2), n-1}$

for Z_c: $Z_{tab} = Z_{\alpha/2}$

To determine the sample size needed to estimate the population mean, μ, with a given precision $d = x - \mu$ and a degree of confidence of $[100(1 - \alpha)]\%$ that the estimate will be within the desired precision, we use the equation

$$n = \frac{[(Z_{\alpha/2})\sigma]^2}{d^2}$$

To use this formula, we must have a good estimate of σ. For example, if we wish to estimate the mean percentage of protein content of IR8 within $\pm 0.05\%$ with a degree of confidence of 95% and $\sigma = 0.3$ the sample size should be:

$$n = \frac{[Z_{0.025}(0.3)]^2}{(0.05)^2}$$

$$= \frac{[(1.96)(0.3)]^2}{0.0025}$$

$$= 138$$

Simple Statistical Designs and Analysis of Data

The three main principles of experimental design are: (1) replication; (2) randomization; and (3) local control. Replication provides for an estimate of the experimental error (variation due to experimental units treated alike). It also provides for the increase in the precision of the estimate of treatment effects. On the other hand, randomization ensures an unbiased estimate of experimental error and makes the test of significance valid. Proper choice of experimental design, proper choice of size and shape of experimental units, and full utilization of concomitant variables (covariance analysis) are ways to minimize the magnitude of the experimental error of the experiment.

TABLE 6. Summary of the estimation and testing hypotheses used for normal and binomial populations.

Population	Parameter	Sample estimate	Null hypothesis (H_0)	Test criterion
Normal	μ	$\bar{x} = \dfrac{\sum x_i}{n}$	$\mu = \mu_0$	$t_c = \dfrac{(\bar{x} - \mu_0)n}{s}$
	σ^2	$s^2 = \dfrac{\sum(x_i - \bar{x})^2}{n-1}$	$\sigma^2 = \sigma_0^2$	$\chi_c^2 = \dfrac{(n-1)s^2}{\sigma_0^2}$
Binomial	θ	$p = \dfrac{n_E}{n}$	$\theta = \theta_0$	$Z_c = \dfrac{(p - \theta_0)\sqrt{n}}{\sqrt{\theta_0(1 - \theta_0)}}$

TABLE 7. Data for completely randomized design (CRD).

Machine	Replications					Total (T)	Mean (x)
	1	2	3	4	5		
A	68.2	68.1	68.5	68.7	68.5	342.0	68.4
B	66.3	66.9	66.6	66.7	66.5	333.0	66.6
C	67.9	68.0	67.7	68.2	67.7	339.5	67.6
Grand total and mean:						1014.5	$\bar{\bar{x}} = 67.6$

The Completely Randomized Design (CRD)

The main objective in setting up an experiment in CRD is to compare the means of effects of two or more treatments. We shall let k = number of treatments. The use of this design assumes that the total number of experimental units, say n, are homogeneous or more or less homogeneous. The treatments then are assigned into the experimental units giving: n_1 replications to treatment 1; n_2 replications to treatment 2;. . .; and n_k replications to treatment k.

Example

Fifteen samples of rough rice are available to study the mean performance of three milling machines. The samples are assumed to be homogeneous. The layout and the data on the percentage of whole grains, x, are shown below:

1	4	7	10	13
A 68.2	C 67.9	A 68.1	B 66.3	B 66.9

2	5	8	11	14
B 66.6	C 68.0	B 66.7	A 68.5	A 68.7

3	6	9	12	15
C 67.7	C 68.2	A 68.5	B 66.5	C 67.7

The tabular format for these data is given in Table 7. We next compute the following quantities (sum of squares, SS) for the analysis of variance table (AOV).

$$\text{Correction factor (CF)} = \frac{(1014.5)^2}{15} = 68\,614.02$$

$$\text{Total SS} = (68.2)^2 + (66.3)^2 + \cdots$$
$$+ (67.7)^2 - CF$$
$$= 68\,623.27 - 68\,614.02$$
$$= 9.23$$

$$\text{Machine SS} = \frac{(342.0)^2}{5} + \frac{(333.0)^2}{5}$$
$$+ \frac{(339.5)^2}{5} - CF$$

$$= 68\ 622.65 - \text{CF}$$

$$= 8.63$$

$$\text{Error SS} = \text{Total SS} - \text{Machine SS}$$

$$= 0.60$$

The AOV table is given in Table 8. Since $F_c = 86.3 > F_{0.01(2,12)} = 6.93$, we conclude that the means differ significantly at the 1% level.

Several methods are available for determining which pair of means differ significantly. One of the best of these methods is Scheffé's Test. The procedure is given below.

Let $L = \bar{x}_i - \bar{x}_j$, where $i \neq j$. We find the following quantities:

$$(1) \qquad \text{var } (L) = s_E^2\left(\frac{1}{n_i} + \frac{1}{n_j}\right)$$

$$(2) \qquad F_o^2 = (k - 1)[F_{\alpha,(k-1,n-k)}]$$

The comparison L is significant at the α level if:

$$|L| \geq \sqrt{(F_o^2)\ \text{var } (L)}$$

The summary of the analysis usually includes the treatment means, the standard error of a treatment mean, $\text{SE}(\bar{x}_i) = \sqrt{s_E^2/n_i}$, the coefficient of variation, $\text{CV} = (\sqrt{s_E^2}/\bar{x})\ 100$, and the comparison L.

Randomized Complete Block Design (RCB)

As in the CRD, the main objective in the use of this design is to compare the means of k treatments where $k \geq 2$. The n experimental units can no longer be assumed to be homogeneous and it is possible to subdivide them into r blocks. The experimental units within each block are then assumed to be more homogeneous compared to experimental units from block to block. The number of experimental units within each block is k. The k treatments are allocated at random within each block.

Example

The same machines, A, B, and C are to be tested using the same variety of rice but the tests are to be conducted at four different places. The rice samples now are assumed to be homogeneous only with respect to moisture content within places, but they may differ from place to place.

The layout and data are shown below ($x = \%$ whole grain).

Place 1	Place 2	Place 3	Place 4
A 68.2	C 66.0	A 68.4	A 68.5
C 67.8	B 67.5	B 66.3	C 67.8
B 66.1	A 68.0	C 67.9	B 66.6

The data format is shown in Table 9. The computation of SS and AOV is as follows:

$$\text{CF} = \frac{(809.1)^2}{12}$$

$$= 54\ 553.57$$

$$\text{Total SS} = (68.2)^2 + (66.1)^2 + \ldots$$
$$+ (67.8)^2 - \text{CF}$$

$$= 54\ 562.85 - \text{CF}$$

$$= 9.28$$

$$\text{Machine SS} = \frac{(273.1)^2 + \ldots + (269.5)^2}{4} - \text{CF}$$

$$= 54\ 559.03 - \text{CF}$$

$$= 5.46$$

$$\text{Place SS} = \frac{(202.1)^2 + \ldots + (202.9)^2}{3} - \text{CF}$$

$$= 54\ 553.94 - \text{CF}$$

$$= 0.37$$

$$\text{Error SS} = \text{Total SS} - \text{Machine SS}$$
$$- \text{Place SS}$$

$$= 3.45$$

The analysis of variance is given in Table 10. Since $F_c = 4.75 \leq F_{0.05(2,6)} = 5.14$, the machine means are equal. No further test is necessary in this case.

For RCB, the summary of analysis includes: (1) the treatment means, $\bar{x}_i$; (2) SE $(\bar{x}_i) = \sqrt{s_E^2/r}$; (3) CV $= (\sqrt{s_E^2}/\bar{x})\ 100$; and (4) the comparison L if the computed F value is significant.

Latin Square (LS)

Again the main objective in the use of this design is to compare the effects of k treatments. It is best for k between 5 and 8.

TABLE 8. Analysis of variance (AOV) table for completely randomized design (CRD).

Source of variation (SV)	Sum of squares (SS)	Degrees of freedom (DF)	Mean square (MS)	F value
Total	9.23	$n - 1 = 14$		
Machine	8.63	$k - 1 = 2$	$4.315 = s_M{}^2$	$s_M{}^2/s_E{}^2 = 86.3$
Error	0.60	$n - k = 12$	$0.05 = s_E{}^2$	

The features of this design are: (1) the total number of experimental units is $n = k^2$, i.e. a perfect square of k; (2) when used in field experiments, it is assumed that the experimental area (rectangular or square) varies in two directions, say, by row and column. It may also be used in experiments where the effects of two other factors (the row and column factors) are also to be investigated, but it is assumed that the effects of the factors are independent.

In LS, the randomization is restricted in two ways: (1) the treatments are allocated at random within each column and within each row; and (2) no two treatments must appear more than once within each row and within each column.

Example

Let A, B, and C be the machines, C_1, C_2, and C_3 be the moisture content, and V_1, V_2, and V_3 be the varieties. Measurement $x =$ the percentage of whole grain in the sample. The layout for this 3×3 LD design is shown below.

	C_1	C_2	C_3
V_1	B 68.2	C 67.8	A 66.1
V_2	A 68.2	B 67.7	C 66.2
V_3	C 66.6	A 68.4	B 66.3

The tabular format for computation of the AOV is shown in Table 11.

Machine total: $A = 202.7$; $B = 202.2$; and $C = 200.6$

Machine mean: $\bar{x}_A = 67.6$; $\bar{x}_B = 67.4$; and $\bar{x}_C = 66.9$

Computation:

$$CF = (605.5)^2/9 = 40\,736.69$$

TABLE 9. Data format for randomized complete block (RCB) design.

Machine	Place 1	2	3	4	Machine total	Machine mean
A	68.2	68.0	68.4	68.5	273.1	68.3
B	66.1	67.5	66.3	66.6	266.5	66.6
C	67.8	66.0	67.9	67.8	269.5	67.4
Total:	202.1	201.5	202.6	202.9	809.1	
Mean:	67.4	67.2	67.5	67.6		67.4

TABLE 10. Analysis of variance (AOV) table for randomized complete block (RCB) design.

Source of variance (SV)	Sum of squares (SS)	Degrees of freedom (DF)	Mean square (MS)	F value
Total	9.28	$kr - 1 = 11$	—	
Machine	5.46	$k - 1 = 2$	2.73	$s_M{}^2/s_E{}^2 = 4.75$
Place	0.37	$r - 1 = 3$	0.12	
Error	3.45	$(k - 1)(r - 1) = 6$	0.575	

Total SS $= (68.2)^2 + \ldots + (66.3)^2 - CF$

$= 40\ 744.07 - CF$

$= 7.38$

Moisture content SS

$= \dfrac{(203.0)^2 + \ldots + (198.6)^2}{3} - CF$

$= 40\ 742.06 - CF$

$= 5.37$

Variety SS $= \dfrac{(202.1)^2 + \ldots + (201.3)^2}{3} - CF$

$= 40\ 736.84 - CF$

$= 0.15$

Machine SS $= \dfrac{(202.7)^2 + \ldots + (200.6)^2}{3} - CF$

$= 40\ 737.50 - CF$

$= 0.81$

Error SS $=$ Total SS $-$ Moisture content SS
$-$ Variety SS $-$ Machine SS

$= 1.05$

The AOV table is given in Table 12.

Factorial Designs

When the effects of two or more factors are being investigated in an experiment in which the factorial combination of the various levels of the factor is the total number of treatment, then the design is said to be factorial. For instance, if factor A has r levels, factor B has b levels, and the treatment combination AB has been used in any one of the basic designs, then the design is an $a \times b$ factorial in CRD, RCB, or LS. Factorial design measures the effect of the various main effects and interaction effects.
— M. B. DE RAMOS. *College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

TABLE 11. Tabular format for computation of analysis of variance (AOV) for Latin square (LS) design.

Variety (row)	Moisture content (MC) (column)			Variety total	Variety mean
	C_1	C_2	C_3		
V_1	(B) 68.2	(C) 67.8	(A) 66.1	202.1	67.4
V_2	(A) 68.2	(B) 67.7	(C) 66.2	202.1	67.4
V_3	(C) 66.6	(A) 68.4	(B) 66.3	201.3	67.1
MC total	203.0	203.9	198.3	605.5	
MC mean	67.7	68.0	66.2		$67.3 = \bar{x}$
Machine total	A = 202.7	B = 202.2	C = 200.6		
Machine mean	$\bar{x}_A = 67.6$	$\bar{x}_B = 67.4$	$\bar{x}_C = 66.9$		

TABLE 12. Analysis of variance (AOV) table for Latin square (LS) design.

Source of variance (SV)	Sum of squares (SS)	Degrees of freedom (DF)	Mean square (MS)	F value
Total	7.38	$k^2 - 1 = 8$	—	
Moisture content	5.37	$k - 1 = 2$	2.685	5.11[ns]
Variety	0.15	$k - 1 = 2$	0.675	1.29[ns]
Machine	0.81	$k - 1 = 2$	0.405	1
Error	1.05	$(k - 1)(k - 2) = 2$	$0.925 = s_E^2$	

NOTE: ns = not significant; $F_{0.05(2,2)} = 19.00$.

Laboratory

Tests

A laboratory analysis shows the value of the sample tested. To determine the quality of the whole bulk of rice, from which the sample has been taken, it is essential that the sample be truly representative; it should: (1) contain the same elements present in the whole; (2) contain these elements in the right proportion; and (3) maintain these elements in a stable condition. The first two points involve proper sampling techniques; the third is related to the preservation of the sample (dry airtight containers).

The representative sample collected from the bulk grain is in excess of the quantity required for laboratory tests and reference purposes. To ensure that the parts of the sample contain the same proportion of light and heavy grains, dust, and other impurities as the bulk, the sample must be properly mixed and divided.

A hand turned seed mixer (Fig. 38) is used to mix the sample. After a thorough mixing the sample is divided in a sample divider (Fig. 39). The grain from the hopper (1) flows through a throttle (2) over the surface of a cone where it is collected by pockets (3) and is channelled into two containers (4).

Rice samples can also be mixed and divided by hand if the sample is spread in a thin layer on a board and then divided and subdivided into even portions.

Laboratory Scales

All figures used for rice testing are expressed or referred to in weight. When paddy, according to local custom, is measured by volume, data obtained from laboratory tests must be converted.

In rice testing, accurate weighing is of paramount importance as any slight weighing error can greatly alter the results of the analysis.

Two types of scales are required for rice testing (Fig. 40): (1) A scale for weighing the paddy samples. It should have a capacity of 500–1000 g and be accurate to 0.1 g. The scale pan is removable and shaped to facilitate pouring the grain into the hoppers of the milling equipment; (2) A precision balance to weigh dust and other foreign matter that is generally present in very small quantities. It should have a 50 g capacity and be sensitive to 0.1 g.

The bulk density of a sample is determined by weighing a known volume of grain, which is obtained by pouring the grain into a container with a known capacity and levelling with a straight edge.

Cleaning (Dockage)

Three distinct operations are needed to clean rough paddy or milled rice: (1) separation of straw, dust, chaff, and other coarse materials from the grains; (2) removal of weed seeds; and (3) grading to separate immature, undersized, and broken kernels from whole grains. These operations are done with various screens and sieves and indented plate graders.

The difference between a sieve and a screen is not in the component's construction, but in the type of work performed. With a sieve the good grain falls through the openings (scalping); whereas, a screen allows the good
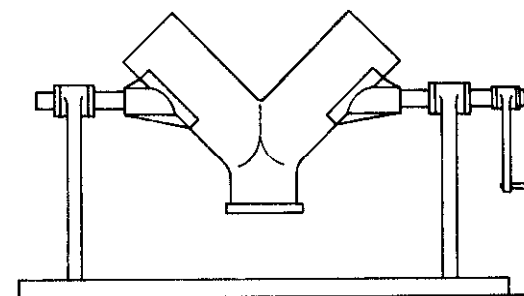

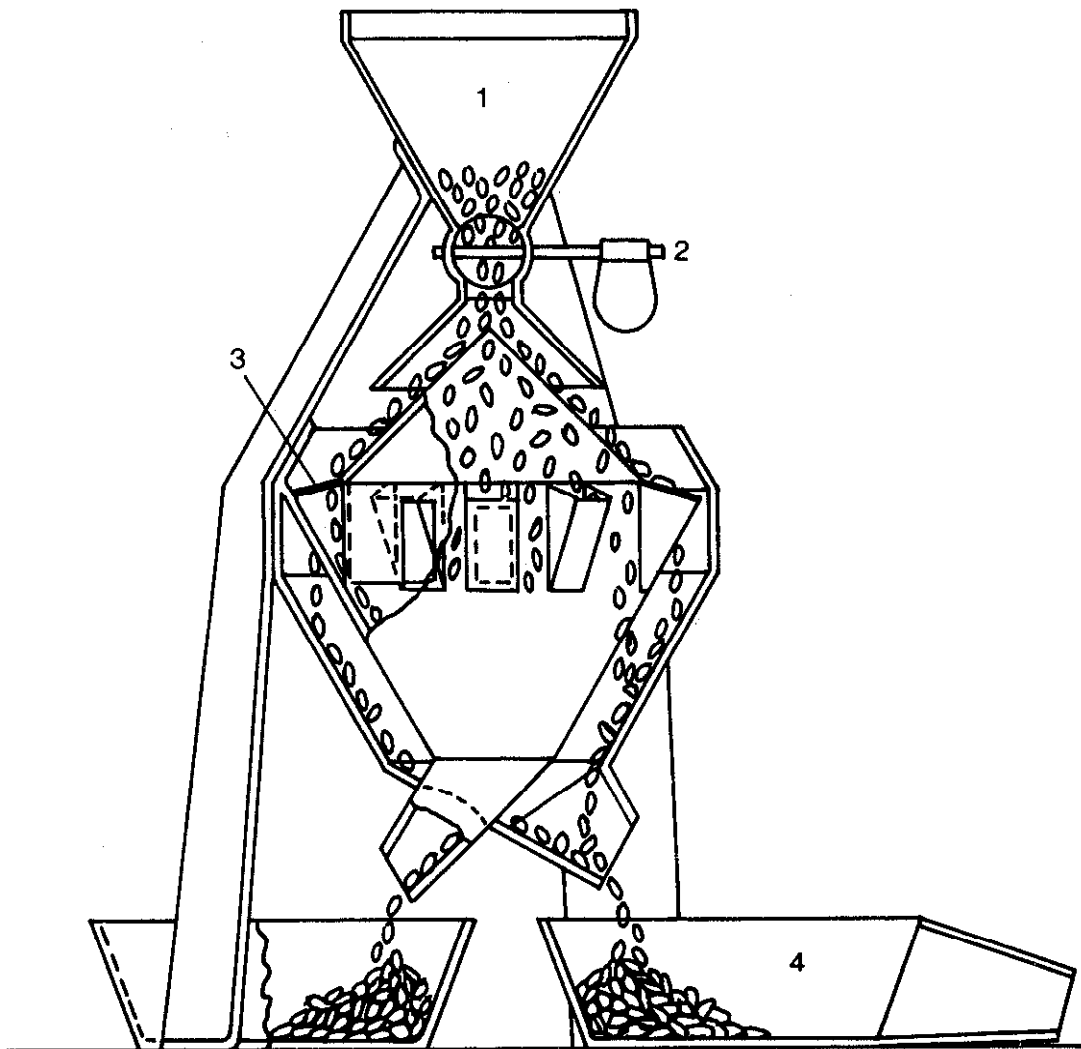
FIG. 38. Hand turned sample mixer.

FIG. 39. Sample divider: (1) hopper; (2) throttle; (3) pockets; and (4) containers for divided samples.
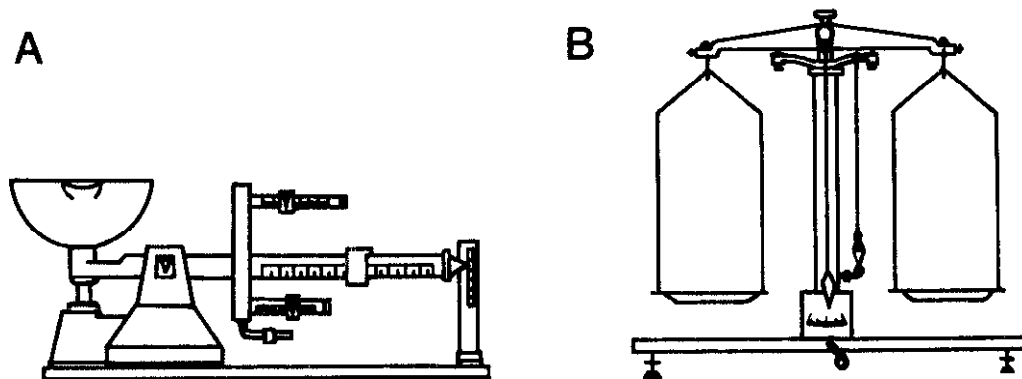
A

B

FIG. 40. A. Scale for grain sample. B. Analytical dial-reading balance.

grain to pass over the top while the weed seeds and small dockage fall through the sieve apertures (screening).

Wire-mesh, perforated plates, and indented plates for laboratory use can be made into pans for hand operation, or built into machines of the following main types: reciprocating sieve or vanner; plansifter; and rotating reel or trommel. Special machines using indented discs are also available. The plates and discs on laboratory machines should be interchangeable to suit the work to be done. There should be an ample range of sifting pans to deal with different rice varieties.

Foreign matter is separated in the laboratory with the same methods that are used in commercial milling, i.e. by taking advantage of the difference in size, shape, and weight of foreign matter as compared to the good grain.

Simple hand sieves and a special hand machine can be used to separate by thickness (Fig. 41). The hand machine consists of a helical wire cylinder (1), which is turned by hand. Rice is poured through the opening (2) and after screening, it is discharged at the other end of the cylinder; whereas, weed seeds and undersized materials passing through the

screen are collected in a hopper (3). A comb (4) keeps the screen clean.

Figure 42 is a sectional drawing of a laboratory apparatus for removing light foreign matter by an air blast. The paddy is poured through the receiving hopper (1) and flows through the regulating valve (2) into the second hopper (3) where an induced blast of air removes light foreign material from the paddy and delivers it into the cylone (4). The blast of air can be adjusted by regulating the speed of the fan through control (5).

Figure 43 shows a laboratory fanning mill. From the hopper (1) the paddy falls on the reciprocating sieve through which the good grains pass to the screen underneath. Coarse foreign matter is collected in (2) while good seeds and dockage fall through the screen and are collected in (3). As the grain falls from the screen it passes through the air blast that blows dirt and chaff into a bag (4). Clean paddy is collected in (5). The strength of the blast has to be such that unwanted matter, but not the good grains, is blown out. Depending on the type of mill, the blast can be adjusted either by regulating the speed of the fan (6) or by altering the air spout in the fan housing.
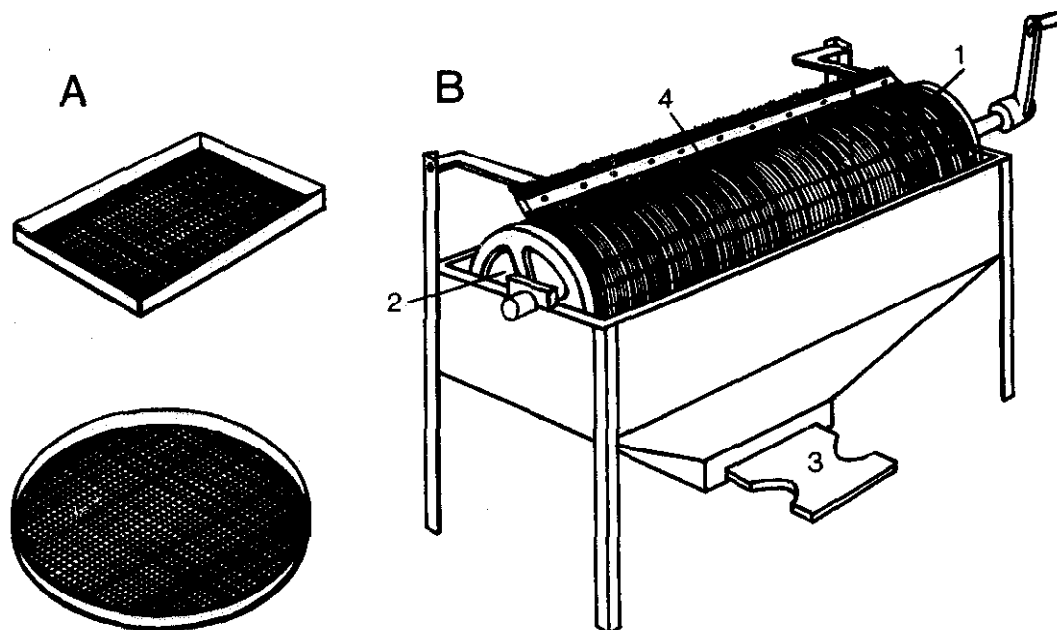
Fig. 41. A. Hand sieves. B. Hand operated rice grader with concave wire screen.
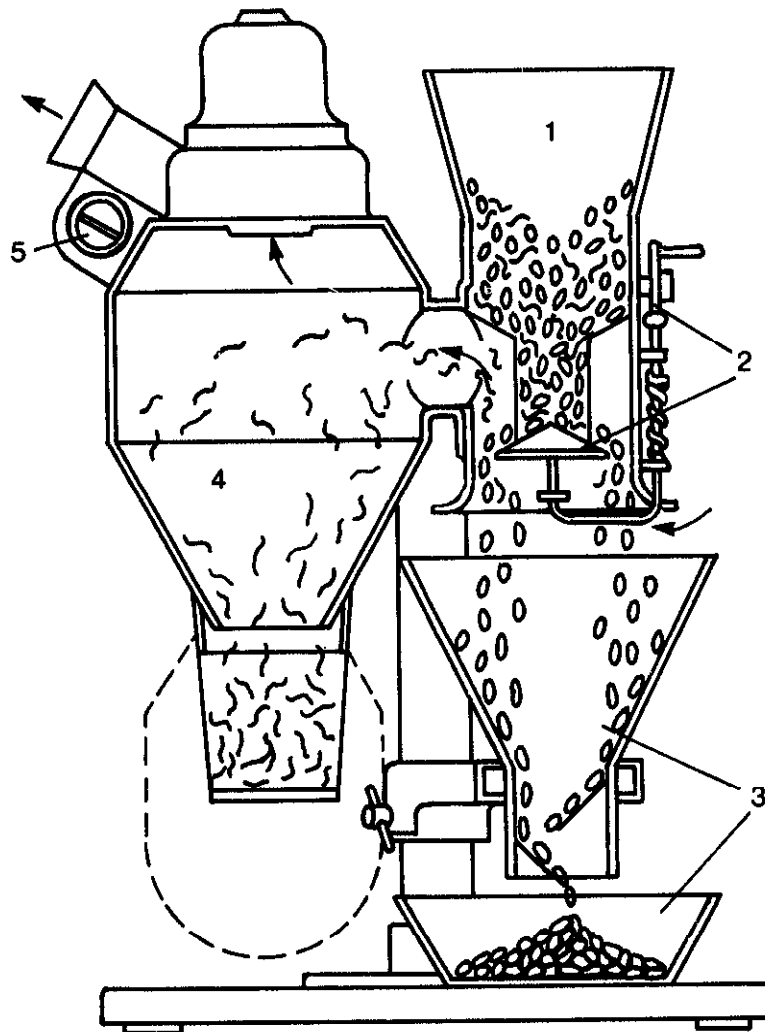
FIG. 42. Laboratory grain cleaning aspirator: (1) receiving hopper; (2) regulating valve; (3) second hopper; (4) cyclone; and (5) fan control.

Moisture Content

The moisture content of rice has a bearing on: (1) keeping quality; (2) loss of weight by evaporation during storage and processing; (3) milling output; and (4) cooking characteristics of milled rice.

It is, therefore, important to determine the moisture content of paddy during the following stages: (1) in the field to determine the proper time of harvesting; (2) on the farm or in the drying facility, to control the degree of drying; (3) during storage to obtain safe storage, and determine possible evaporation losses; and (4) during milling, to prevent excessive breakage.

Accuracy combined with rapidity are the most important points. Because accurate, direct, methods are time consuming, quick testing methods are used even if they are not 100% accurate, provided the error is small and constant.

Thermostatic ovens for the conventional determination of moisture content are essential in any laboratory to check rapid-type moisture testers, to ascertain their errors, and
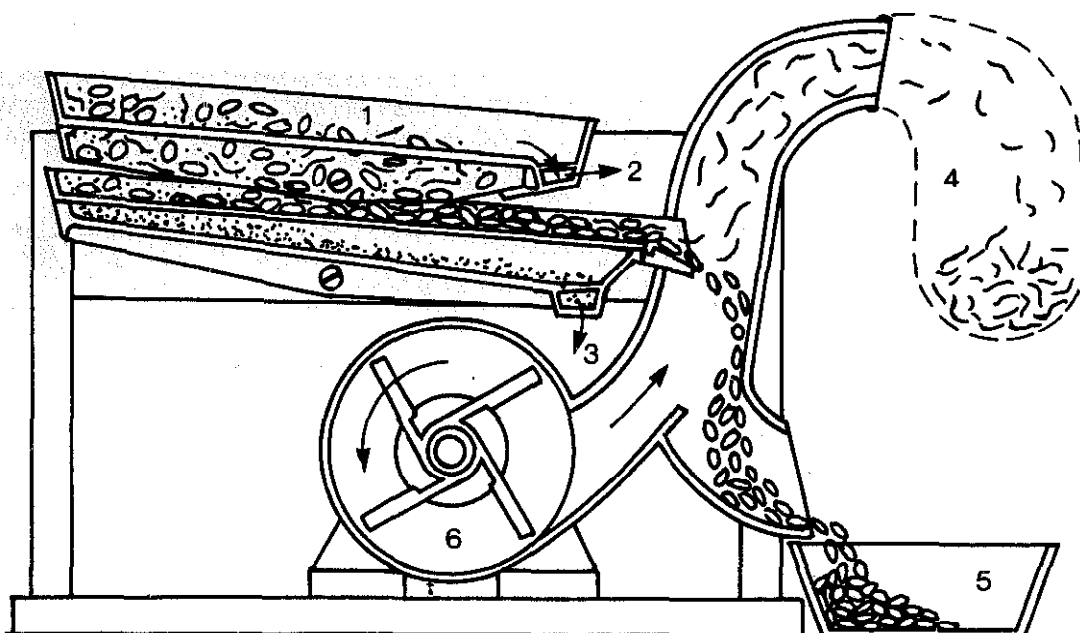
FIG. 43. Laboratory fanning mill: (1) hopper; (2) path for coarse foreign matter; (3) path for good seed and dockage; (4) bag for chaff and dirt; and (5) bin for clean paddy.

work out correction factors (calibration).

The methods used to determine moisture content can be divided into four groups, based on their principles of operation: (1) evaporation; (2) direct distillation; (3) alteration in some physical property; and (4) chemical reactions.

Testing methods based on water evaporation are the most popular and practical. Because of the biological aspect of the rice grain, errors between 0.5 and 1.0% are not uncommon. Too high a temperature may also gelatinize some of the external part of the kernel, which impedes water evaporation.

Moisture determinations based on direct distillation involve the use of hydrocarbons such as toluol and xylol that, after dilution with water, condense in separate layers in a graduated tube to allow quick determination of distilled water.

Chemical methods are based on a reaction between a given substance and the water contained in the grain. For example, the "Chopin" method is based on the measurement of the amount of acetylene gas generated by the reaction of calcium carbide with the water in the rice kernels.

Electric moisture testers base their measurements on changes in the electrical properties of the grain. For example, the higher the moisture content, the higher the conductivity, and the higher the flow of electric current through the metre.

Purity of Rice Variety

The degree of purity of rice varieties is related to: (1) varietal impurity; and (2) natural diversity.

Varietal impurities are caused by the presence of other varieties in the bulk. Natural diversity is malformation with respect to the morphological characteristics of the variety. Such malformations can be of heritable origin or may be caused by alterations that occur during the growing and ripening process.

Rice varieties can be grouped according to the shape of the kernel – long, medium, short, or round. As a consequence, when the mass includes varieties of different shapes, separation can be done with sieves and screens to grade the sample according to length and thickness. On the other hand, when different varieties of the same group are present (i.e.

having the same shape) grading can only be done by hand.

Grading for purity can be carried out on both paddy and milled rice.

Drying Paddy Samples

If the paddy sample to be tested is milled after threshing and before drying, the milling test will either give inaccurate results or not be possible at all. Damp paddy cannot be milled, and very dry paddy may produce a higher (or even lower) percentage of brokens than paddy dried to the correct degree of moisture for safe storage.

Laboratory paddy driers have been developed that enable testing of damp paddy samples taken after threshing. All laboratory samples obtained from the same lot should be dried in the same manner. In addition, the drying process should be as similar as possible to commercial drying, or should give the same results, or, at least, constantly proportional results.

Drying can be carried out in stages with resting periods to allow the moisture inside the kernel to become evenly distributed. Drying time, temperature, air pressure, velocity, and resting periods should be chosen in accordance with the moisture content of the grain and to attempt to reproduce as closely as possible commercial drying methods.

While drying, moisture losses are checked by weighing the sample, i.e. by determining reductions in weight due to water evaporation. Once the moisture contents before and after drying are known, the percentage reduction in weight of the sample that occurred during the drying process is found:

% reduction in weight

$$= 100 \times \frac{\% \text{ MC before} - \% \text{ MC after}}{100 - \% \text{ MC after}}$$

For example: original MC = 17.5%; MC after drying = 12%

% reduction in weight

$$= 100 \times \frac{17.5 - 12}{100 - 12}$$

$$= 6.25\%$$

Milling Quality

After removing foreign matter, drying the sample, and ascertaining the moisture content, the potential milling properties are determined. Many factors have an influence on the value of paddy and they require an expert for their identification, but even he is not infallible and his opinion cannot be precisely checked. Therefore, to avoid an empirical or biased verdict, this operation should be done mechanically, by actually milling the rice.

The main objectives of sample milling are to ascertain: (1) the total milled yield, i.e. the total quantity of whole and broken grains recovered from the sample; and (2) the head rice yield, which is the quantity of whole grains recovered from the sample.

Assessing the milling quality calls for a testing device capable of simulating in the smallest space and in the shortest time the main processes that are carried out in a commercial mill. Moreover, the device must give results closely approximating those of the mills, so that its output can be compared with that from a commercial mill.

Several different types of testing devices are available. The performance of each is closely related to the principles of operation, accuracy of adjustment, and to the capability of the operator in interpreting the results. They can be classified according to steps followed, type of feeding, and the principle of operation.

(1) Steps followed while processing, i.e. (a) shelling and whitening followed in two different steps through two different machines; or (b) shelling and whitening in one run through a single machine.

(2) Whether or not feeding is continuous, i.e. (a) batch type, which is fed with a given quantity of grain; (b) a unit fed with a continuous flow of grain; or (c) a combination of the two, e.g. a continuous feed sheller and a separate batch fed whitening unit.

(3) The principle of operation, i.e. (a) following the European method, which includes the pearling cone; or (b) following the American method where whitening is done by the so-called huller.

The milling technique practiced in the country concerned will decide the type of
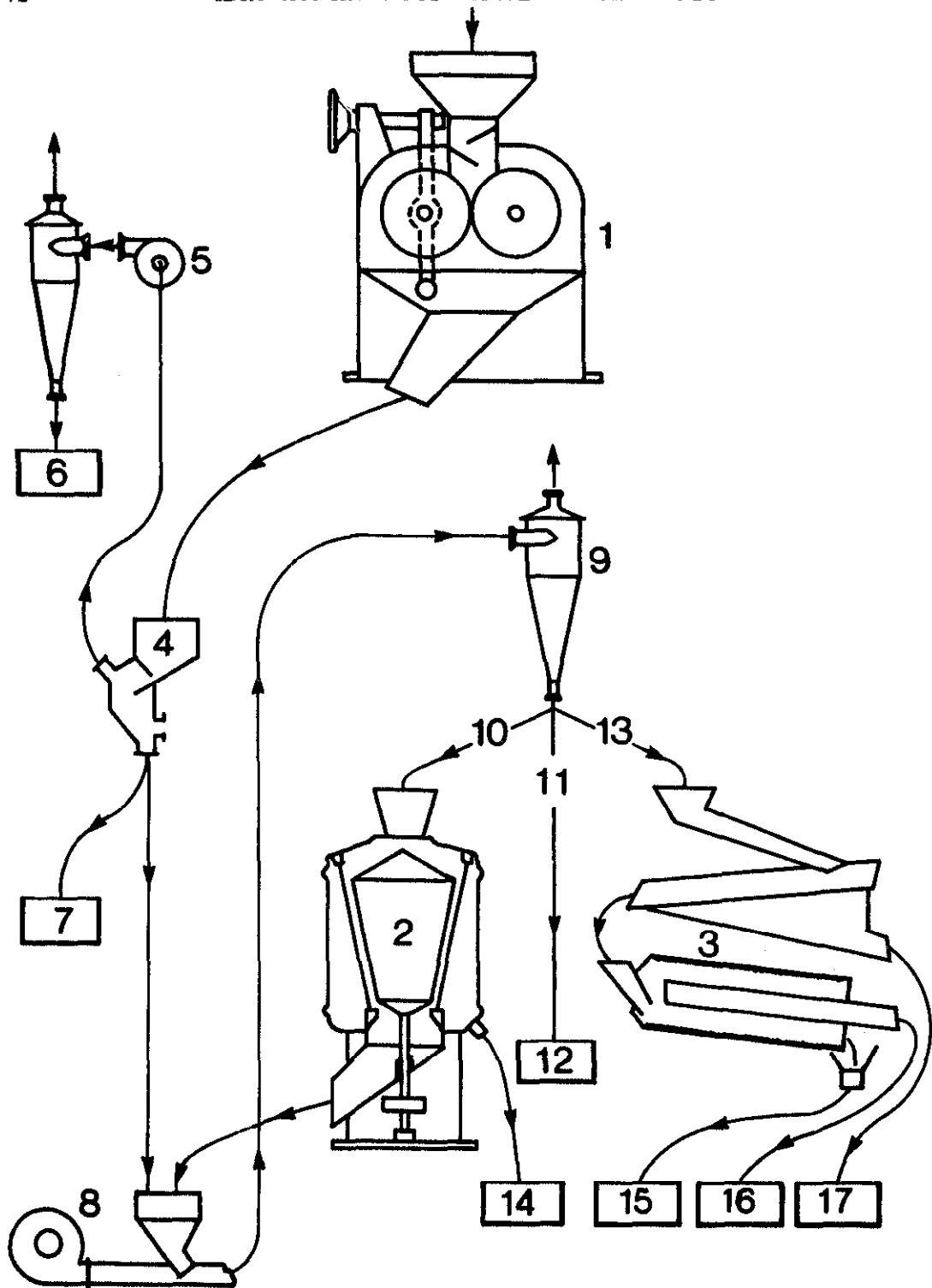
FIG. 44. Flowchart showing the complete operation of a rice testing mill: (1) sheller; (2) whitening machine; (3) grader; (4) separator; (5) aspirator; (6) bin for aspirated material; (7) bin for husked rice; (8) blower; (9) cyclone; (10) conduit to whitening machine; (11) conduit to bin for total yield; (12) bin for total yield determination; (13) conduit to grader; (14) bin for bran; (15) bin for head rice; (16) bin for big brokens; and (17) bin for small brokens.

laboratory mill to be used.

Figure 44 shows in principle the layout of a complete sampling unit, including sheller (1), whitening machine (2), grader (3), and mechanical handling devices. After the sheller the products pass into a separator (4) where the husks are removed by an aspirator (5) and collected in (6). The husked rice is delivered to (7), or it may continue through milling machines. In the latter case the grain is transported by blower (8) into cyclone (9), from where, through conduit (10) it is conducted into the whitening machine (2), which discharges the bran into (14) and the rice kernels back to (8) again to be elevated and recycled once more. By repeating the cycle several times the rice is progressively whitened until it reaches the desired milling condition.

The cyclone can now be placed at position (11) to deliver the product into (12) if the total milling yield must be determined. On the other hand, if separation of brokens from head rice is desired, by moving the cyclone to (13), the product can be discharged into the grader (3), which delivers head rice into (15), big brokens into (16), and small broken into (17). Such a testing unit will determine: the husked rice yield in (7); the total milling yield in (12); and the whole grain yield in (15). — *Extensive use was made of Gariboldi's 1973 paper "Rice testing methods and equipment" in the preparation of the text and adaptation of the illustrations for the foregoing section on Laboratory Tests.*

Model

Grading

System

The standardization of national rice grading systems as a means of facilitating international trade in rice has been one of the objectives pursued by the FAO Intergovernmental Group on Rice since its inception in the mid-1950's. The Group's earlier efforts materialized in

1958 in the approval of a Model System of Grading Rice in International Trade, including standard definitions of terms, which was recommended for adoption by governments.

A number of countries used the Model in revising their grading systems, but many new developments also occurred in methods of grading, in the varieties available for export, and in the milling practices. Taking stock of these developments over a 10-year period, the Group agreed at its thirteenth session in 1969 that the Model System needed reconsideration. It was felt that it should be made more broad-based by taking into account all the important characteristics of rice traded currently in the world market.

The task of revising the original Model System and the definitions of the terms used in rice trade has been accomplished by the Intergovernmental Group's subsidiary body — the Sub-Group on Rice Grading and Standardization — with the collaboration of national experts and government representatives from 41 countries during its two meetings in 1970 and 1972. The Recommended Model Grading System for Rice in International Trade and the definitions of terms, as revised by the Sub-Group, are presented here.

In considering the results of this work, the Intergovernmental Group on Rice agreed that the practical value of the Model System would be determined by the follow-up action taken by governments to ensure that national rice standards were generally compatible with the recommended principles, provisions, and terms. At its request, therefore, the Director-General of FAO transmitted the recommended Model Grading System for Rice in International Trade, together with the definitions, to all governments concerned with achieving consistency in national rice grading standards.

Recommended Model Grading System for Rice in International Trade

(As revised by the Seventh Session of the Sub-Group on Rice Grading and Standardization, May, 1972)

1. The description of rice entering international trade should cover three main headings:

A. Intrinsic character, i.e. the class, or variety of rice; B. Processing; C. Acquired characteristics, i.e. qualities not inherent in, but subsequently acquired by the same class of rice.

A. Intrinsic Character

2. The intrinsic character must be described through classing by external characteristics, with indication of size and/or shape. Additionally, the variety and weight may be specified, where required.

3. Four classes should be provided for describing rice by the external characteristic 'size':

Aa: *Extra-long:* Rice with 80 percent or more of whole milled kernels having a length of 7.0 mm and above.

Ab: *Long:* Rice with 80 percent or more of whole milled kernels having a length of 6.0 to 6.99 mm.

Ac: *Medium:* Rice with 80 percent or more of whole milled kernels having a length of 5.0 to 5.99 mm.

Ad: *Short:* Rice with 80 percent or more of whole milled kernels having a length of less than 5.0 mm.

4. Three classes should be provided for describing rice by the external characteristic 'shape':

Ae: *Slender:* Rice with whole milled kernels having length/breadth ratio over 3.0. Also known as *'Long grain rice.'*

Af: *Bold:* Rice with whole milled kernels having length/breadth ratio between 2.0 and 3.0. Also known as *'Medium grain rice.'*

Ag: *Round:* Rice with whole milled kernels having length/breadth ratio less than 2.0. Also known as *'Short grain rice.'*

5. Three classes for describing rice by the external characteristic 'weight' should be provided:

Ah: *Extra heavy:* Rice with whole milled 1000 kernels, with 14 percent moisture, weighing over 25 grams.

Ai: *Heavy:* Rice with whole milled 1000 kernels, with 14 percent moisture, weighing 20 to 25 grams.

Aj: *Moderately heavy:* Rice with whole milled 1000 kernels, with 14 percent moisture, weighing under 20 grams.

6. In the description of milled rice, the adjective 'glutinous' should be added, wherever applicable. All rice not bearing this adjective should be regarded as nonglutinous.

B. Processing

7. National standards should specify:

Ba: Parboiling[2] and any other processing prior to milling; and

Bb: The degree of milling; and

Bc: Any processing supplementary to ordinary milling.

8. In addition to the category of husked rice, four degrees of milling should be defined:

Bba: *Husked rice:* Paddy from which the husk only has been removed. Also known as 'brown rice,' 'cargo rice,' 'hulled rice,' 'loonzain rice,' and 'sbramato rice.'

Bbb: *Undermilled rice:* Paddy from which the husk, a part of the germ, and all or part of the outer bran layers, but not the inner bran layers, have been removed.

Bbc: *Reasonably well milled rice (Medium milled rice):* Paddy from which the husk, the germ (part of the germ in the case of round rice), the outer bran layers, and the greater part of the inner bran layers have been removed, but parts of the lengthwise streaks of the bran layers may still be present on not more than 30 percent of the kernels.

Bbd: *Well milled rice:* Paddy from which the husk, the germ (part of the germ in the case of round rice), the outer bran layers, and the greater part of the inner bran layers have been removed, but parts of the lengthwise streaks of the bran layers may still be present on not more than 10 percent of the kernels.

---

[2]Since parboiling is a process applied prior to milling, different degrees of milling (such as 'parboiled – well milled,' 'parboiled – extra-well milled' etc.) should be provided wherever applicable.

Bbe: *Extra well milled rice:* Paddy from which the husk, the germ (part of the germ in the case of round rice), and the bran layers have been completely removed.

9. Bc: When rice is subjected after milling to further processing either to improve its appearance and keeping quality, or to enhance its nutritive value, or to ameliorate its cooking characteristics, such processing supplementary to milling should be mentioned in the description to enable buyers of rice to examine it in relation to the existing regulations in their countries. The use of soap-stone containing magnesium silicate should be prohibited.

10. When milled rice is coated or treated to enhance its nutritive value, the term 'enriched' should be added in the description of the rice.

C. Acquired Characteristics: Grades

11. When describing rice, a clear distinction should be made between intrinsic characteristics and acquired characteristics. Differences in acquired characteristics should be regarded as constituting the *quality* of rice, and should form the basis for distinction between grades.

12. The following *essential criteria* should be included in national grading standards:
Ca: Percentage of broken kernels;
Cb: Percentage of red and red-streaked kernels;
Cc: Percentage of damaged kernels;
Cd: Percentage of chalky kernels;
Ce: Percentage of foreign materials;
Cf: Percentage of paddy;
Cg: Percentage of contrasting classes of rice;
Ch: Percentage of moisture;
Ci: Percentage of yellow kernels;
Cj: Percentage of immature or green kernels;
Ck: Maximum limit of chemical residues;
Cl: Minimum limit of whole rice.

13. One or more of the following two *optional criteria* may be included in national grading standards where considered necessary:
Cm: Percentage of stained or spotted kernels.

Cn: Percentage of other discoloured kernels.

14. In the case of *parboiled rice*, the following two optional criteria may be included:
Co: Maximum limit of nongelatinized kernels;
Cp: Maximum limit of nonparboiled kernels.

15. The maximum or minimum limit for each of the above criteria should be on the basis of weight and not on the basis of volume.

16. When grading by the percentage of broken rice, there should be at least two categories of brokens:
Caa: *Big brokens:* Pieces of kernels smaller than three fourths but bigger than one half the average length of the unbroken kernel.
Cab: *Brokens other than big brokens:* Pieces of kernels equal to or smaller than one half the average length of the unbroken kernel.

Intergovernmental Group on Rice of the Committee on Commodity Problems, Food and Agriculture Organization of the United Nations, Rome, Italy.

Specifications[3]

Rough Rice

This standard specification for Philippine Palay or Rough Rice is hereby promulgated under a fixed designation PTS (Philippine Trade Standard) No. 042-01.02; 1968. This standard was formulated by the Philippine Standards Council, in order to fix a uniform basis for determining quality. The cooperation of the Rice and Corn Administration, Rice and Corn Board, U. P. College of Agriculture, Bureau of Plant Industry, International Rice

[3]Philippine Trade Standard Specifications for Palay (Rough Rice) PTS 042-01.02; 1968, and Milled Rice (Second Revision) PTS 042-02; 1973.

Research Institute, Rice and Corn Production Coordinating Council, Agricultural Productivity Commission, Araneta University Foundation, and Greater Manila Rice and Corn Association, were in a large measure responsible for the formulation of this standard.

Suggestions for revision should be addressed to the Bureau of Standards, P.O. Box 3719, Manila, Philippines.

1. Scope

1.1 This standard covers the system of classifying and grading palay of Philippine origin.

2. Definition of Terms

2.1 For the purpose of this specification, the following terms are hereby defined:

2.1.1 Rough rice — Those which contains 50% or more of unhulled kernels.

2.1.2 Foreign matters — These are impurities such as stones and sand but excluding weed seeds.

2.1.3 Immature kernels — Those which are mostly green and/or chalky.

2.1.4 Damaged kernels — Those which are distinctly discoloured or damaged by water, insects, heat, or any other means.

2.1.5 Other varieties — Those kernel which differ distinctly from the characteristics of the palay under consideration.

2.1.6 Fermented kernels — Those which are yellowish or otherwise discoloured.

2.1.7 Cracked kernels — Those which are either cracked or broken.

2.1.8 Red rice — Those palay, the kernels of which are red.

2.1.9 Weed seeds and other crop seeds — All seeds which are other than palay.

2.1.10 Moisture content — This is the water content of the grain computed on a wet basis, as received.

2.1.11 Percentages — These are quantities expressed in weight.

3. General Requirements

3.1 It shall be free from such foreign odors as mouldy ground, insect, rancid, sharp acrid and chemical, which are common to unsound rice.

3.2 It shall be free from live insect infestation.

3.3 The unit of trading shall be by weight expressed in kilograms or in metric tons.

4. Classification and Grading

4.1 Palay varieties shall be classified in accordance with the length of the kernel.

4.1.1 The types of palay based on the length of the brown kernel shall be the following:

Type I — Long grain — the length of the kernel is above 6.5 mm.

Type II — Medium grain — the length of the kernel ranges from 5.5 to 6.5 mm.

Type III — Short grain — the length of the kernel is below 5.5 mm.

4.2 Each type of palay shall be grouped as follows:

4.2.1 Fancy — the kernels have a flinty uniform appearance, and are shiny, translucent, or creamy white.

4.2.2 Special — the kernels exhibit a desirable uniform white, creamy white, or gray colour.

4.2.3 Ordinary — the kernels exhibit a white to dull white or light gray colour.

4.2.4 Inferior —

1. Milled rice with coloured pericarps regardless of cooking characteristics and translucency.

2. Milled rice which is discoloured due to handling and storage.

4.3 Each group of palay shall be graded according to the result of analysis as follows:

4.3.1 Grade 1 — Palay having at least 98% purity, foreign matter not more than 2%, weed seeds none, immature kernels none, damaged grains 2%, cracked kernels 3%, other varieties 3%, fermented kernels none, red rice trace, moisture content not exceeding 14%.

4.3.2 Grade 2 — Palay having at least 96% purity, foreign matter not more than 4%, weed seeds none, immature kernels 2%, damaged kernels 3%, other

TABLE 13. Standard grade requirements for rough rice.

Grade	Purity (max %)	Foreign matter (max %)	Weed and other crop seed (max %)	Cracked kernels (max %)	Im-mature kernels (max %)	Dam-aged kernels (max %)	Other varieties (max %)	Fer-mented kernels (max %)	Red rice (max %)	Mois-ture content (max %)
1	98	2	none	3	none	2	3	none	trace	14
2	96	4	none	4	2	3	5	0.5	1	14
3	94	6	trace	5	4	4	8	1	2	14
4	92	7.75	0.25	6	7	6	12	2	3	15
5	90	9.5	0.5	7	10	8	17	3	4	15

NOTE: Paddy + Foreign matter + Seeds = 100%.

TABLE 14. Variety—Classification of grain as to group and size.

Fancy	Special	Ordinary
Type I—Long size grain		
1. None	1. Tjeremas	1. Ramadia
	2. Intan	2. Peta
	3. Bengawan	
	4. AC 440 Dr. 260	
	5. Azucena	
	6. BPI-121	
	7. Raminad Str. 3	
Type II—Medium size grain		
1. Milfor	1. BE-3	1. Peta
	2. BPI-76	2. IR-8
	3. Macapagal	3. Macan
	4. Raminad	4. Kinandang Puti
	5. 12-36	5. Kinandang Pula
	6. Bencer	6. Ramai
	7. Sinampablo	7. Palawan
	8. Seraup Ketchil	
	9. Kinanda	
	10. Elon-Elon	
	11. C-18	
	12. Milbuen	
	13. Dinalaga	
Type III—Short size grain		
1. Milagrosa	1. Hinumay	1. Binato
2. Wagwag		2. Palagad Imus
3. Minantika		3. Ninoro
		4. Mangarez
		5. Macan—700

varieties 5%, cracked kernels 4%, fermented kernels 0.5%, red rice 1%, moisture content not exceeding 14%.

4.3.3 Grade 3 — Palay having at least 94% purity, foreign matter not more than 6%, weed seeds trace, immature kernels 4%, other varieties 8%, damaged kernels 4%, cracked kernels 5%, fermented kernels 1%, red rice 2%, moisture content not exceeding 14%.

4.3.4 Grade 4 — Palay having at least 92% purity, foreign matter not more than 7.75%, weed seeds 0.25%, immature kernels 7%, damaged kernels 6%, other varieties 12%, fermented kernels 2%, red rice 3%, cracked kernels 6%, moisture content not exceeding 15%.

4.3.5 Grade 5 — Palay having at least 90% purity, foreign matter not more than 9.5%, weed seeds 0.5%, immature kernels 10%, damaged kernels 8%, other varieties 17%, fermented kernels 3%, red rice 4%, cracked kernels 7%, moisture content not exceeding 15%.

4.3.6 Sub-standard grade — Palay that would not meet any of the above requirements but the moisture content shall not exceed 16%.

5. Packing and Marking

5.1 Packing

5.1.1. Palay shall be packed in jute gunny sacks or in similar protective containers, weighing 50 kilograms net on the basis of 14% moisture content.

5.2 Marking

5.2.1 Each bag shall be properly labelled in big letters with a suitable tag measuring approximately 18 × 12 cm, containing the following information:

5.2.1.1 Province where grown and crop year

5.2.1.2 Type, group, variety, and grade

5.2.1.3 Name and address of warehouse

5.2.1.4 Net weight in kilograms

6. Sampling

6.1 Samples are drawn from the lot with the use of sampling instruments like the Stick Trier or Sleeve-type Trier or Hobbe Trier. When there are 10 bags or less, each bag shall be sampled. If there are more than 10 bags but not exceeding 100 bags at least every tenth bag but not less than 10 bags shall be sampled. If a lot contains more than 100 bags, at least 10% of the number of bags shall be sampled at random.

6.2 When a lot is sampled, several individual samples are drawn from different places in the bulk. Each probe or each handful of sample is called the primary sample. All primary samples drawn are combined in a suitable container. This combined primary sample is called the composite sample. When the composite sample has been properly reduced, it is called the submitted sample. This sample is submitted to the laboratory for quality tests. The reduced sample, obtained from the submitted sample, is termed the working sample.

6.3 The sampling shall be done at random from the top, middle, and bottom of each container. The inspector shall be responsible for sampling the entire lot and the submitted samples should carry the following information:

6.3.1 Name and address of owner

6.3.2 Variety name

6.3.3 Lot number

6.3.4 Number of bags in the lot

6.3.5 Date harvested

6.3.6 Name of inspector

6.4 Preparation of the working sample — Samples received in the laboratory are reduced to a working sample. The sample submitted shall be repeatedly divided so that the working sample will be as representative as the original. An efficient divider must be used.

6.4.1 Use of Mechanical Divider — The equipment usually used is the Boerner Sample Divider. The sample is emptied into a hopper at the top of the divider and released by a hand lever to let it flow over an inverted cone. It passes through a series of slots around the circumference of the cone and falls into two chutes. At the mouth of each chute is a bucket into which half of the sample runs. The sample is divided into approximately

equal halves again and again until it is about 1 kilogram.

6.4.2 Halving Method — In the absence of a mechanical sample divider, the halving method will be used. The submitted sample is repeatedly divided until about 100 grams of the quantity remains.

7. Inspection

7.1 Destination Inspection — When the palay is passed through points other than destination, the contract may require that the palay be inspected at destination for quantity and quality.

7.2 At the time of loading palay for foreign trade, shipping weights shall be taken and certified before the inspectors of the Bureau of Standards or a government weigher in the locality.

8. Test Methods

8.1 Grading Test — Weigh about 100 grams of palay from the representative sample. The palay shall be separated from other extraneous matters and weighed to determine the percentages.

8.2 Moisture content determination — The moisture content of palay shall be determined by using a properly calibrated moisture tester.

8.2.1 Brown-Duvel Moisture Tester — Duplicate samples of 100 grams each are taken from a thoroughly mixed palay sample. Each weighed sample is transferred into the flask of the tester, which is then filled with 450 ml of the Brown-Duvel testing oil (Spica oil has similar properties). A thermometer is inserted through the stopper of this flask. Four-fifths of the mercury bulb of the thermometer should be submerged in the sample and the oil. After tightly fitting the stopper, the flask is connected to the condensing tube of the tester. Heat is applied until the cut-off temperature, or 210 °C, is reached. The moisture distilled off is collected in a clean, dry graduated cylinder. The amount of moisture collected will determine directly the percentage moisture content of the sample. It is read after the temperature has gone down to 160 °C (as prescribed in the direction for using the Brown-Duvel Moisture Tester).

8.2.2 Air-Oven Method — Two to five grams of the sample are ground and weighed in a weighing bottle with a constant weight. The powdered sample is placed in an electric oven for 5 hours at a temperature of 130 °C. Then it is allowed to cool inside a desiccator and weighed afterwards. The percentage moisture content is computed on the wet basis.

9. Effectivity

9.1 This Standards Administrative Order shall take effect upon its approval.

Milled Rice

This standard specification for Milled Rice is hereby promulgated under a fixed designation PTS (Philippine Trade Standard) No. 042-02; 1973.

This standard was revised due to the request of the National Grains Authority and upon the suggestion of the Technical Committee to update the standard specification and the definition of terms to suit the present trend in the rice industry. It also includes the weight per sack of rice to be 50 kilograms in accordance with NGA Act.

Suggestions for revision should be addressed to the Bureau of Standards, P.O. Box 3719, Manila, Philippines.

1. Scope

1.1 This standard specification covers milled rice produced in the Philippines, both for foreign and domestic trade.

2. Definition of Terms

2.1 For the purpose of this standard, the following terms relating to milled rice are hereby defined as follows:

2.1.1 Milled rice — whole or broken kernels where the hulls and at least the outer bran layers and a part of the germ are removed.

2.1.2 Nonglutinous rice — generally translucent with greater amylose content than amylopectin and turns bluish when treated wih potassium iodide – iodine solution.

2.1.3 Glutinous rice — generally opaque, sticky when cooked, with higher amylopectin than amylose content and turns reddish-brown when treated with potassium iodide – iodine solution.

2.1.4 Brewer or binlid — portions of a kernel which will pass through a 4/64 sieve (1.587 mm).

2.1.5 Broken kernels — milled rice smaller than head rice but larger than brewer or binlid.

2.1.6 Chalky kernels — kernels with 50% or more white portion.

2.1.7 Flinty kernel — kernel with less than 50% white portion.

2.1.8 Foreign matter — impurities such as weed seeds, stones, sand, dirt, etc. foreign to milled rice.

2.1.9 Head rice — whole kernels and those not less than ¾ in size.

2.1.10 Kernel — edible portion of a paddy grain.

2.1.11 Milling degree — the extent or degree of polishing the rice kernel.

2.1.12 Other varieties — rice kernels of different variety/ies other than the variety under consideration.

2.1.13 Paddy or Palay — unhulled grain.

2.1.14 Red rice — rice with any degree of redness.

2.1.15 Yellow kernel — yellowish milled rice due to fermentation or heat.

2.1.16 Damaged kernel — kernels attacked by microorganisms, insects and/or other means.

3. Classification and Grading

3.1 Philippine milled rice shall be of the following type based on the length of the kernel.

3.1.1 Type I — Long grain — longer than 5.9 mm.

3.1.2 Type II — Medium grain — length ranges from 5.0 to 5.9 mm.

3.1.3 Type III — Short grain — shorter than 5.0 mm.

3.2 Each type shall be graded into subtypes according to the shape based on the length-width ratio.

3.2.1 Slender — Length-width ratio 3.0 or more.

3.2.2 Bold — Length-width ratio ranges from 2.0 to 2.9.

3.2.3 Round — Length-width ratio is less than 2.0.

3.3 The description of the milled rice according to types and sub-types shall be taken collectively under the term Grain type.

3.4 Rice shall be classified according to varietal names. See Table 16.

3.5 Each group of milled rice shall conform to any of the following classes according to the degree of milling.

3.5.1 First class — milled rice from which the husk, the germ, the outer and the inner bran layers have been removed.

TABLE 15. Standard grade requirements for Philippine milled rice.

	Premium grade	Grade I	Grade II	Grade III
1. Head rice (%)	95 min	85.0 min	75.0 min	65.0 min
2. Brokens (%)	4 max	12.0 max	20.0 max	28.0 max
3. Binlid (Passes through sieve 4/64) (%)	1	3.0 max	5.0 max	7.0 max
4. Yellow and damaged (%)	0.5	1.0 max	2.0 max	4.0 max
5. Chalky and immature kernels (%)	2.0	4.0 max	6.0 max	8.0 max
6. Paddy (No. /100 g)	none	1 max	2 max	3 max
7. Other varieties (%)	2	4 max	6 max	8.0 max
8. Red rice (%)	none	0.50 max	1.0 max	1.5 max
9. Foreign matter (%)	none	0.25 max	0.5 max	1.0 max

TABLE 16. Philippine rice varieties classified as to grain types and subtypes.

Variety	Length (mm)	Width (mm)	L/W ratio	Type	Subtype
1. Milagrosa	4.095	2.020	2.02	III	Bold
2. Milfor	5.468	2.041	2.67	II	Bold
3. Wagwag	5.314	2.246	2.36	II	Bold
4. C-4-63-G	6.877	2.097	3.27	I	Slender
5. C-4-137	7.000	2.163	3.23	I	Slender
6. C-18	6.751	2.096	3.22	I	Slender
7. C-12	6.028	2.156	2.79	I	Bold
8. Intan	6.795	2.041	3.32	I	Slender
9. BE-3	5.502	2.293	2.30	II	Bold
10. BPI-76	5.904	2.251	2.62	II	Bold
11. BPI-121	6.820	2.136	3.19	I	Slender
12. IR-22	6.199	1.952	3.17	I	Slender
13. IR-24	6.636	2.081	3.18	I	Slender
14. IR-661	6.460	2.187	2.93	I	Bold
15. IR-20	5.503	2.130	2.58	II	Bold
16. IR-12	5.876	2.261	2.59	II	Bold
17. IR-5	6.131	2.450	2.50	I	Bold
18. IR-8	6.440	2.387	2.69	I	Bold
19. Tjeremas	6.770	2.083	3.24	I	Slender
20. Seraup Ketchil	5.617	2.457	2.28	II	Bold
21. Peta	6.168	2.474	2.49	I	Bold
22. Pinili	5.774	2.233	2.58	II	Bold
23. Binato	4.971	2.500	1.98	III	Round
24. Ramadia	6.005	2.339	2.56	I	Bold

3.5.2 Second class — milled rice from which the husk, germ, the outer and the major part of the inner bran layers have been removed.

3.5.3 Third class — milled rice from which the husk, a part of the germ and outer bran layer but not the inner bran layer has been removed.

3.5.4 Pinawa (brown rice) — milled rice from which only the husk and part of the germ has been removed.

3.6 Each class of milled rice shall be graded according to the following description.

3.6.1 Premium grade — Head rice not less than 95%, not more than 5% of which are ¾ kernels, broken 4%, binlid 1%, yellow and damaged 0.5%, chalky and immature kernels 2%, paddy none, other varieties 2%, red rice none, and foreign matter none.

3.6.2 Grade I — Head rice not less than 85%, not more than 5% of which are ¾ kernels, broken 12%, binlid 3%, yellow and damaged 1%, chalky and immature kernels 4%, paddy 1 grain/100 grams, other varieties 4%, red rice 0.5%, and foreign matter 0.25%.

3.6.3 Grade II — Head rice not less than 75%, not more than 5% of which are ¾ kernels, broken 20%, binlid 5%, yellow and damaged 2%, chalky and immature 6%, paddy 2 grains/ 100 grams, other varieties 6%, red rice 1%, and foreign matter 0.5%.

3.6.4 Grade III — Head rice not less than 65%, not more than 5% of which are ¾ kernels, broken 28%, binlid 7%, yellow and damaged 4%, chalky and immature kernels 8%, paddy 3 grains/100 grams, other varieties 8%, red rice 1.5%, and foreign matter 1%.

4. General Requirements

4.1 Moisture content shall not exceed 14%.

4.2 It shall be free from unpleasant and/or repulsive odor.

4.3 It shall be free from insect infestation.

4.4 The unit of trading shall be by weight expressed in kilograms or metric tons.

5. Packing

5.1 Milled rice shall be packed in new or good used Hessian cloth bag, jute gunny, or plastic sacks without patches and weighing 50 kilograms net to afford maximum protection from normal hazards of transportation and handling. Smaller packages may be allowed provided the net weight shall be in full kilograms of 1, or multiple of 5 kilograms subject to buyer/seller agreement.

6. Marking

6.1 Each bag shall be properly labelled with the following information:

(a) Type and subtype, variety, class, and grade
(b) Name and address of miller
(c) Net weight in kilograms
(d) Crop year and date of milling

7. Sampling

7.1 Ten percent (10%) of the total number of bags should be sampled but in no case should the number of bags sampled be less than five (5) bags.

7.2 Each probe or handful of sample drawn is called the primary sample. The combined primary samples are called a composite sample. When a composite sample has been properly reduced, it is called the submitted sample. A sample obtained from the submitted sample is called a working sample.

7.3 The submitted sample should carry the following information:

7.3.1 Name and address of owner
7.3.2 Variety
7.3.3 Lot number
7.3.4 Number of bags in the lot
7.3.5 Crop year and date of milling
7.3.6 Date of sampling
7.3.7 Name of inspector

7.4 Preparation of the working sample — Samples received in the laboratory are reduced to a working sample. The sample submitted shall be repeatedly divided so that the working sample will be the representative of the original. An efficient divider must be used in the absence of a mechanical divider.

8. Test Method

8.1 Grading test — Weigh about 100 grams of milled rice from the representative sample. The head rice shall be separated from other extraneous matter and weighed to determine the percentage.

8.2 Moisture content determination — The moisture content of milled rice shall be determined by using a properly calibrated moisture tester or by oven drying. In the air-oven method the temperature should be maintained at $105 \,°C \pm 0.1 \,C°$.

8.3 Potassium iodide – iodine test — In case of doubt whether a variety is glutinous or not, a KI-I test shall be made on the kernels.

9. Effectivity

9.1 This Standards Administrative Order shall take effect 20 days after completion of its publication.

HARVESTING and THRESHING

Equipment

and

Operations

Improper harvesting and threshing usually result in losses of up to 5% of the crop; therefore, better production techniques alone are not sufficient to solve the food problem. Attention must also be paid to the correct methods for harvesting and threshing to minimize field losses. These two processes constitute about 30% of the total time spent in producing clean dry paddy that is ready for milling.

As harvesting approaches, the plants must be observed daily, and the panicles on the most mature tillers inspected. Water is drained from the field 1–1.5 weeks before harvesting. Harvesting should be carried out when the
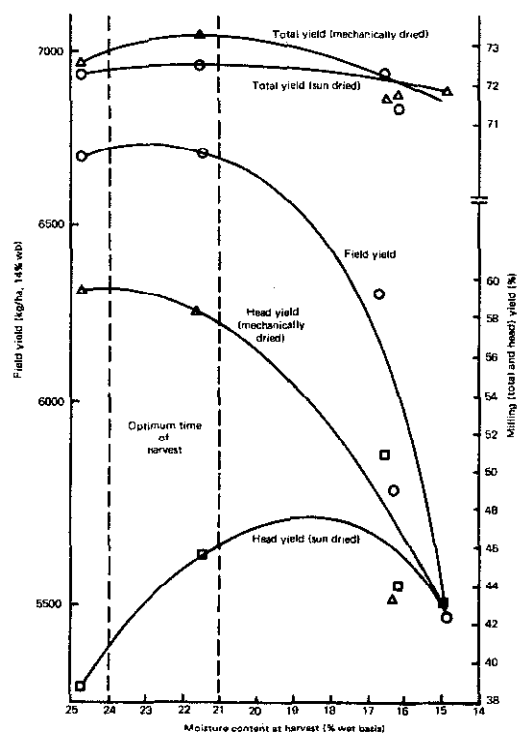
FIG. 45. Effect of moisture content at harvest on field yield and milling yield of IR8 (Bhole et al. 1970).

hulled grain on the upper portion of the panicles are clear and firm and most of the grain at the base of the panicle is in the hard dough stage. At this time at least 80% of the grains are straw-coloured.

The moisture content of the paddy at harvest varies with location. In most areas of Asia the paddy is left standing in the field to sun dry, in some areas it is harvested at a moisture content of 20–25% and stacked until it is dry before it is threshed; whereas, in other areas, it is harvested and threshed at a relatively high moisture content. Figure 45 shows the effect of moisture content at harvest on the field and milling yields of IR8. It can be seen that the optimum moisture content for harvesting is 21–24%.

Ruiz (1965) concluded that the average grain losses at different harvesting times were: 1 week before maturity 0.77%; at maturity 3.35%; 1 week after maturity 5.63%; 2 weeks after maturity 8.64%; 3 weeks after maturity 40.70%; and 4 weeks after maturity 60.46%.

Therefore, timing of the harvest and the moisture content at harvest are very important for achieving maximum yield and quality of the rice.

With the introduction of new varieties of rice, fertilizers, and pesticides, the problems of harvesting and threshing have increased because of the greater amount of crop that has to be handled. In the double-cropping areas, the harvesting and threshing of the first crop and the land preparation for the second crop come so close together that it is often difficult to handle these operations with traditional methods. Johnson (1968) studied the labour requirements for rice production in the Philippines for both the single- and the double-cropped farms. The study indicated that while there was some surplus of labour during the slack period, a labour shortage occurred during the harvesting-threshing season.

The predominant methods used in the tropics consist of manually harvesting the paddy plants and then threshing either by manual, animal, or mechanical means. In the advanced countries, however, harvesting and threshing of rice has almost entirely changed to mechanical methods and this has resulted in tremendous labour savings. Stout (1966)

TABLE 17. Power requirements for rice harvesting in man-hours, animal-hours, and rated horsepower-hours per hectare (information collected from various publications in rice production, Johnson 1963).

	Man-h/ha			Animal-h/ha			Rated hp-h/ha		
	Min	Max	Average range	Min	Max	Average range	Min	Max	Average range
Hand harvest, individual panicles with small knife			240						
Hand harvest with sickle, transport, and stack	72	370	69* 80–160						
Tractor and binder (40 hp)									
1. Binding	4.0						80		
2. Shocking (stacking)	8.0						—		
3. Threshing	12	30					240		
4. Hauling	2						80		
Combine, 2-man crew (60–80 hp)									
1. In US	2.2	7.5	4.4						175
2. In tropics	3.2	21.5	6–12				100	600	180–360
Thresh									
1. Foot threshing by man	200 69*								
2. Flail threshing	16*	35*	20–30*						
3. Beating on bamboo frame, basket, etc.	16*								
4. Pedal thresher	8–10*	25*	100 20*						
5. Trample by ox or buffalo	60 89 6*			150 178 6*					
6. Powered Japanese thresher 0.5–3 hp	48 20*	197 25*	100				15 3*	25 5*	
7. Treading with standard tractor			80				55	150	80
8. Treading with 15-hp tractor and disc harrow							50*	80*	
9. Stationary large thresher	12	30	12				90	180	
10 NIAE thresher	52*	155*	80*				3.2*	9.7*	5*
Cleaning of grain									
1. Tossing in air	10*								
2. Field winnowing with hand fan			6.7*						
3. Fan mill, hand operated	1.5*	7*							
4. Chaff sieve	4.0*	8.0*							

NOTE: Figures marked with asterisk (*) are for number of hours per 1000 kg (or metric tonne).

estimates that countries of Southeast and Far East Asia expend 5–7 h of labour to produce 20.4 kg of rice while only 5–7 min are required to produce the same amount of rice by highly mechanized production methods. Johnson (1963) collected the power requirements for harvesting and threshing of paddy by different methods from various references (Table 17). With the exception of Japan, where rice is mechanically harvested and then dried on straw before threshing, the rest of the advanced countries have changed to direct combining of rice. Even in Japan, with the recent introduction of small head-threshing

type combines, a shift to direct combining of paddy is rapidly taking place.

In the tropics, interest in mechanizing the harvesting-threshing operation is high due to the increasing cost and seasonal shortage of labour and the timing problems involved in double cropping. The recently introduced dwarf paddy varieties are also better suited for mechanized harvesting and threshing. Furthermore, the increased income of the farmers from higher paddy yields has provided additional incentive for mechanization. There are, however, a number of constraints that have hindered the mechanization of harvesting-threshing operations.

Farmer Constraints

Low income, inability to raise capital, reluctance to change traditional methods, poor mechanical aptitude, and the desire to save straw for other uses.

Farm Constraints

Small farm holdings, very small plot size with high bunds, poor water control, inadequate ground support for harvesting equipment, and lack of access roads to the fields.

Crop Constraints

Excessive moisture content at harvest time, uneven ripening, severe lodging and entangling of paddy (especially the traditional varieties), varieties with high-shattering tendency, and low grain-straw ratio.

Equipment Constraints

Lack of functionally and economically suitable equipment for tropical conditions, and the high cost of imported equipment, which must compete with relatively low-cost labour.

In spite of some of these impediments, interest in mechanizing the harvesting-threshing operation is substantial in the tropical region. The introduction of new high-yielding varieties that are less susceptible to lodging and ripen more evenly has been the most encouraging development for the introduction of mechanized harvesting-threshing practices. The present combines have been developed to

a stage where crop moisture is no longer a major problem. Some new combines can harvest paddy at moisture levels of 25–30%. The problems of inadequate ground support and machine mobility are being tackled by reducing machine weight and increasing ground contact area. Adequate water control in the farmers' fields is still a difficult problem and will have to be approached both from the machine design and the farm improvement level.

The various operational elements of paddy harvesting and threshing are cutting, binding, transporting, threshing from panicle, separating grain from straw, separating grain from chaff, separating grain from empty grains and finer impurities, and the delivery of grain for storage or drying. Various harvesting systems have evolved in different parts of the world and some do not necessarily follow the above sequence in total. In the most mechanized system of harvesting-threshing, all the operations are simultaneously done in the field with a combine that facilitates the operation and substantially reduces the labour requirements.

Harvesting of Plants

The operation of cutting a plant is achieved by four different actions: (1) slicing action with a sharp, smooth edge; (2) tearing action with a rough, serrated edge; (3) high-velocity, single-element impact with a sharp or dull edge; and (4) a two-element, scissors-type action.

Generally, manual harvesting involves slicing and tearing actions that result in plant structure failure due to compression, tension, or shear. The serrated sickle combines a slicing and a sawing action. The serrated edge used in cutting devices restricts the sliding action of the plant on the blade edge and helps to retain the plant on the blade for adequate cutting. It has also been reported that sickles with serrated edges do not require the repeated sharpening needed by smooth-edge sickles.

Single-element impact cutting is an economical method of cutting unrestrained vegetation and has been widely used in rotary

lawn mowers, forage choppers, and some tractor-mounted cutterbars. Generally, machines based on this principle are quite simple. Usually a single-element, sharp-edged blade requires a velocity of about 10 m/s (2000 fpm) for impact cutting. The sharpness of the cutting edge has a significant effect on the velocity necessary for effective cutting. A dull-edged, single-element blade requires a velocity of about 45 m/s (9000 fpm) for cutting. Most rotary cutters operate at blade velocities of 40–70 m/s (8000–14 000 fpm).

A tractor-mounted swath harvester cutterbar based on the single-element impact cutting principle is marketed by a European manufacturer. This machine has a series of small-hinged rotating blades mounted closely on a frame to harvest a wide swath. The machine is popular in Europe for upland crops and brush cutting operations. It is more rugged than the conventional reciprocating cutterbar, which is the most popular crop-harvesting mechanism. The single-element cutting approach has been used, in Japan, for some portable paddy harvesters and two makes of reapers. These machines are equipped with high-speed rotary saws for cutting plants.

The two-element scissors action is the most widely used for harvesting agricultural crops. The reciprocating cutterbars that are commonly used for harvesting paddy use this principle. Cutting is done by shearing rice stems between moving knife sections and ledger plates. The included angle between the cutting edges is about 38 degrees. Serrated blades permit a larger included angle because the plants cannot easily slip between the two cutting edges. Reel cutters also use the two-element scissors action but their use has been limited to lawn mowers and some forage choppers. Reciprocating cutterbars do an excellent job of harvesting but are characterized by high energy losses, short service life, dynamic imbalance, and restricted operating speeds. Improvements have been relatively limited by the high inertial and frictional forces involved in this type of mechanism. Many experimental attempts have been made to replace the reciprocating cutterbars; however, none of the experimental devices has been able to match their overall performance.

Manual Methods

The practice of harvesting paddy plants, drying in the field, and then threshing predominates in the major rice-growing areas of the tropics. A sickle is generally used for manual harvesting of paddy. There are many variations in sickle designs and both smooth and serrated blades are popularly used. Chancellor (1963) studied energy requirements for cutting rice stalks with smooth and serrated sickles and concluded that both are equally effective in cutting the plants. Paddy plants are harvested by holding the sickle in one hand and gathering the plants for cutting with the other hand. Plants are cut from 3 to 20 cm above the ground depending on the method of threshing to be used. The hand-holding of straw, while harvesting, reduces grain scatter losses as compared to harvesting with tractor mowers (Fig. 46). Ezaki (1963, 1969) reports that the harvesting output of a skilled man in nonlodged rice is about 0.01 ha/h and that of a woman is about 0.006 ha/h.

In some parts of Indonesia, Malaysia, and the Philippines, only the panicles are harvested. This is done by using a small knife or a special tool that has a small metal blade fitted in a short wooden block. This is a high labour-consuming practice that requires about
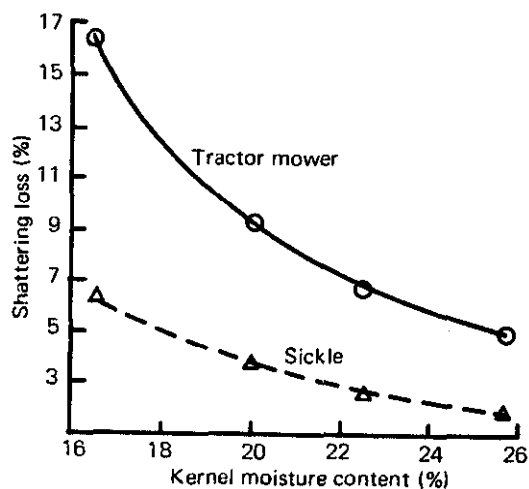

Fig. 46. Effect of two methods of harvesting on shattering losses at different kernel moisture levels. Paddy variety Dular (Gupta 1963).

175% more labour than sickle harvesting. Often religious or traditional reasons are given for this practice. In Java, custom allows a harvester to gather only one basket from each field for it is believed that taking more than a basket will displease the "godmother of good harvest." This practice, however, seems to have some practical reasons in areas where fields are inaccessible by roads and the harvested paddy has to be carried for miles along field levees. In such areas, fields are far away from the roads and no threshing equipment can be conveniently carried into the fields. Harvesting of paddy with long straw under such conditions would certainly create a serious transportation problem. The harvested panicles are tied in small bundles for sun drying. Usually a skilled person can harvest about 15 kg of paddy per hour.

In Japan, a manually operated, push-type harvester called a hand dropper was developed. It consisted of a pair of serrated blades mounted at a 30 degree angle to each other, a mechanism to retain the harvested plants, and a lever to drop the harvested plants. A harvesting rate of 0.02–0.025 ha/h has been reported by Ezaki (1963, 1969); however, Taneja (1963) reported that such a dropper was tried in India on rice, but it was not found satisfactory.

Animal-drawn reapers have been tried at the Central Rice Research Institute at Cuttack, India, for harvesting rice. Using a pair of bullocks, an average output of 0.2 ha/h (0.5 acre/h) has been reported. Compared to manual harvesting, working costs were less than one-third. However, these were old horse-drawn reapers from Western countries and many operational problems were encountered in harvesting rice; therefore, the units were not considered practical for harvesting paddy in India.

Power-Operated Harvesters

In the early stages, the mechanical harvesters developed in Japan were single or multirow side-delivery windrowers (Fig. 47), equipped with reciprocating cutterbars and some type of side-delivering mechanisms.
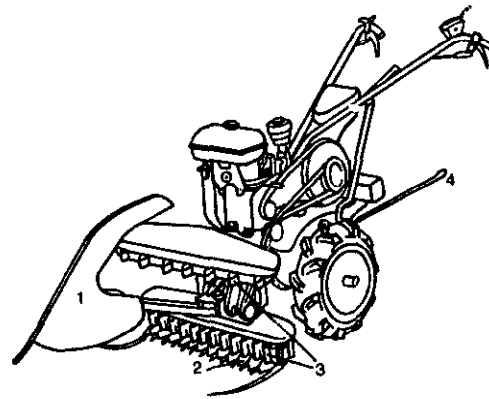

FIG. 47. Multi-row side-delivery windrower: (1) deflecting cover; (2) cutter bar; (3) feeding conveyor; and (4) manual header control.

Paddy plants were laid in a continuous swath. These harvesters were equipped with 60–70 cm cutterbars and were mostly offered as attachments to small walking tractors. Subsequently, some machines, called droppers, were developed that intermittently dropped untied bundles of paddy, making it easier to collect the harvested crop. In the last few years, portable power scythes have been marketed by Japanese manufacturers with rice harvesting attachments. Most of these harvesters have not been well accepted by the farmers. A slightly different Japanese reaper, which has been in production for some years, is equipped with a small rotary saw mounted on a planetary drive arrangement. A 1-m wide swath is harvested by the small saw and is collected inside a circular passage. The collected untied bundles of paddy are dropped to one side of the machine.

Ezaki (1963, 1969) reports that in 1950, work on developing a binder was started at the Institute of Agricultural Machinery at Omiya, Japan. Subsequently, many manufacturers developed binders that dropped tied bundles of paddy on one side of the machine. During the last few years, these new binders have received wide acceptance in Japan. Sales figures of 1000 units in 1966, 10 000 in 1967, 80 000 in 1968, and 150 000 in 1969 have been reported.

These binders are equipped with reciprocating cutterbars. Plants are cut with the cutterbar and are conveyed to the side for tying

in bundles. The bundles are ejected on the side and fall at right angles to the plant rows with the panicles away from the machine. These binders have moving nylon fingers for lifting lodged crops with a combing action. The binders can work successfully even when paddy is lodged at angles of 20–30 degrees. Generally the grain losses average about 2%.

The earlier binders were designed for one- or two-row operation; however, during the last few years, many manufacturers have introduced three- and four-row machines. The one- and two-row, side-delivery binders are equipped with offset-mounted cutterbars and this necessitates manual harvesting of one or two rows of paddy before harvesting with the machine. The larger three- and four-row machines have in-line cutterbars that do not require the initial manual harvesting. Another interesting low-cost, single-row binder recently introduced in Japan is designed to drop the paddy bundles along the travel path of the machine. The manufacturer claims that this feature facilitates the collection of bundles from the ground. The larger tractor-trailed or self-propelled harvester-binders from Western countries have not been successful for harvesting rice in the tropics.

Threshing

Threshing involves the detachment of paddy kernels from the panicle and can be achieved by three methods: (1) rubbing action; (2) impact; and (3) stripping. The rubbing action occurs when paddy is threshed by trampling by men, animals, or tractors. It is not an efficient method of threshing. The impact method is the most popular method of threshing paddy. Most mechanical threshers primarily utilize the impact principle for threshing, although some stripping action is also involved.

Paddy threshers can be classified by two methods of feeding: (1) hold-on; and (2) throw-in. In the hold-on method, paddy straw is held stationary while threshing is done by the impact on the panicle from cylinder bars, spikes, or wire loops. In the throw-in type of machines, whole paddy plants are fed into the machine and a major portion of the grain

is threshed by the initial impact of the bars or spikes on the cylinder. The initial impact also accelerates the straw and further threshing is accomplished as the moving panicles hit the spikes or bars of the concave.

The third type, stripping, has also been used in paddy threshing. Some impulsive stripping occurs ordinarily with impact threshing in conventional threshing cylinders. Non-impulsive type of stripping has been experimentally tried in centrifugal threshers and strippers but no commercial machine has so far been successfully developed.

Cleaning of grain involves the separation of bulk straw, chaff, empty kernels, and very light and fine impurities from the grain. In the simplest form, straw and chaff is manually separated and the grain is dropped through a cross wind to remove the lighter impurities. Air can only remove impurities that have different aerodynamic properties from the grain. Many different grain cleaning systems are used in threshers, depending mostly on the type of feeding method and the threshing capacity. In the hold-on type of thresher, a major amount of the straw does not pass through the machine and only the removal of chaff and light impurities from the grain is necessary. This is achieved mostly by pneumatic means and in some cases by a combination of screens and air. In the throw-in type of thresher, a large amount of straw is handled through the machine. These machines use straw walkers to initially separate the loose grain from the large bulk of straw and chaff. A chaffer screen is used to separate chaff from the grain before the finer impurities are removed by an air blast.

Manual Threshing

The methods used for threshing rice manually are: treading by feet; flail-threshing; and beating on tubs, threshing boards, or racks. A man can thresh from 15 to 40 kg of brown rice per hour by these methods. The only mechanical equipment used for manual threshing is the pedal thresher that originated in Japan during the early stages of mechanization. This thresher is also popular in Taiwan where a threshing team of 5–7 men work with

each machine. The crew moves in a circle, while one or two men are threshing the others collect and bring new paddy bundles. The cylinder rotates at about 300 rpm and the inertia of the cylinder keeps the drum rotating as men take turns at pedalling the machine. There is no cleaner with this thresher. Tests at IRRI with this thresher indicate an output of about 30–70 kg of paddy per hour. Attempts have been made to introduce the pedal thresher in other Asian countries; however, it has not been well accepted. In Taiwan, 60–65 man-h/ha are required for threshing with a pedal thresher, which gives an approximate output of about 50–80 kg/h. The improved pedal thresher performance in Taiwan is perhaps due to better coordination and teamwork of the threshing crew.

Power Threshing

Treading under Tractor Tires

This method of threshing paddy has been used in some Asian countries. It is quite popular in Ceylon for custom threshing. The popularity of this method can be attributed only to a lack of suitable tractor PTO-driven threshers. A threshing capacity of 640 kg/h has been reported from Ceylon when two threshing floors are alternately worked with one tractor.

Threshing Cylinders

All power paddy threshers are equipped with one of the following types of cylinder and concave arrangement: (1) rasp bar with concave; (2) spike tooth with concave; (3) wire loop with concave; and (4) wire loop without concave. Tests at IRRI indicate that the spike tooth cylinder performs well both with the hold-on and the throw-in methods of feeding and its threshing quality is less affected by changes in cylinder speed. Figure 48 illustrates the cylinder test stands and Fig. 49 and 50 show their comparative performance with the two methods of feeding. The wire loop cylinder exhibited excellent performance with the hold-on method of feeding. The following optimum cylinder peripheral

velocities, in feet per minute, were obtained for threshing paddy based on the performance limits of 2.0% minimum unthreshed paddy, 1.0% maximum milled paddy, and 85% minimum head grain yields:

	Hold-on method	Throw-in method
Wire loop without concave, overfed	2650	3650[4]
Wire loop with concave, underfed	2150	2900
Peg tooth	2150	2900
Rasp bar	2650	3650

Hold-On Thresher

Three types of hold-on threshers are popular for paddy.

(1) Engine-driven threshing drum. In Taiwan and some other countries, pedal threshers have been converted for power operation by using small air-cooled engines. These machines have no grain separators or winnowers. Cleaning is a time-consuming problem and the output is relatively low. These threshers are, however, simple and can be manufactured in most Asian countries. Attempts are being made in many Asian countries to incorporate simple separating and winnowing mechanisms in such threshers. A number of small manufacturers have recently introduced such threshers in the Philippines.

(2) Japanese power threshers. These machines are equipped with a wire loop threshing drum and regular cleaning and winnowing mechanisms. Due to the hold-on method of feeding, output is not too high, but the machine can do a good job of grain cleaning. Relatively high labour is required because the paddy bundles have to be held by the operator until threshed. Gupta (1963) reported the visible and invisible seed damage with this type of thresher in tests conducted in India on Aman paddy (Fig. 51).

Both single- and double-drum threshers are offered by Japanese manufacturers. These machines can be operated either as hold-on or

---

[4]Compromise cylinder peripheral velocity wherein: unthreshed paddy loss = 2.01%; milled paddy at threshing = 0.64%; and head grain yield = 78.9%.
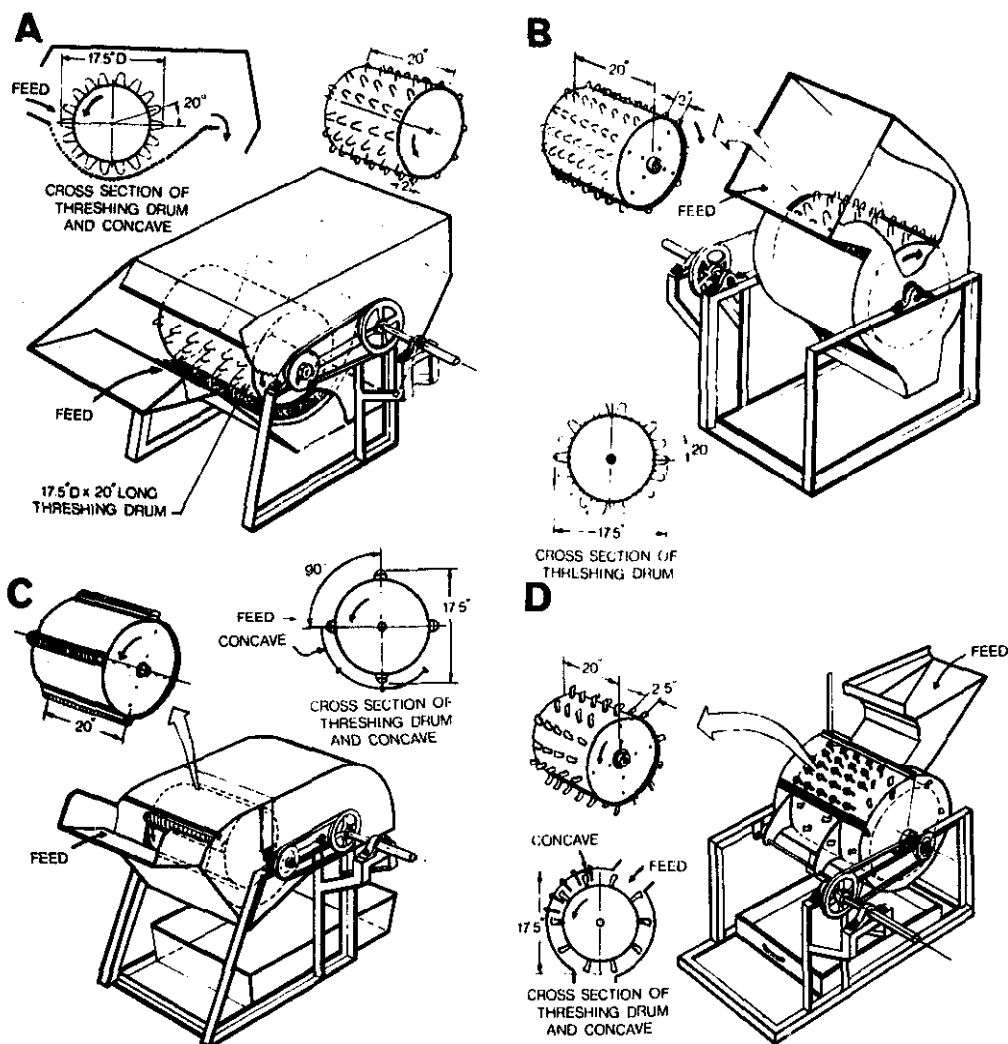
FIG. 48. Threshing cylinder test stand.

throw-in threshers. In the throw-in operation, threshed material is moved axially along the cylinder axis because of the helical arrangement of the wire loops and fins in the cylinder cover. Most of the threshing occurs at the first cylinder, which operates at a slower speed. The hard-to-thresh grain is threshed in the second cylinder, which rotates at a higher speed. The machine will perform well when the quantity of straw is not too excessive. Experience with the double-drum thresher in the Philippines indicates that it is quite well suited for threshing both wet and dry paddy

and other agricultural crops such as wheat and sorghum.

(3) Self-feeding automatic threshers. These machines are similar to the nonautomatic thresher except that these machines are equipped with paddy gripping feed chains that automatically feed the paddy in a continuous layer. The threshing output is high and the machine requires less labour.

Tests conducted at IRRI on a Japanese automatic thresher equipped with a 3100 W (4.2 hp) engine indicated an output of about 200 kg/h with three operators. Comparative
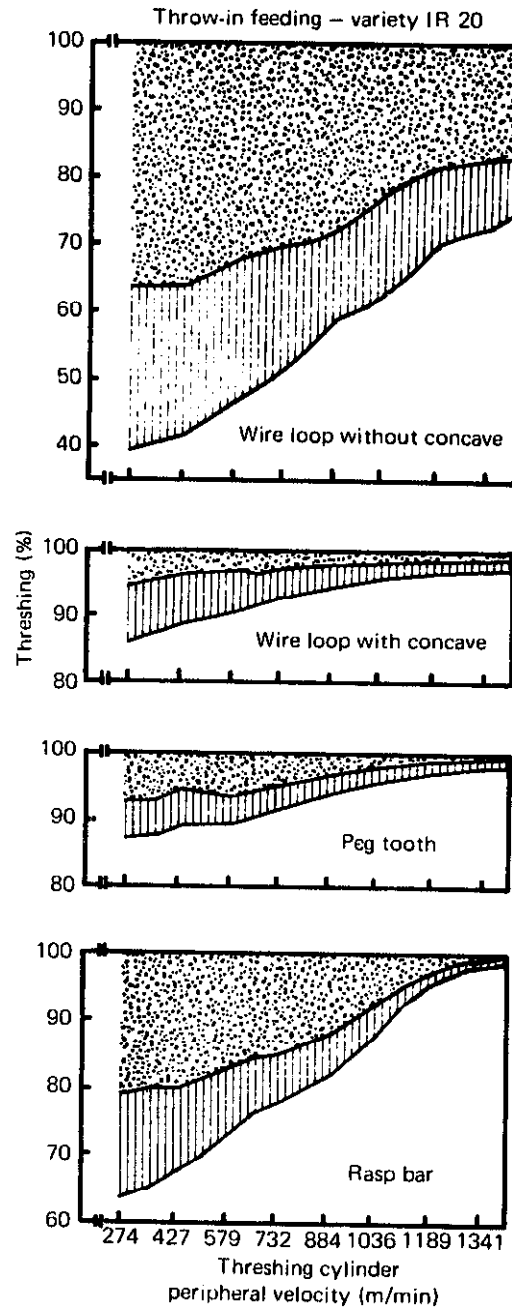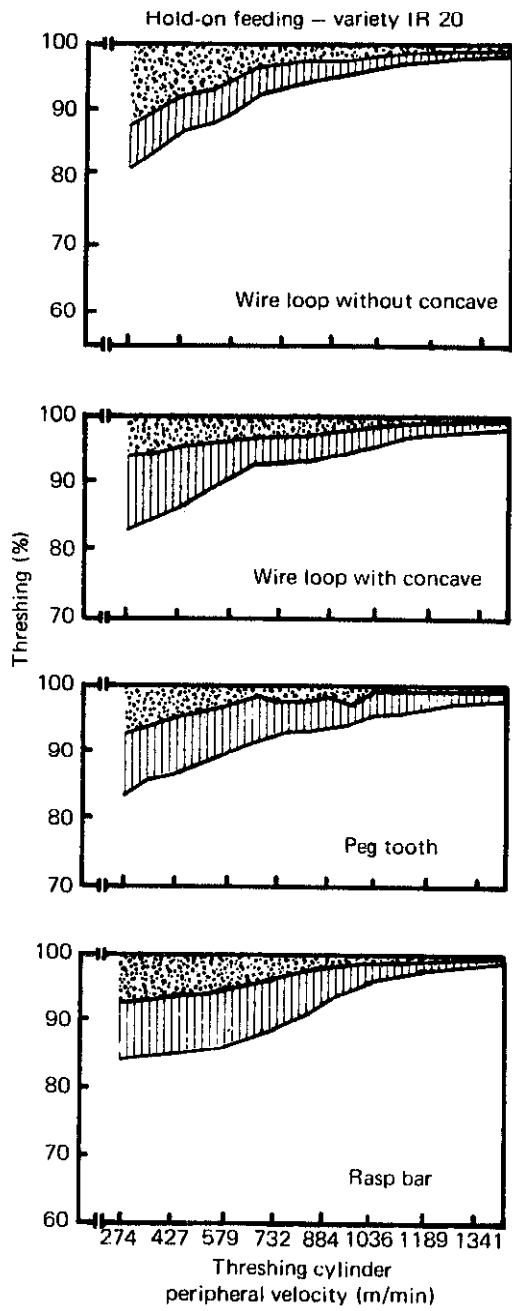
FIG. 49. Comparative threshing cylinder performance for hold-on feeding.

FIG. 50. Comparative threshing cylinder performance for throw-in feeding.
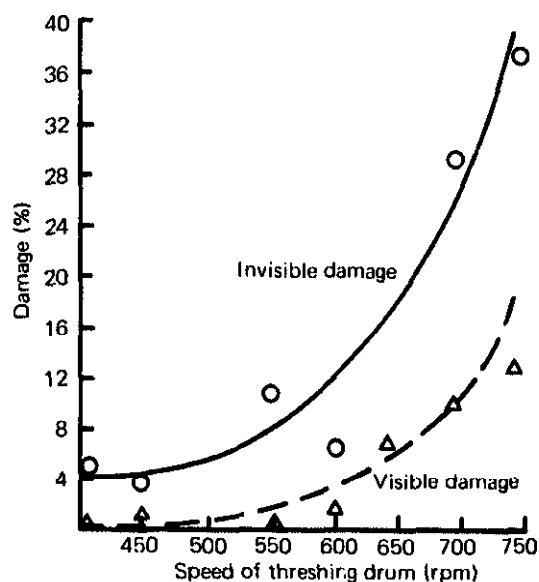
FIG. 51. Visible and invisible seed damage at different threshing drum speeds of a Japanese power thresher (Gupta 1963).

performance of nine paddy threshers tested at IRRI in 1968 is listed in Table 18. These tests include the performance results on the two IRRI threshers, the drum and the table threshers. The table thresher is of a nonconventional design v. .h a flat, rotating threshing surface with a built-in radial fan on its underside. This machine can thresh high-moisture paddy without clogging.

Through-Flow Threshers

In this type of thresher, paddy plants are completely fed into the machine. These machines are equipped with a threshing cylinder and concave and have some separating and cleaning mechanisms. The rasp bar cylinder was previously considered suitable for rice; however, all of the new rice threshers and combines are equipped with spike tooth cylinders. The spike tooth cylinder can operate without clogging even with large amounts of straw at fairly high moisture levels, and the grain is subjected to lower intensity impact forces resulting in lower grain damage.

In the Philippines, large McCormick-type threshers are widely used for custom threshing. These threshers are exact copies of the

old threshers that were developed 50–70 years ago in Europe and America. Many small machine shops fabricate this machine in the Philippines. A major portion of the paddy in the Central Luzon area of the Philippines is custom threshed with these threshers. These threshers are belt-driven from a 45 000 W (60 hp) tractor PTO pulley. Usually a crew of 8–12 men operates these machines, which thresh about 20–30 t of paddy per day. Because of the high threshing capacity, the machine is moved often, which results in substantial down time. This type of thresher is equipped with an elevator feeder mechanism, rasp bar cylinder, straw walker, chaffer, sieves, blower, and straw thrower. Since the introduction of combines in the developed countries, new threshers have not been developed. Consequently, the 50- to 70-year-old designs are still being fabricated in the Philippines. These threshers are sold in the Philippines for about US$5000. Studies at IRRI indicate a need for a lightweight, tractor PTO-driven, three-point-linkage mounted thresher with a capacity of approximately 12–15 t/day for custom threshing in many Asian countries.

Axial-Flow Thresher

The axial-flow thresher, which combines threshing with air and screen cleaning mechanisms, was developed by IRRI. It is lightweight and is mounted on wheels to provide good mobility in either wet or dry soil (Fig. 52). It can be pulled behind a small hand tractor, a jeep, or a truck.

The machine consists of a steel cylinder equipped with peg teeth (Fig. 53). The fins on the upper concave are positioned spirally to move the material axially to the discharge end. A blower is located under the concave, which winnows the chaff and empty grain that fall through the concave. An auger collects and conveys the winnowed grain to a rotary screen sieve. This sieve separates pieces of straw that pass through the perforated concave and that are not blown by the air from the full grain. The grain from the screen sieve drops to a trough and is then conveyed by elevator flaps to the bag.

The thresher is powered by a 5200 W (7

TABLE 18. Comparative performance of selected rice threshers (IRRI, Los Baños, Laguna, Philippines, 1968).

Thresher model	Threshing blade type	Machine performance		Power performance		Labour performance			Economic performance	
		kg/h	ha/h[a]	Engine hp	hp-h per 44 kg	No. of men[b]	man-h per ha[a]	Grain output per man-h (kg)	Machine cost	Threshing cost per 44 kg (pesos)
Pedal thresher	Wire loop	68.64	0.0156	—	—	2	128.20	34.32	NA	
Locally manufactured nonautomatic single drum	Wire loop	158.40	0.0360	4.0	1.333	3	83.33	52.80	2464	0.930
IRRI drum type	Wire loop	252.12	0.05373	4.2	0.695	5	87.26	50.42	3000	1.06
IRRI table type	Wire loop	228.80	0.0520	4.2	0.807	5	96.17	45.76	2500	0.912
Japanese automatic	Wire loop	195.36	0.0444	4.2	0.946	3	67.56	65.12	3500	0.765
Locally manufactured drum type	Spike tooth	117.04	0.0266	12.5	4.700	4	172.94	29.26	6750	1.512
Vogel nursery	Spike tooth	126.72	0.0288	10.0	3.473	4	138.81	31.68	NA	
Turner "Economy"	Rasp bar	170.72	0.0388	10.0	2.577	4	120.00	39.60	NA	
Garvie Type DA	Rasp bar	163.24	0.0371	17.5	4.717	4	107.85	40.79	NA	

[a]Based on 4400 kg/ha yield.
[b]Number of men includes one man who collects and sacks the grain.
SOURCE: Semi Annual Substantive Report No. 8 and No. 9, IRRI-AID Mechanization Research Contract, IRRI, Philippines.
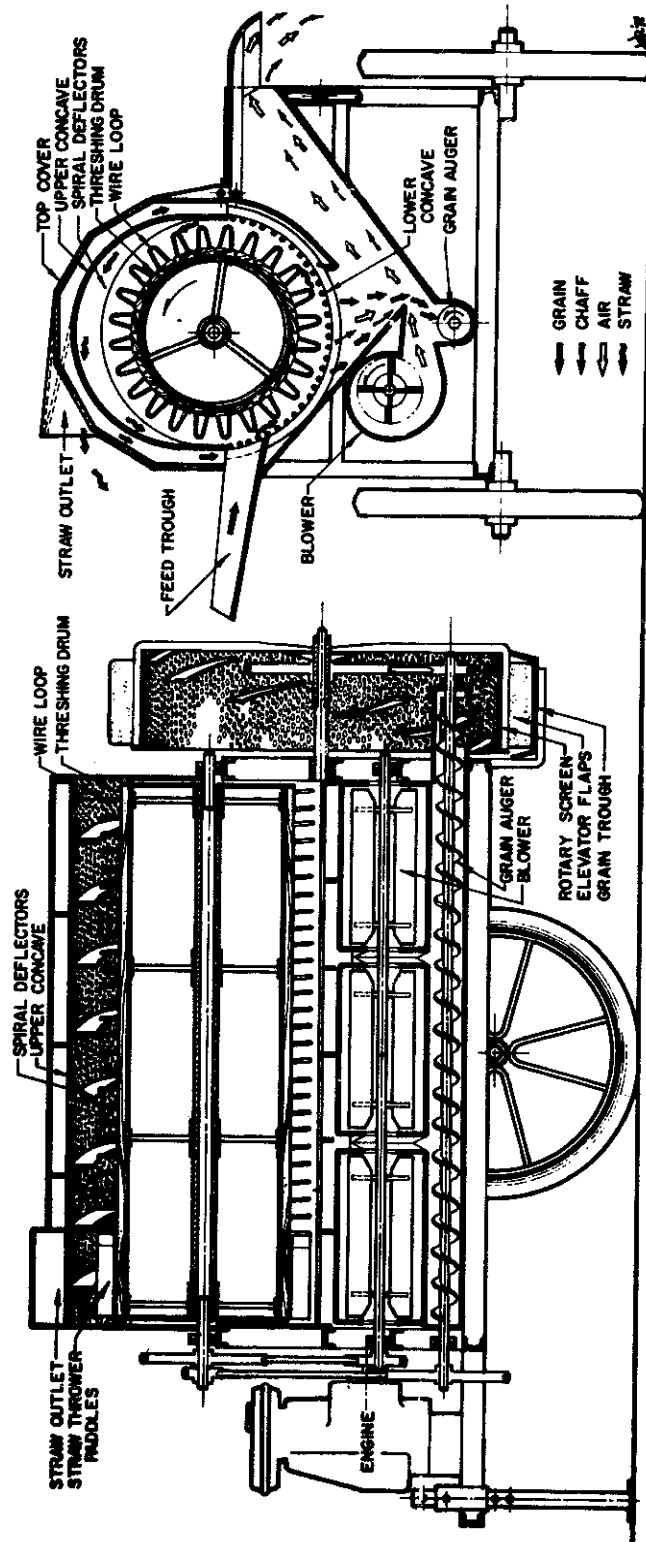
Fig. 52. Schematic drawing of IRRI axial-flow thresher.
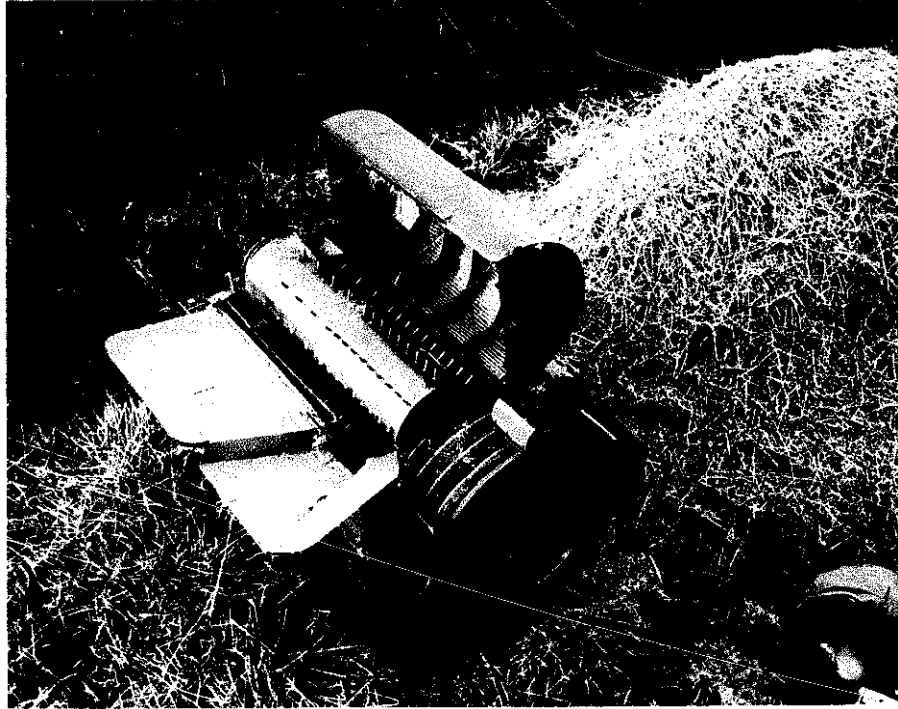
FIG. 53. Threshing cylinder and upper concave exposed in IRRI axial-flow thresher (courtesy IRRI).

hp) air-cooled engine, and can handle freshly harvested paddy with good separation and cleaning performance. The operation requires three men to feed, thresh, and bag the paddy, and the output is 1 t/h. Because of the simplicity of the design there are few operation and maintenance problems.

Direct Field Harvesting-Threshing

Head-Threshing Combines (Japanese Style)

During the late fifties and sixties interest was generated in Western style combines in Japan. Between 1962 and 1968 about 400 such combines with 1.5- to 2.4-m (5- to 8-ft) headers were imported in Japan. A number of Japanese manufacturers also developed their own versions of small, through-flow type combines that were basically patterned after the Western style through-flow machines. These machines, however, were not well accepted as the grain loss and damage was generally higher than the Japanese farmers were willing to accept. These machines also consumed more power and required larger engines due to the energy lost in bruising the straw. The very small field size in Japan also created some operational problems.

Simultaneously, with the development of the small, Western style, through-flow combines in Japan, some manufacturers developed small head-threshing type combines. Basically, these combines consisted of a Japanese automatic thresher mounted on a self-propelled crawler platform and equipped with paddy lifting, cutting, elevating, and feeding mechanisms. Because the straw is not damaged in harvesting, Japanese farmers prefer these machines to the through-flow combines. The automatic threshers used in these combines were already popular in Japan for threshing dry paddy. The threshers used with the earlier combines did not perform well because of the high moisture levels encountered in direct combining. The major limitations of the Japanese automatic threshers are in the separating and cleaning mechanisms when working with high-moisture paddy. A number

of companies have now improved the cleaning capacity of the threshers by installing straw walkers and oscillating sieves; therefore, these machines can successfully harvest high-moisture paddy.

These improved head-threshing combines have 2–3% grain loss, and less than 1% grain damage. The machines are equipped with well-designed dividers and moving nylon pickup fingers that lift the lodged crop with a combing action. Two-row walking combines weigh approximately 600 kg and are equipped with crawler tracks that enable them to work in wet paddy fields. However, these machines still encounter problems of mobility in wet fields with a very high clay content or a very deep hardpan.

Although this type of thresher has gained acceptance in Japan, it has not been marketed successfully in other parts of Asia.

Through-Flow Combines (Western Style)

There are three types of through-flow combines: (1) tractor-trailed; (2) tractor-mounted; and (3) self-propelled. The trailed combines have almost been replaced by the self-propelled machines because of improved mobility and performance. One European manufacturer has recently developed a tractor-mounted 1.8-m (6-ft) combine that is lower-priced than the self-propelled combine and offers somewhat similar field mobility. The manufacturer claims that it can work in rice; however, no test data or information is available on its performance with rice.

The earlier tractor-drawn combines had 1.8-m (6-ft) cutterbars and an output of 3.22 ha/10 h although these combines required about 50% more labour than the self-propelled machines. However, these machines required one-third as much labour as with the old binder method. A self-propelled 3.6-m (12-ft) combine can harvest about 5.9 ha/10-h working day and a 4.2-m (14-ft) combine can harvest about 6.88 ha/10-h day.

A standard self-propelled rice combine consists of components for cutting, feeding, threshing, separating grain from straw, cleaning, and temporary storage. Power is provided both to the wheels and the harvesting-threshing mechanism from an engine mounted on the combine. Rice combines differ from other grain combines because they have higher ground clearance, a higher header lift, crawler tracks instead of wheels for improved mobility in muddy fields, sealed bearings, adjustable pickup-type reel and lift guards for lodged crops, and oversize straw walkers. Almost all machines are equipped with spike tooth cylinders and the cylinders rotate at a slower speed for rice than for other grains.

Manufacturers claim that nearly 80–90% of the grain is separated from the straw at the concave, thus improving grain separation at the rack and reducing losses with straw. Generally, the popular header size is from 2.4 to 4.2 m (8 to 14 ft) although combines with up to 8.2-m (27-ft) headers are now being manufactured in the United States. The new combines are equipped with hydrostatic transmission drives and make extensive use of hydraulic motors for driving the harvesting and threshing components. The use of hydraulics has simplified the design of the combine and has resulted in easier operation.

Careful operation and adjustments are necessary to obtain satisfactory performance from the modern combine. A brief description of various losses and the precautions necessary to minimize such losses are given below.

Scatter Losses

These are due to natural causes, such as overripe paddy, wind, rain, and birds.

Cutting Table Losses

Pickup reels, rather than bat reels, are essential for rice harvesting as nearly all fields have some lodged or tangled plants. In standing rice, pickup reels are driven 50% faster than the forward speed of the combine. In lodged rice, reel speed should be about twice the forward speed. The pickup fingers should be adjusted about 2.5–5 cm above and 35–43 cm ahead of the tip of the knife section when the fingers are in their lowest position. When the crop is flat on the ground, harvesting must be done along the direction of lodging. Cutter-

bar losses may increase due to dull knives and ledger plates, improper register, or too fast a reel speed.

Cylinder Losses

Spike tooth cylinders are normally used. The cylinder peripheral velocity ranges from 20 to 25 m/s (4000 to 5000 ft/min). If the rice is dry (14–18%), or is harvested for seed, cylinder speed should be set at about 20 m/s (4000 ft/min). Cylinder and concave tooth overlap should be about one-half the tooth length. The cylinder has teeth over the whole surface; whereas, the concave usually only has two to four rows of teeth at the front of the concave. Losses depend on the cylinder speed, the clearance between cylinder and concave, the condition of cylinder and concave, the combine travel speed, the variety of rice, the stage of maturity, the moisture content, the weather conditions, and the straw-grain ratio. Early morning or late evening harvest increases cylinder loss. Minimizing cylinder loss (unthreshed grain) can sometimes result in increased field hulling and damage to the paddy.

Rack Loss

This is affected by varietal characteristics and the amount of straw passing through the racks. In down rice, plants are harvested very close to the ground and because more straw passes through the machine the rack losses are increased.

Shoe Loss

Air-blast control is most important to minimize losses. Air should be sufficient to lift and float the chaff and light material and prevent it from falling through the sieves. The air should blow evenly throughout the entire area of the sieves. The air setting must be based on the amount of grain loss rather than the cleanliness of the grain in the tank. Damp, green paddy requires more air than dry paddy.

Hulling and Breaking

In long grain varieties, paddy is more easily removed from the panicle than in medium and short grain varieties. Too dry a crop (below 16% moisture content) can result in more hulling.

Operator Losses

These are perhaps the most important. Cutting the rice too high with less straw results in increased cutterbar and cylinder losses. Many heads on shorter straw or lodged straw are lost in the field. When the straw is too short it cannot be held by the beater and the feed rolls while the cylinder impacts it; therefore, cylinder losses are higher. If cutting is too low, excessive straw can clog the cylinder. Operating the machine too fast overloads it and increases losses.

Lo. s in Down Rice

Combine loss in down rice is usually double the loss in standing rice. The proper speed of the pickup reels is essential. The pickup reel should not have a combing action in down rice or it will knock off some of the grain or panicles. To reduce losses, combining must be done in the direction of lodging. Combining in a cross-direction is not recommended. The least amount of straw is taken into the machine when the cutting is in the direction of lodging.

Some rice combines have been tried in Malaysia, Vietnam, and the Philippines, mostly in government farms or farmers with large holdings. During August 1970, a study was made on six Clayson 975 rice combines with 53 500 W (72 hp) diesel engines and 4-m (13-ft) cutterbars. These machines weighed nearly 7 t each and were equipped with crawler tracks. The average production was found to be 1.74 ha/10-h working day. An average of 2.77 machine-h/ha was considered realistic, which is much more than the 1.23 h/ha quoted in other reports on combine harvesting. Some of the major causes of high downtime were: (1) rainy weather; (2) mechanical breakdown, mostly of a minor nature; and (3) poor field organization in locating farmers' plots for harvesting.

This study showed an inverse relation between plot size and harvesting time per unit area. It indicated that beyond a 0.8-ha (2.0-

acre) plot area, the effect of plot area on combine productivity is not too significant. It also indicated poor combining output on plots of less than 0.4 ha (1 acre). The main problems were: (1) shortage of access road systems and strong bridges; (2) uneven ripening of crop within a farming locality; (3) too large initial investment for farmers; and (4) inability of the machine to work in areas where the soil has a very high clay content or a very deep hardpan.

The study indicated, however, that it would be potentially profitable to operate these combines in spite of the high initial costs. Problems of accessibility, soil conditions, and small size of plots limit the areas available for combine harvest in the Muda region. The selling price of some of the self-propelled through-flow combines ranges from US$20 000 to $25 000 in the Philippines and other Asian countries.

It is highly doubtful that even some of the larger farmers in the tropics could raise that much capital. Perhaps such machines could only be bought by governments. The experience in the Muda Irrigation Scheme of Malaysia, where these combines are now being used for harvesting crops on a custom basis, should be watched carefully. If it is successful it may have application elsewhere.

Lawrence (1970) reports a study in which he compared the economic aspects of seven levels of mechanization in Pakistan from the traditional animal-drawn implements to a completely mechanized system of farming. He concludes that in the cropping sequence considered in this study, the labour demand for field operations fell only slightly when tractors were introduced and lower levels of mechanization actually increased labour demand. Combining, on the other hand, did reduce the demand for field labour considerably. The employment effects of introducing large combines will clearly continue to be a matter of concern.

Recent Developments and Trends

The idea of directly stripping grain from standing plants in the field has been experimentally tried for some time. A small stripper-

harvester has been developed for plot harvesting in Australia; however, when this machine was tried at IRRI on rice, loss of grain on the ground due to scatter was excessive. Strohman et al. (1965) reported the development of a stripper-harvester with a conical rotor. The machine performed well with very low grain losses in tests conducted on rice in Arkansas. The large diameter of the conical rotor, however, did not adapt well for multi-row harvester design. Experimental stripper-harvesters have also been built in Taiwan and Japan but none have reached a commercial stage.

The idea of stripping grain is of special interest for paddy harvesting because the elimination of handling straw through the machine can reduce substantially the machine weight and improve its mobility in soft paddy fields. Also, the cutting and elevating mechanisms can be dispensed with in a stripper. The IRRI Agricultural Engineering Department has been working on the development of a swath type stripper-harvester rather than a row machine. This concept differs primarily from all other experimental attempts in that initially, the plants are gently bent into the machine before a violent contact is made with the belt-type threshing mechanism. The deflection of plants is done to reduce grain scatter on the ground and to improve the collection of grain. The experimental machine (Fig. 54) is able to thresh all the grain on the plant panicles. However, grain loss is still above acceptable limits, and work is underway to minimize this loss.

Interest in stripper-harvesters is high and it is hoped that a successful machine can be developed, because it would certainly be better suited for harvesting rice in the tropics than the Japanese or the through-flow Western style combines. From the recent developments it seems probable that within a few years lightweight stripper-harvesters may be offered by manufacturers.

Recent developments in conventional through-flow rice combines are mostly directed toward increasing the machine capacity and size with increased width, wide flexible cutterbars, larger grain tanks, and bigger engines. Whereas these developments are well
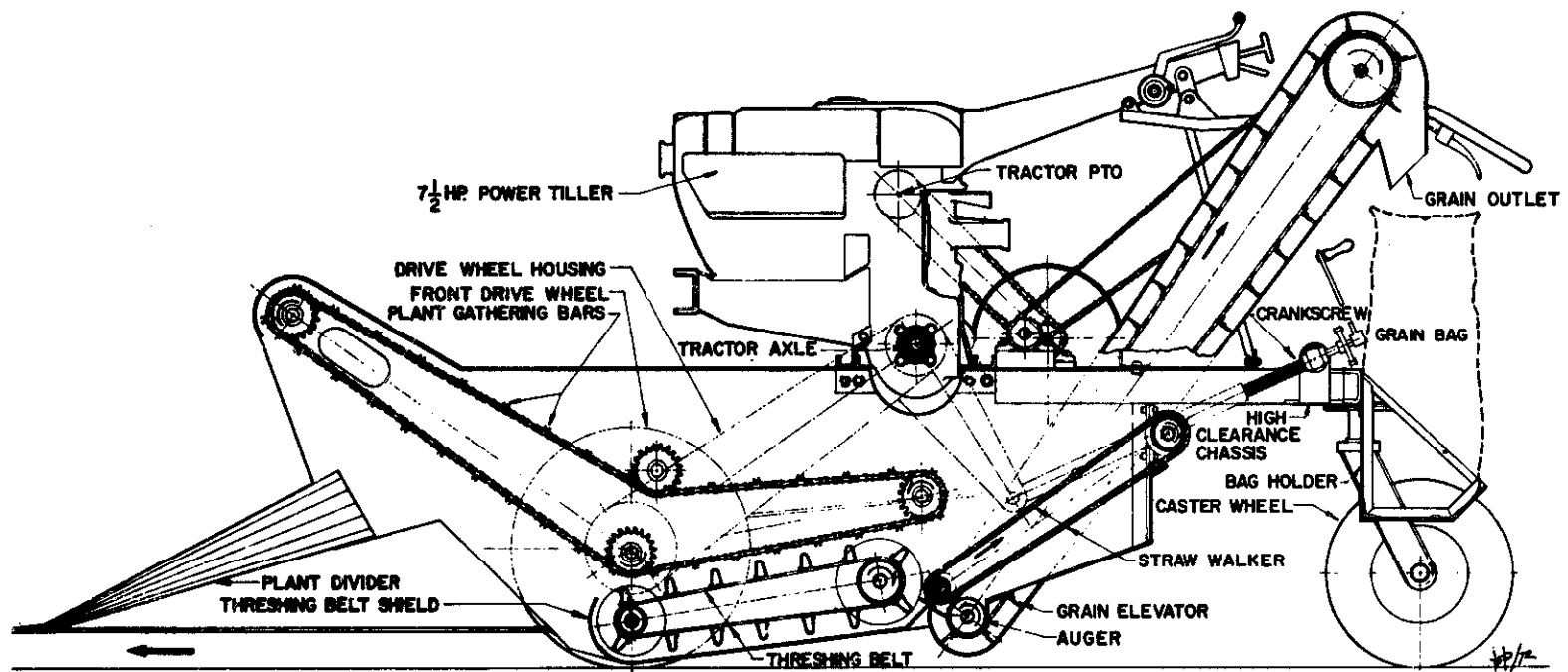
$7\frac{1}{2}$ H.P. POWER TILLER

TRACTOR PTO

GRAIN OUTLET

DRIVE WHEEL HOUSING
FRONT DRIVE WHEEL
PLANT GATHERING BARS

CRANKSCREW

GRAIN BAG

TRACTOR AXLE

HIGH
CLEARANCE
CHASSIS

BAG HOLDER

CASTER WHEEL

PLANT DIVIDER
THRESHING BELT SHIELD

STRAW WALKER

GRAIN ELEVATOR

AUGER

THRESHING BELT

Fig. 54. Schematic drawing of IRRI field stripper-harvester.

STRAW

GRAIN

CHAFF

AIR

OUTER CYLINDER

SCREEN NO. 2
(3/8" PERFORATION)

RECYCLING CYLINDER

SCREEN NO. I
(1/2" PERFORATION)

SPIRAL FINS

STRAW THROWER

PADDLE

RAKE

INCLINED GRAIN
POCKET

GRAIN TROUGH
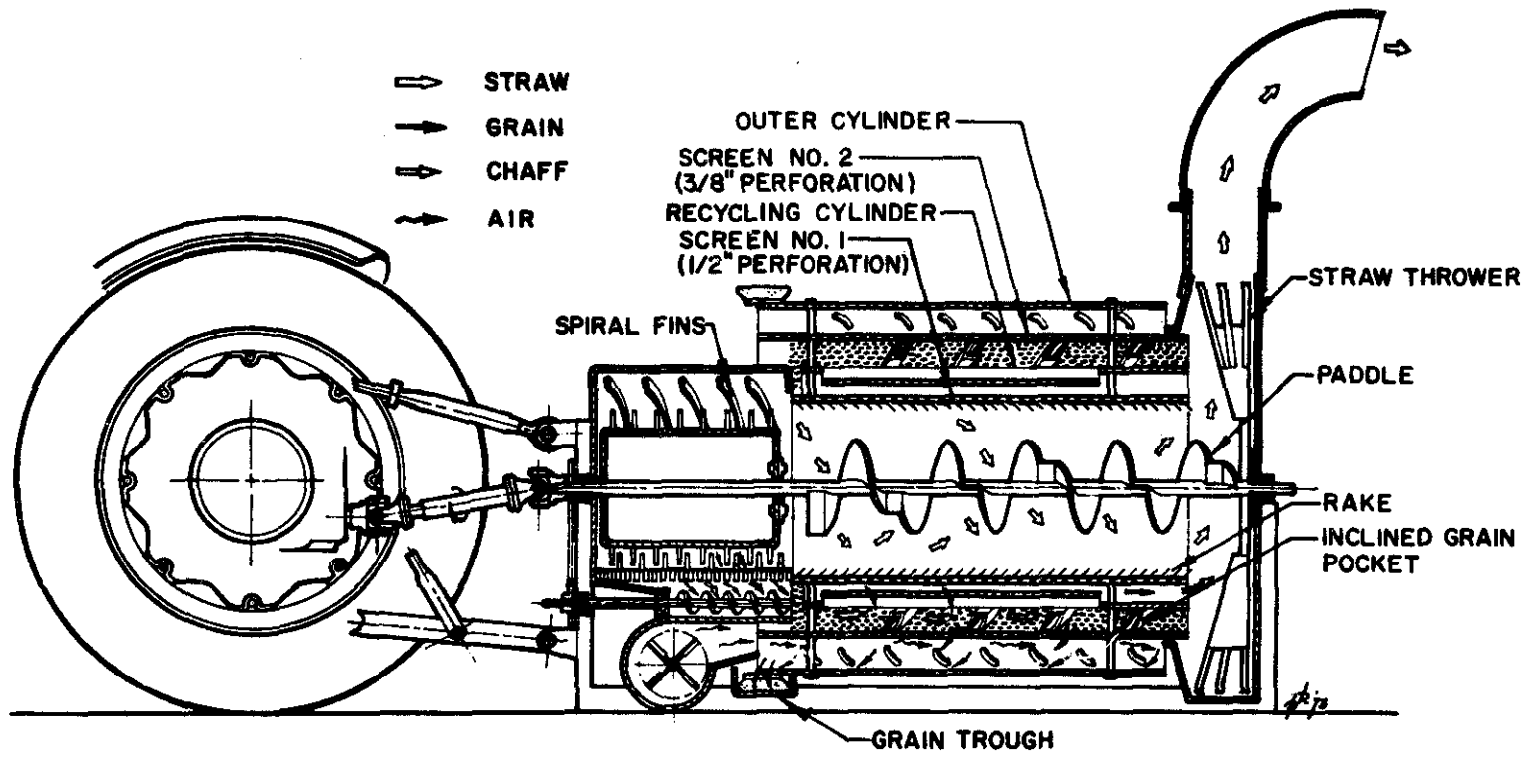
FIG. 55. Schematic drawing of the IRRI PTO-driven thresher.

suited for the advanced countries, this trend, unfortunately, is taking the newer combines farther away from the requirements of the developing countries. It is highly doubtful that such large machines could be widely accepted in the developing areas of the world.

For some years IRRI has been working on the development of a thresher using rotary threshing and separating components. A tractor-mounted, PTO-driven, through-flow thresher (Fig. 55) is currently under development at the Institute and so far the test results are very promising. The machine can thresh high-moisture paddy without clogging. It uses a spike tooth threshing cylinder and a multiscreen rotary cleaner that are mounted uniaxially. The threshed material continuously moves in a spiral path through the threshing cylinder and the rotary cleaner. Up to 92% grain-straw separation has been achieved at the cylinder concave. Work is on hand to optimize the recovery of the remaining grain in the rotary cleaner. The thresher concept is such that it can be easily adapted for a low-cost rice combine. Harrington (1970) also reports the development of a multicrop, tractor-mounted, PTO-driven thresher in India using a large-diameter beater-type threshing mechanism. The machine can thresh paddy, wheat, and many other crops.

Recent developments in Japan on harvesting and threshing machines indicate a rapid shift to combining. The basic Japanese automatic head-threshing machine has remained unchanged in design for a long time. During the last 2 years, some marginal improvements have been made in the cleaning mechanisms to improve performance with wet crops and increase capacity. These were necessitated because these threshers are used with combines that harvest high-moisture paddy. Combine size is gradually increasing from two rows to three and four rows. The Japanese combine can work well in the tropics for harvesting and threshing of paddy. Recent attempts to introduce this machine in Asia, however, indicate that it is not very economical. The Japanese combine is a complex piece of equipment, and from a design point of view, it is doubtful that the basic machine concept could be sufficiently simplified to substantially reduce

the price. The home market in Japan is moving towards larger three- and four-row combines that are even higher-priced than the two-row machines.

Requests received at IRRI for information on threshers for tropical countries indicate an intense demand for machines, both for the individual farmers and for custom threshing operators. Attempts are being made in many developing countries to manufacture simple hold-on type drum threshers.

The Japanese automatic threshers are gradually being introduced in Asia but their high landed cost restricts their acceptance. The indigenous manufacture of small threshers is gradually developing in many tropical countries but is hampered by the lack of thresher designs that can be manufactured by simple production methods. Developments indicate considerable interest in large PTO-driven threshers and it is hoped that some successful design will appear in the near future. It seems doubtful that rice harvesting in Asia will go through the reaper-binder stage like in Japan and the United States.

There is little doubt that in the long run the harvesting and threshing of paddy in the tropics will have to be done directly in the field. The present combines, however, do not seem to meet the special requirements of tropical regions. Recent developments indicate an intense interest in developing simpler machines for paddy harvesting and threshing. Looking at some of the recent technical developments, it seems that a breakthrough can be made in the development of economical, small-sized machines for direct field-harvesting and threshing of paddy in the tropical regions of the world.

Comparing Machinery, and Capacity and Cost Data

Grain harvesting, threshing, and cleaning affect the final product. Therefore, there is a need to have a more critical look at the available processing methods for harvesting, threshing, and cleaning. We wish to be able to determine where and when losses in efficiency occur during the entire process of cutting the

standing crop, removing the grain from its parent attachment, and cleaning the grain prior to drying. To accomplish this, we must be able to evaluate the performance of existing machines or methods against a standard, which considers many variables. For example, it is not sufficient to associate milling damage only with the effects of threshing, whether it be the traditional method of beating or a more modern mechanical method, because there are many other constraints in the process. In time we must be able to identify these variables whether they are biological, time-space, or socioeconomic in nature.

It is important that the rated capacity of a machine be determined when evaluating its performance. However, this performance must be based on standardized variables; otherwise, comparisons between different machines are not possible.

One of the most important variables to consider when evaluating the performance of a machine is the moisture content of the grain. Because the same machine may have an entirely different capacity for wet and dry grain, the moisture content of the grain should always be recorded when evaluating the rated capacity. The capacity of the machine should be stated either for raw and wet paddy with a moisture content greater than 15%, or for precleaned and dried paddy with a moisture content equal to 15%.

The threshing efficiency of a hold-on thresher could reach 100% because the threshing time can be increased until all the grains are removed. However, for a throw-in type of thresher one of two indices can be used to determine threshing efficiency, de-pending on whether the rice is threshed raw and wet or clean and dry.

(1) Raw standard
% raw threshing efficiency =
$$\frac{\text{unclean grain}}{\text{unclean grain + unthreshed grain}} \times 100$$

(2) Dry standard
% effective threshing efficiency =
$$\frac{\text{clean grain}}{\text{clean grain + unthreshed grain}} \times 100$$

A machine is considered to have good threshing characteristics when the efficiency is equal to or greater than 97%.

The amount of mechanical damage caused by the machine must be minimal. Damage in excess of 1% of the rated capacity is considered to be high. In addition, the machines must not lower the germination percentage of the grain. The germination percentage is acceptable only when it is greater than 80%.

Other factors that should be considered when evaluating the performance of a machine are fuel consumption (1/kg), labour supply (man-h/kg), and investment cost (per kg). Although standards have not yet been established for these variables they should always be recorded.

By using standardized variables, accurate comparisons of the performance of different machines are possible. — AMIR U. KHAN. *Department of Agricultural Engineering, International Rice Research Institute, Los Baños, Laguna, Philippines.*

DRYING

Psychrometry

A knowledge of the terms used in psychrometry, which is the study of the properties of the air, and use of the psychrometric chart are essential for an understanding of the processes involved in grain drying and storage and for analyzing individual requirements for a particular climatic condition.

Psychrometric Chart

The psychrometric chart is a device that simplifies the measurement of air properties and eliminates many time-consuming and tedious calculations that would otherwise be necessary. Different air-conditioning manufacturers have slightly different forms of this chart, which may differ in the location of information. All, however, are basically the same in that any psychrometric chart is simply a graphic presentation of the conditions or properties of air, such as temperature, humidity, and dewpoint.

Psychrometric Terms

The essential terms that are most commonly thought of in connection with the psychrometric chart are dry-bulb temperature, wet-bulb temperature, relative humidity, dewpoint, and grains of moisture. *Dry-bulb temperature*

is the temperature of the air as measured by an ordinary thermometer such as a household thermometer (Fig. 56). *Wet-bulb temperature* is the temperature of the air as measured by an ordinary thermometer whose glass bulb is covered by a wet cloth or gauze (Fig. 57). The temperature is recorded after the thermometer has been moved rapidly in the air. A wet-bulb thermometer is so-called because the bulb of the thermometer is wet when a temperature reading is taken. This is accomplished by slipping a cloth "sock" onto the bulb end of the thermometer and then dipping both into water. Except for the "sock," a wet-bulb thermometer is the same as a dry-bulb or ordinary thermometer. To measure wet- or dry-bulb temperature, a sling psychrometer is used. A sling psychrometer (Fig. 58) has two thermometers mounted on a base plate. The one with the "sock" is the wet-bulb thermometer; the other is the dry-bulb. The wet-bulb extends below the dry-bulb. This is done purposely so that the "sock" can be dipped in water without wetting the dry-bulb thermometer. If the "sock" is wetted as described, and the two thermometers are moved quickly through the air until the water evaporates from the "sock," the thermometer with the dry-bulb will register the dry-bulb or ordinary temperature, and the thermometer with the wet "sock" on the bulb will register a wet-bulb temperature. Although the air passing over the dry-bulb is the same temperature as the air passing over the wet-bulb, the temperature registered by the two thermometers is not the same. The dry-bulb always registers the actual air temperature; the wet-bulb registers a temperature that is lower than the dry-bulb reading. The key to the seemingly apparent
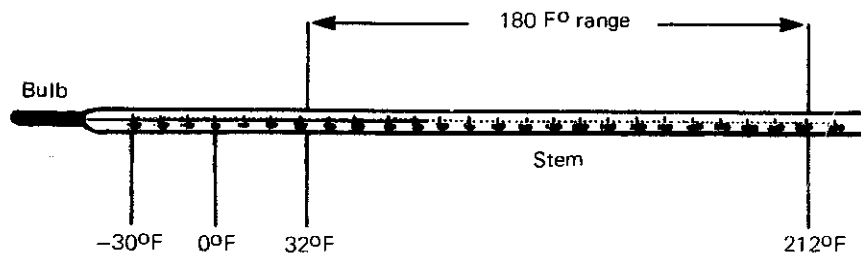
FIG. 56. Dry-bulb thermometer. The bulb is the sensitive portion of the instrument. As the temperature of the bulb increases, the liquid in the bulb expands and rises in the stem.
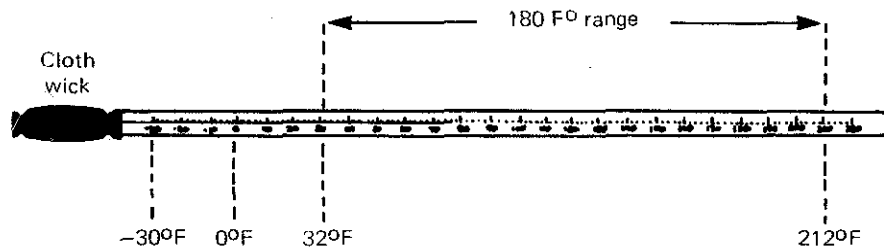
FIG. 57. Wet-bulb thermometer. The clean cotton wick absorbs water. Evaporation of this water reduces the temperature of the wick, and the resultant temperature is indicated by the mercury in the thermometer stem.
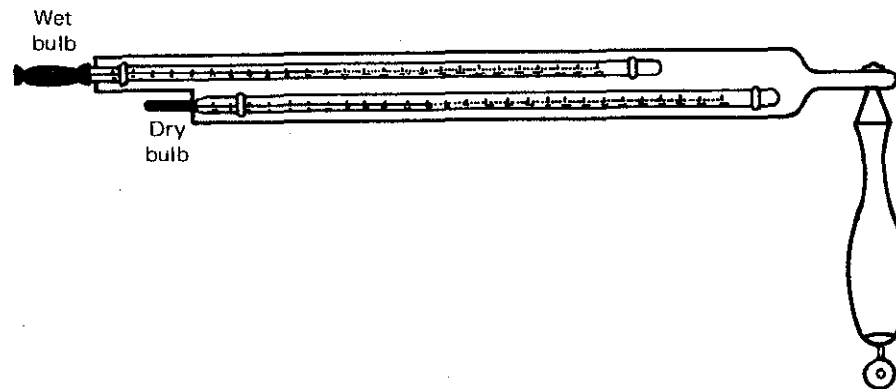

FIG. 58. Sling psychrometer. The two thermometers should be matched by the manufacturer; that is, the readings obtained when the wick is removed and both thermometers are exposed to dry-bulb conditions should be the same. The instrument is rotated about two to three times per second until readings attain constant values.

discrepancy in temperature readings is the word "evaporation." As moisture evaporates from a surface, it removes heat from the surface. In this instance, moisture evaporates from the wet "sock" on the wet-bulb thermometer and consequently cools the surface of the thermometer bulb. This is primarily the reason for a lower wet-bulb thermometer reading.

The temperature spread between the dry-bulb and wet-bulb readings depends upon the amount of moisture in the air. If moisture content is high, evaporation at the "sock" on the wet-bulb takes place at a slower rate. If the moisture content of the air is low, the air is dry and can readily absorb moisture. Therefore, evaporation at the "sock" takes place rapidly and heat is removed in larger quantities. This makes the surface of the wet-bulb cool rapidly. As a result, the reading on the

wet-bulb thermometer is lower than for air that has a high moisture content. Dry air, or air that has a low moisture content, therefore, has a low wet-bulb temperature; humid air, or air that has a high moisture content, has a high wet-bulb temperature. In fact, when the moisture content reaches 100%, or 100% relative humidity, the wet-bulb temperature becomes the same as the dry-bulb temperature. This can readily be seen on the psychrometric chart. At this condition evaporation ceases because the air cannot absorb more moisture. Therefore, it is not possible to remove heat by evaporation from the "sock" on the wet-bulb, and the two thermometers register the same temperature.

Relative humidity is the ratio of the partial pressure of water vapour in the air to the pressure that saturated water vapour exerts at the temperature of the air. Grains of mois-

ture is the unit of measurement used to determine the amount of moisture in the air; 700 grains equal 1 lb (0.45 kg) of water. *Dewpoint temperature* is the temperature at which moisture condenses on a surface.

In relation to the psychrometric chart, these terms can quickly tell many things about the condition of the air: if the dry-bulb and wet-bulb temperatures are known, the relative humidity can be read from the chart; if the dry-bulb temperature and relative humidity are known, the wet-bulb temperature can be determined; if the wet-bulb temperature and relative humidity are known, the dry-bulb temperature can be found; if the wet-bulb and dry-bulb temperatures are known, the dewpoint can be read from the chart; and if the dry-bulb temperature and relative humidity are known, the dewpoint can be found.

The grains of moisture in the air can be determined from any of the following combinations: dry-bulb temperature and relative humidity (RH); dry-bulb temperature and dewpoint; wet-bulb temperature and relative humidity; wet-bulb temperature and dewpoint; dry-bulb and wet-bulb temperatures; or dewpoint alone.

Identification of Lines and Scales on the Chart

Picture the chart as a shoe or boot with the toe on the left and the heel on the right. Refer to the skeleton psychrometer charts, Fig. 59 (A–F), to clarify the following points. (1) The dry-bulb temperature scale extends along the sole from toe to heel. The dry-bulb lines extend straight up from the sole, one for each degree of temperature. (2) The wet-bulb scale extends along the instep from the toe to the top of the shoe. The wet-bulb lines extend diagonally downward to the sole and the back of the shoe, one for each degree of temperature. (3) The condensation or dewpoint is the same as the wet-bulb scale. However, the dewpoint lines extend horizontally to the back of the shoe, one for each dewpoint temperature. (4) The relative humidity lines are located along the side of the shoe and follow approxi-

mately the same curve as the instep. The instep line is actually the 100% relative humidity line. (5) The grains of moisture scale follows along the back of the shoe from the heel to the top. The lines are the same as the dewpoint lines. (6) All properties of air at any given condition can be represented on a psychrometric chart by plotting a single point.

Relationship of Terms

The following examples illustrate all of the foregoing relationships. Each example directly relates to the psychrometric chart; therefore, the chart should be used to clarify the solution to each example.

Example 1

To calculate from the dry-bulb and wet-bulb temperatures the relative humidity.
Given: Dry-bulb = 78 °F and wet-bulb = 65 °F
Find: Relative humidity
Solution: (Fig. 60, chart 1)
(1) Locate 78 °F on dry-bulb scale at bottom of chart; (2) draw a line straight up the 78 °F line to the curve line at the instep; (3) follow down the instep (wet-bulb scale) to 65 °F; (4) draw a line diagonally along the 65 °F wet-bulb line until it crosses the 78 °F dry-bulb line; and (5) read 50% relative humidity at the intersection of the dry-bulb and wet-bulb lines.

Example 2

To calculate from the dry-bulb and wet-bulb temperatures the dewpoint.
Given: Dry-bulb = 78 °F and wet-bulb = 65 °F
Find: Dewpoint
Solution: (Fig. 60, chart 2)
(1) Find the intersection of the 78 °F dry-bulb line and the 65 °F wet-bulb line; (2) proceed horizontally to the instep line; and (3) read 58 °F dewpoint temperature. At 78 °F dry-bulb and 65 °F wet-bulb, the dewpoint temperature is 58 °F.
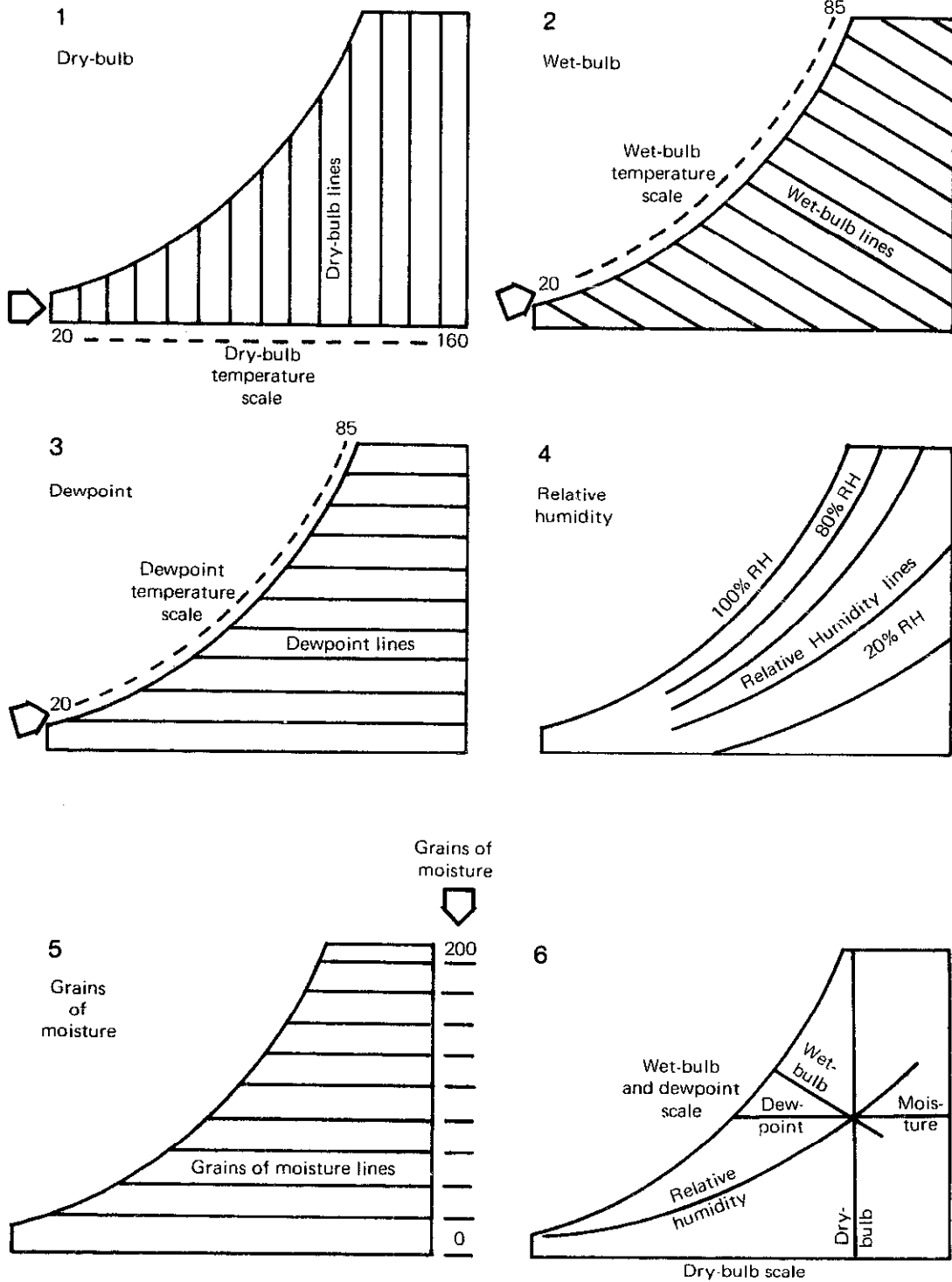
1 Dry-bulb

Dry-bulb lines

20 — — — — — — — — — 160
Dry-bulb
temperature
scale

2 Wet-bulb

85

Wet-bulb
temperature
scale

Wet-bulb lines

20

3 Dewpoint

85

Dewpoint
temperature
scale

Dewpoint lines

20

4 Relative humidity

100% RH   80% RH

Relative Humidity lines

20% RH

Grains of
moisture

200

5

Grains
of
moisture

Grains of moisture lines

0

6

Wet-bulb
and dewpoint
scale

Wet-
bulb

Dew-
point

Mois-
ture

Moisture scale

Relative
humidity

Dry-
bulb

Dry-bulb scale

FIG. 59. Skeleton psychrometric charts identifying the lines and scales on the chart.

1

65°F   50% RH

Wet-bulb

Dry-bulb   78°F

2

Wet-bulb

65°F

58°F

Dewpoint

Dry-bulb   78°F

Grains of
moisture

3

58°F   50% RH

Dewpoint

Dry-bulb   78°F

4

Wet-bulb

65°F

72

Dry-bulb   78°F

5

Wet-bulb

65°F

72
Grains

Dry-bulb   78°F
12.5   13.0   13.5   14.0
                          13.8 ft^3
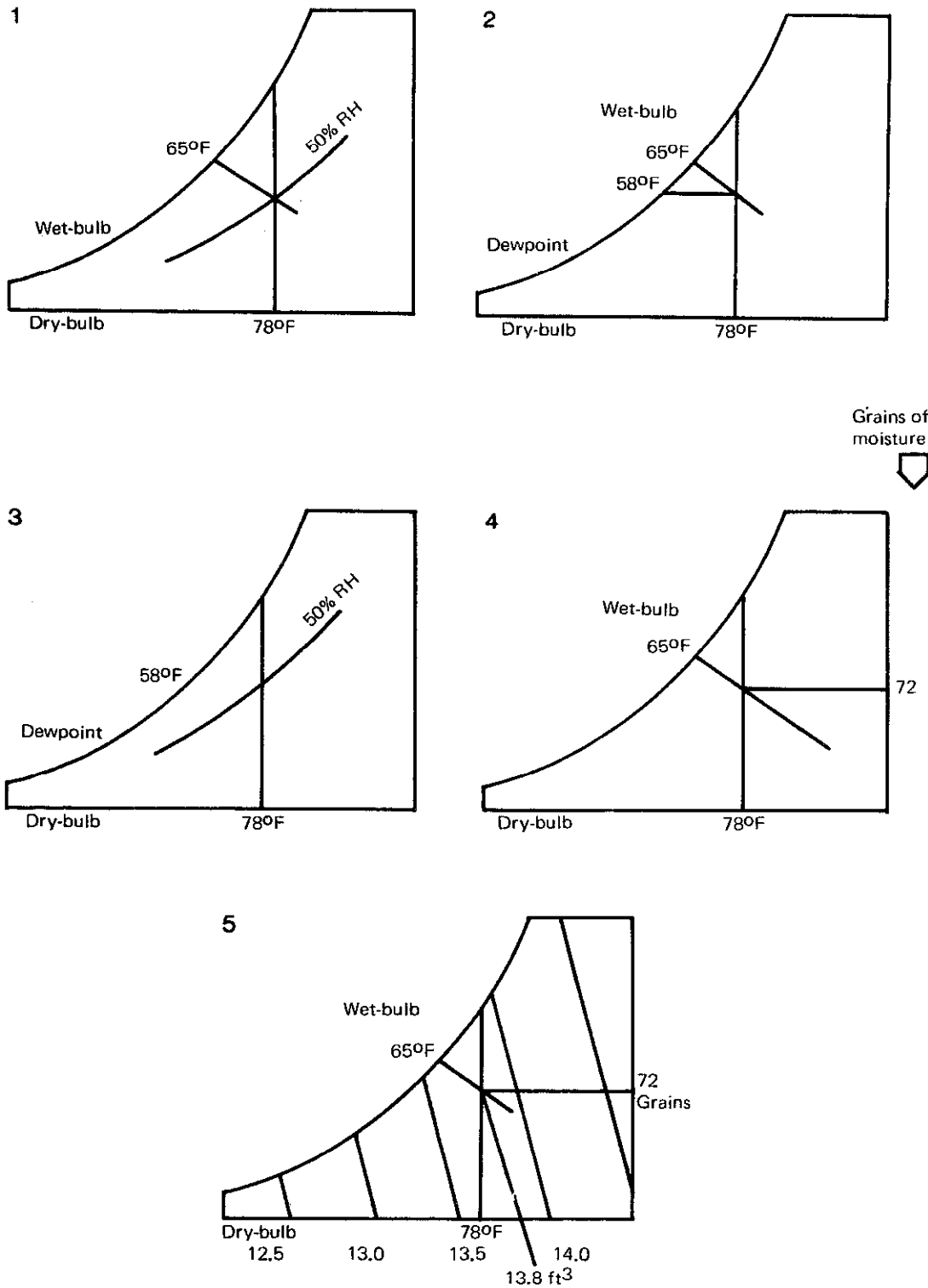
FIG. 60. Skeleton psychrometric charts demonstrating the relationships between the psychrometric terms.
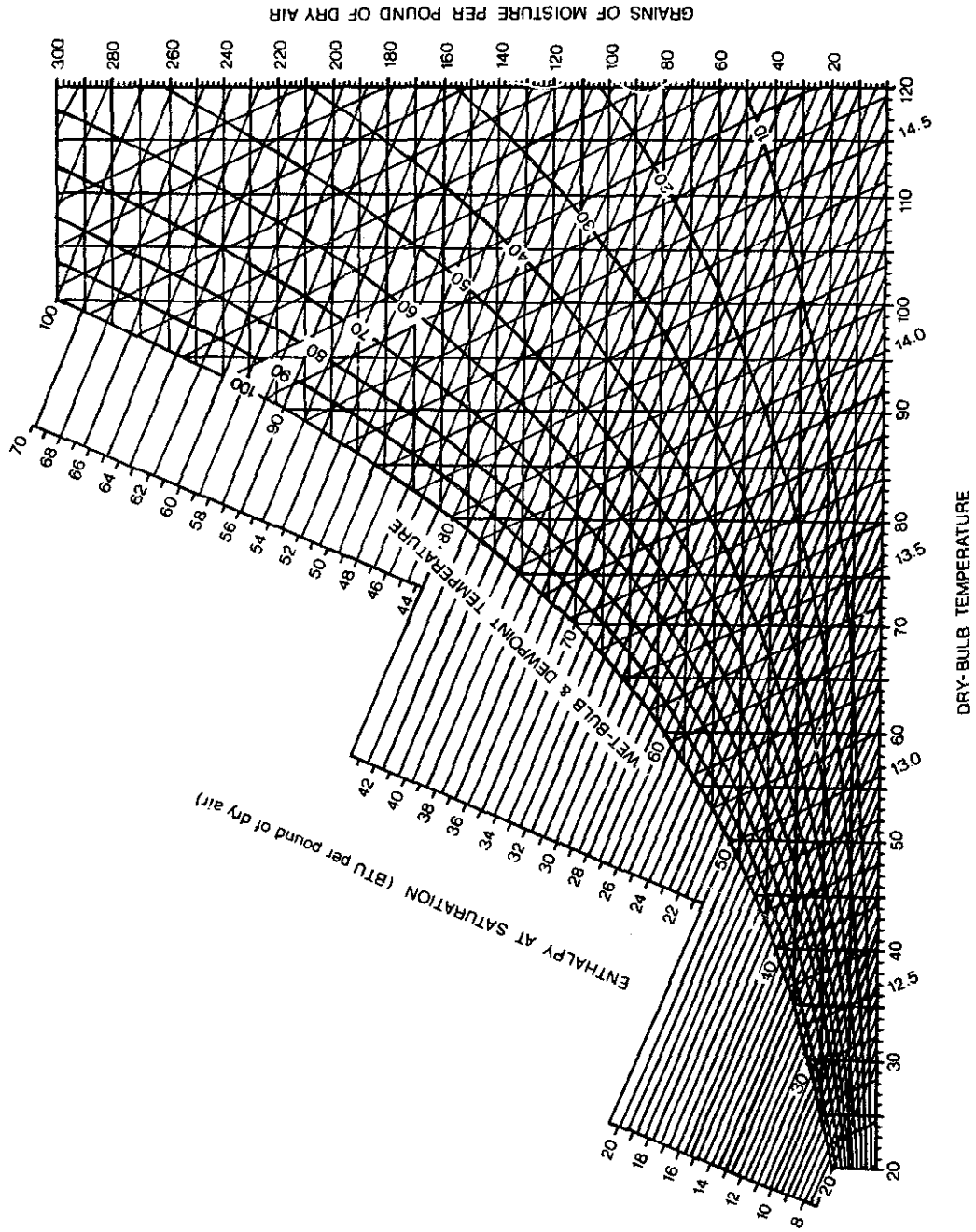
Fig. 61. A typical psychrometric chart (barometric pressure 14.696 lb/in.²).

Example 3

To calculate from the dry-bulb temperature and relative humidity the dewpoint.
  Given: Dry-bulb = 78 °F and relative humidity = 50%
  Find: Dewpoint
  Solution: (Fig. 60, chart 3)
  (1) Find the intersection of the 78 °F dry-bulb and 50% RH lines; (2) proceed horizontally to the instep line; and (3) read 58 °F dewpoint temperature. At 78 °F dry-bulb and 50% RH the dewpoint temperature is 58 °F.

Example 4

To calculate from the dry-bulb and wet-bulb temperatures the grains of moisture.
  Given: Dry-bulb = 78 °F and wet-bulb = 65 °F
  Find: Grains of moisture
  Solution: (Fig. 60, chart 4)
  (1) Find the intersection of the 78 °F dry-bulb and 65 °F wet-bulb lines; (2) proceed horizontally along the grains of moisture line, to the back of the shoe; and (3) stop at the first column of numbers. This column is the grains of moisture scale. Read 72 grains.

This example shows how to find grains of moisture by using dry-bulb and wet-bulb temperatures. Grains of moisture can also be found on the psychrometric chart by using other combinations of psychrometric properties. These combinations are listed below. Simply find the intersection of the lines listed here and then follow across the chart to the grains of moisture scale: dry-bulb temperature and relative humidity; dry-bulb temperature and dewpoint; wet-bulb temperature and relative humidity; or wet-bulb temperature and dewpoint.

Grains of Moisture Per Pound of Dry Air or Per Cubic Foot of Air

Notice (Fig. 61) the words "grains of moisture per pound of dry air." This means that at 78 °F dry-bulb and 65 °F wet-bulb temperature, the air holds 72 grains of moisture per pound. Moisture can be measured per pound of air or per cubic foot of air. To find the moisture in a cubic foot of air, using the same conditions (78 °F dry-bulb and 65 °F wet-bulb) proceed as follows (Fig. 60, chart 5): (1) find the intersection of the 78 °F dry-bulb and 65 °F wet-bulb temperature lines; (2) proceed horizontally along the grains of moisture line to the grains of moisture scale; (3) read 72 grains; (4) find the cubic foot scale along the sole of the shoe. The cubic foot lines extend diagonally from the sole of the shoe to the instep; (5) again locate the intersection of the 78 °F dry-bulb and 65 °F wet-bulb lines; (6) draw a line parallel to the cubic foot line, from the intersection located in Item 5, to the sole of the shoe. The line crosses the sole at a point that is over halfway between 13.5 and 14 on the cubic foot scale, say 13.8 ft^3; (7) divide 72 grains by 13.8 ft^3; and (8) moisture in air equals 72 ÷ 13.8 = 5 grains/ft^3, approximately. Therefore, at 78 °F dry-bulb and 65 °F wet-bulb temperature, the moisture in the air can be read as 72 grains/lb, or 5 grains/ft^3.

The psychrometric chart simplifies the measurement of air properties. If the value of any two of the psychrometric terms is known, the value of any other term can be found on the psychrometric chart; therefore, its use is very important for an understanding of the processes involved in grain drying and storage.
— JAMES M. BECK. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Moisture

The moisture content of grain is one of the most important indices for determining whether the grain should be harvested, is dry enough for safe storage, or can be milled with maximum recovery. Therefore, it is essential to understand the common methods of representing moisture, and be able to determine moisture content accurately.

Moisture Content Representation

Wet Basis

The rice industry expresses moisture content (MC) as a percentage of the total weight. Algebraically it is expressed as:

$$\% \ MC_{wb} = \frac{W_m}{W_t} \times 100$$

$$= \frac{W_m}{W_m - W_{dm}} \times 100$$

where: wb = wet basis; W_m = weight of moisture (H_2O) in the grain; W_t = total weight of the grain; and W_{dm} = weight of dry matter in the grain.

In the wet basis of expressing moisture content, it is incorrect to state that one has removed 7% of 100 kg or 7 kg of water from 100 kg of grain if the moisture content of 100 kg of grain is lowered from 20 to 13%. This is because the denominator of the equation changes in relation to the amount of moisture removed. For example, at 20% MC, 100 kg of wet grain contains 20 kg (0.20 × 100) of water and 80 kg of dry matter. If the same amount (100 kg of wet grain) is dried to 13% MC, the resulting weight of moisture is calculated using the following equation:

$$0.13 = \frac{W_m}{W_m + 80}$$

$$W_m = \frac{(0.13)(80)}{0.87}$$

$$= 11.96 \ kg$$

Therefore, the amount of water removed from the 100 kg of wet grain when it is dried from 20 to 13% is 8.04 kg (20.00–11.96).

Because it is necessary to reduce the moisture content of the grain to 13% for safe storage, Table 19 has been prepared to facilitate the computation of moisture load. It gives the moisture load in pounds or kilograms of water per pound or kilogram of the wet grain at different moisture contents. For example, at an initial moisture content of 20%, the moisture load is 0.0804 kg/kg of grain. Therefore, drying 100 kg of wet grain to 13% mois-

ture requires evaporation of 0.0804 × 100, or 8.04 kg of water.

Dry Basis

Representing moisture on a dry basis rather than on a wet basis is more convenient. In the dry basis method, the moisture is expressed as a percentage of the bone-dry weight of the grain. Algebraically this is expressed as:

$$\% \ MC_{db} = \frac{W_m}{W_{dm}} \times 100$$

This method is usually used in expressing moisture of soils and other inert matter. The dry basis of representing moisture is sometimes encountered in literature on cereals, and one must be able to convert the dry basis values to a wet basis. For convenience in converting one value to another, Table 20 may be used.

The Importance of Moisture Content Determination

Experienced rice dealers can qualitatively determine whether paddy is wet or dry enough for milling by cracking the grain with their teeth. More accurate methods, however, must be used to determine moisture content for seed certification and safe storage. Accurate de-

TABLE 19. Moisture load in drying grain to 13% moisture content on a wet basis.

Initial moisture content (wet basis)	lb water/lb of wet grain (kg water/kg grain)
25	0.1380
24	0.1265
23	0.1150
22	0.1035
21	0.0920
20	0.0804
19	0.0690
18	0.0575
17	0.0460
16	0.0345
15	0.0230
14	0.0115
13	0.0000

TABLE 20. Table for conversion of percentage moisture on a wet basis to percentage moisture on a dry basis.

% moisture content (wet basis)	% moisture content (dry basis)
10	11.0
11	12.3
12	13.6
13	15.0
14	16.3
15	17.6
16	19.0
17	20.5
18	21.9
19	23.5
20	25.0
21	26.5
22	28.2
23	29.9
24	31.6
25	33.3
26	35.1
27	37.0
28	38.9
29	40.8
30	42.8

TABLE 21. Variation in the weight of a bag of paddy at different moisture contents.

Initial moisture content (% wet basis)	Wet weight of one cavan of paddy required to produce a 44-kg bag at 14% moisture
25	50.5
24	49.9
23	49.3
22	48.5
21	48.0
20	47.4
19	46.9
18	46.2
17	45.7
16	45.1
15	44.6
14	44.0
13	43.6
12	43.1
11	42.7
10	42.1

termination of moisture content is also absolutely necessary for individuals and corpora·tions that purchase, store, or mill thousands of tonnes of paddy. There is about a 0.5 kg change in weight of a 44 kg bag of paddy for every 1% change in moisture content. For instance, if 1000 bags of paddy stored at 16% moisture dry to 15% moisture, there is a loss of 500 kg or 11 bags by weight. Table 21 dramatically shows the variations in the weight per bag of paddy at different moisture contents.

Methods of Determining Moisture Content

Numerous methods for the quantitative determination of moisture are available. The choice of the method to use for a specific product depends upon several factors: (1) the form in which water is present; (2) the nature of the product analyzed (whether easily oxidized or decomposed); (3) the relative amount of water present in the product; (4) the rapidity of the determination; (5) the accuracy desired; and (6) the cost of the equipment required.

Grain moisture can be determined either by primary (direct) or secondary (indirect) methods. The primary method is used by researchers to obtain highly accurate moisture measurements. The values obtained with this method are used to calibrate all the secondary type of moisture-measuring devices. The steps used in the primary method are too cumbersome and time consuming for use in the field or warehouse; therefore, secondary methods, which are much faster and usually depend on the electrical properties of the grain, are used in these cases.

The different forms of water (absorbed, colloidally bound, mechanically accluded, and water of crystallization) vary in the tenacity with which they are held in various products. For this reason, depending upon the forms of water present, the various moisture methods determine more or less the "moisture" in the product. This has necessitated the adoption of standard or official methods for most agricultural and biological products. Whenever possible, these standards should be used if accurate results are desired. If only compara-

tive results are needed, moisture methods other than the standard ones are satisfactory.

Moisture methods that involve oven drying require a sensitive analytical balance and a thermostatically controlled electrically heated vacuum or drying oven. Electrical methods involve more or less complicated and expensive electrical equipment. Distillation methods require the least expensive apparatus of all because only a balance of low sensitivity and a distillation setup are necessary. Methods based on an interaction of a chemical and water also require relatively inexpensive equipment.

Moisture determinations are empirical methods because the various moisture methods determine more or less the water present in the product. In other words, the conditions of the method govern to some extent the amount of moisture obtained. Thus it is necessary to specify the method used along with the moisture percentage, for example 13.5% moisture determined in a vacuum oven at 135 °C.

Primary or Direct Methods

Vacuum-Oven Method

A representative sample of the bulk (2–3 g) is ground and then dried in a vacuum oven (25 mm vacuum) for 72–96 h at 100 °C, and the drop in the weight of the grain is measured based on its initial weight.

Air-Oven Method

(1) One stage — This method is used for grain with a moisture content less than 13%. Grind duplicate 2- to 3-g samples and heat them at 130 °C for 1 h. Place the samples in a desiccator and then weigh. The samples should check to within 0.1% moisture. The American Official Association of Chemists requires drying at 135 °C for 2 h, giving slightly higher moisture content values.

(2) Two stage — This method is used for grain with a moisture content greater than 13%. Remove moisture from the grain sample (25–30 g) until the moisture drops to less than 13%. This usually takes 14–16 h of drying. Then continue as in the one stage method.

Water-Oven or Air-Oven Method

Place duplicate grain samples (25–30 g) in an oven heated to 100 °C. Dry for 72–96 h and then place in a desiccator and weigh. The samples should check to within 0.1% moisture.

Brown-Duvel Fractional Distillation Method

The results of the Brown-Duvel metre (Fig. 62) are considered official. The metre determines moisture by fractional distillation. The whole-grain sample (100 g) is heated to a temperature considerably above the boiling point of water in 150 ml of mineral oil. For unmilled rice the sample should be heated to 190 °C; for brown rice to 190 °C, with a 2-inch diameter by 0.25-inch thick glass-wool pad in the bottom of the flask; for milled rice (first and second head) to 200 °C using the glass-wool pad; and for rice screenings and brewers rice the sample should be heated in a special double-walled flask with 150 ml of oil between the walls of the flask and 150 ml inside the flask. The oil inside the flask should reach 200 °C in 26 min.

The vaporized moisture is condensed and measured in a graduate cylinder. The amount of moisture collected (in millilitres) is also
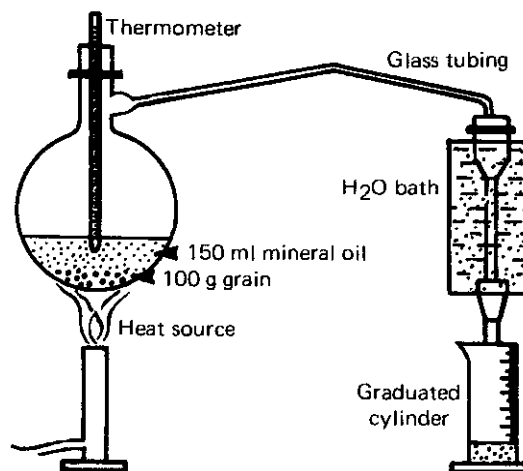
FIG. 62. Brown-Duvel fractional distillation method, used to directly determine the percentage moisture content of grain.

the percentage moisture content on a wet basis. The method takes about 30 min, and the results can be reproduced accurately when the time of heating is properly adjusted.

A comparison of the water-oven method with the Brown-Duvel method using 28 samples gave the following results: (1) Brown-Duvel 17.40%; (2) water-oven 17.26%; (3) a difference of 0.14%. This is valid for moisture levels between 11.54 and 27.05%. The lower reading obtained with the water-oven is expected because starchy grains dried in the oven give levels of free water slightly below the true value. Water-oven drying took 96–120 h (136 h for hard kernels). Using whole kernels the average moisture content in another Brown-Duvel test was

20.13%, using ground kernels it was 20.05%. This relationship between test results for whole and ground kernels is true for moisture contents from 12.71 to 36.68%. A variation of 1–1.5% for samples from the same bulk at the same time is expected because of nonuniformity of the kernels.

Secondary or Indirect Methods

Electrical Resistance Method

This method is based on the principle that the electrical resistance or conductivity of a material depends upon its moisture content. The Universal Moisture Meter, with a self-contained power supply, measures the elec-
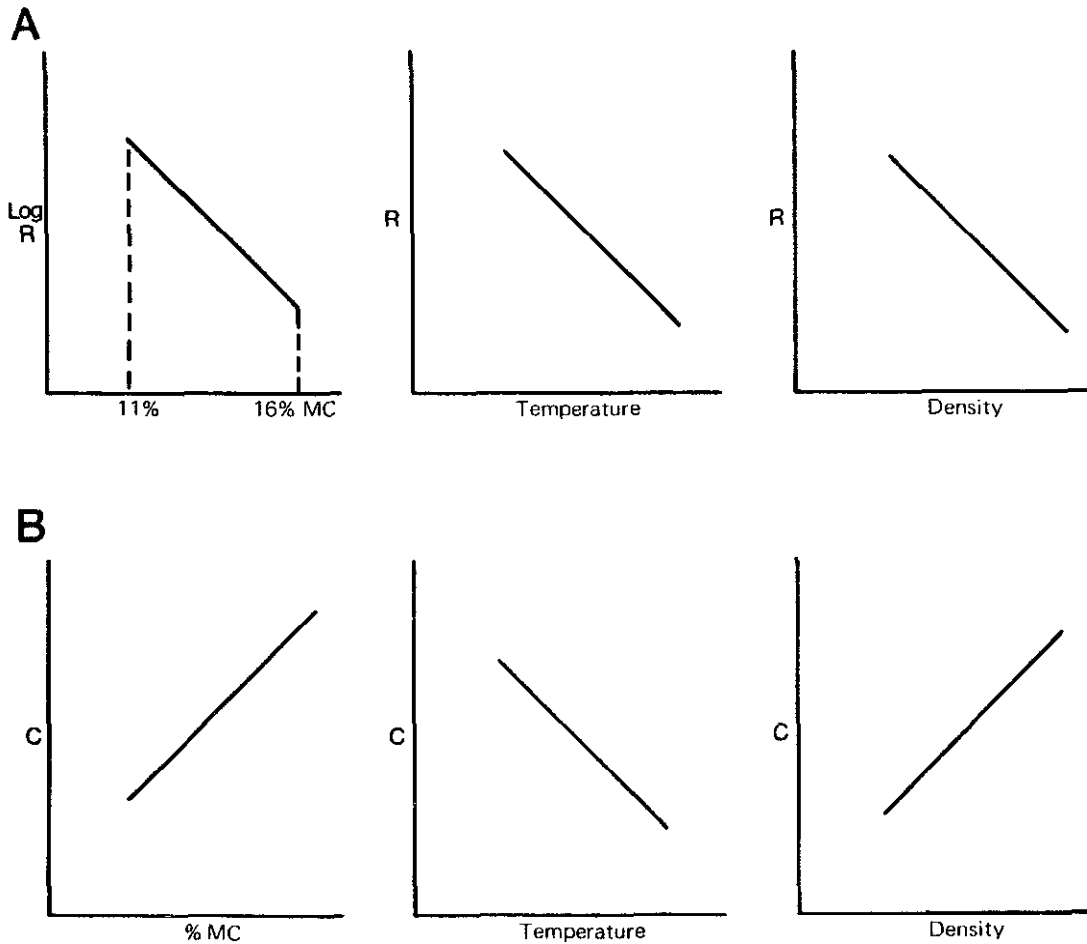
FIG. 63. Indirect methods of determining percentage moisture content by measuring changes in the electric properties of the grain: (A) resistance method; (B) dielectric method.

trical resistance of the grain at a given compaction, which varies with temperature, moisture, degree of compaction, and cleanliness of the grain (Fig. 63A). The readout device gives the moisture content on a wet basis.

Dielectric Method

The dielectric properties of grain are also dependent on moisture content. In the Steinlite Moisture Meter the grain is placed between two capacitor plates and the measured capacitance varies according to the amount of grain moisture, the degree of compaction, and the temperature (Fig. 63B).

The bridge or tuned circuits, which comprise the circuitry of these metres, can be serviced by competent electronic technicians. However, local dealers must carry an inventory of spare parts. It may be necessary to calibrate the electronic moisture metres for each type of rice grain or to each of the recommended varieties because the electrical properties of grain differ in different varieties.

Chemical Method

Water is removed from the sample by the addition of chemicals that either decompose or combine with the water. Calibration curves are established for the quantity of gas produced or the decrease in the weight of the sample due to the chemical reaction, and they are used to calculate the amount of water originally in the sample. The chemical reaction for one method is:

Calcium carbide + water →
Calcium hydroxide + acetylene
$$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$$
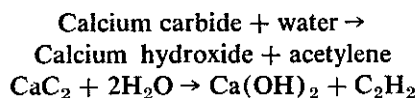
Hygrometric Method

The sample of the grain is placed in a sealed container and allowed to equilibrate with the air in the container, which has a known relative humidity and temperature. The relative humidity of the air when it is in equilibrium with the sample gives a measure of the initial moisture content of the sample. — D. B. DE PADUA. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Principles and Systems

Threshed rice with hull (palea and lemma) is called palay, rough rice, or paddy. Rice grain dehulled by milling is termed milled rice. Paddy storage requires special precautions because it is not an inert product, but a living, respiring biological product. Unfortunately, this very important property of paddy is often unknowingly overlooked in the design and operation of grain drying and storage systems. The respiration process in the grain is externally manifested by decreases in dry weight, utilization of oxygen, evolution of carbon dioxide and moisture, and release of energy in the form of heat. The respiration rate is influenced by the degree of dehydration of the tissue (Fig. 64). Thus, one method of preserving or suppressing the biological deterioration of paddy is to reduce grain moisture by drying. At low moisture content (13–14%), the grain is relatively dormant and can be stored for long periods under proper conditions.

In traditional rice production, when yields averaged 30–40 cavans/ha, the old methods of harvesting, threshing, sun drying, and sack storage of grain were adequate for Philippine farmers. However, the picture changed with the introduction of the new high-yielding varieties and an aggressive irrigation program that led to extraordinary increases in yield. Today's farmers may have to use grain driers to enable them to dry their greater production.

Optimum Moisture Content for Storage and Milling

In the Philippines, the moisture content of newly harvested rice usually ranges from 20
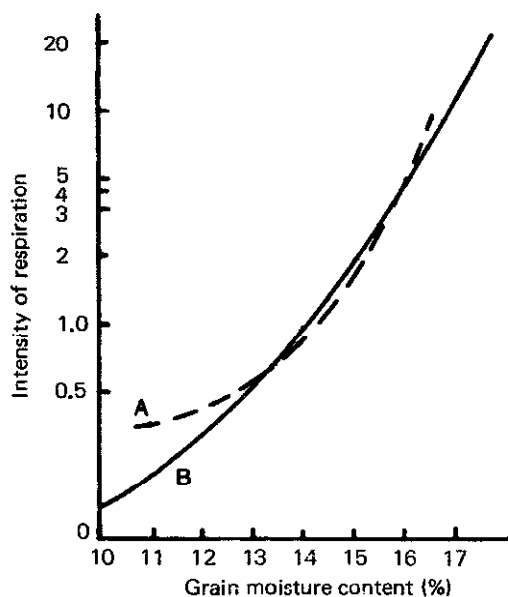
FIG. 64. Intensity of respiration of paddy grain in relation to its moisture content (at 37.8 °C). (A) C. H. Bailey and Cuyon; and (B) C. H. Bailey.

to 26%. These grains are too wet for milling and storage. The optimum content of 14% is considered the threshold value for safe storage. For prolonged storage of over 6 months grain moisture should be reduced to 13%.

Researchers estimate that about 10% of the crop is lost if the grains are left in the field to dry down to 14–16% before they are harvested. Thus, farmers may lose a considerable portion of their produce unless they use more efficient postharvest practices. Other advantages of the use of grain driers are: (1) the drying operation can be controlled more accurately, and thus, the moisture content of the grain can be reduced more closely to the levels necessary for milling with maximum head rice recovery and effective preservation of seed viability; (2) drying can be done in foul or fair weather; and (3) farmers can plan the harvest season for more efficient use of available labour.

The Hygroscopic Nature of Grain

Crop grains are hygroscopic in nature. This means that grains become wet or dry depend-ing on the temperature and relative humidity of the surrounding air. If the vapour pressure of the moisture within the grain is higher than that of the moisture in the atmosphere, the grain will lose its moisture to the surrounding air. In effect, then, the grain undergoes a drying process. Conversely, if the grain is dry and the surrounding atmosphere is wet or humid, the reverse process will occur and the grain will gain or absorb moisture.

Relative Humidity and the Drying Process

The actual vapour pressure of the air relative to saturation is called relative humidity (RH). Relative humidity is expressed as a percentage. In the common convection process of drying, the air must have a relative humidity low enough to absorb moisture from the grain.

A simple method of lowering the relative humidity of the air is heating. Increasing the temperature of air by 11 C° will reduce the relative humidity to half its original value. For example, if air with a temperature of 29 °C and a relative humidity of 90% is heated to 41 °C, the relative humidity will drop to 45%. Air with 45% RH and 41 °C temperature stabilizes moisture content of paddy at about 8%. This means that when paddy with a moisture content higher than 8% comes in contact with air heated to 41 °C, the paddy will lose some of its moisture or will dry until its moisture content is 8%. When in contact with the wet grain, the heated air raises the temperature of the grain and increases the vapour pressure of the moisture within the grain. The heating hastens the transfer of moisture from the grain to the heated air.

The drying rate is, therefore, influenced by the following factors: (1) the temperature of the drying air; (2) the relative humidity of the drying air; (3) the availability of moisture at the surface of the grain where it can be evaporated; and (4) the velocity of the air moving through the grain mass.

A convection drying system is composed of: (1) a method of heating the drying air; (2) a blower to force the heated air through

the grain mass; (3) a device to hold the grain being dried; (4) a system for loading, moving, and unloading the grain on the holding device; (5) a central system for programming the drying process for the prevention of damage to the quality of the grain; and (6) a safety control network.

Heating the Drying Air

Theory of Combustion

The combustible matter in the various heating fuels is composed of carbon, hydrogen, and sulfur. Combustion is the chemical combinations of the fuel elements with oxygen. The equations for combustion are:

$$C + O_2 \rightarrow CO_2$$
$$2C + O_2 \rightarrow 2CO \text{ (partial combustion)}$$
$$2H_2 + O_2 \rightarrow 2H_2O$$
$$S + O_2 \rightarrow SO_2$$
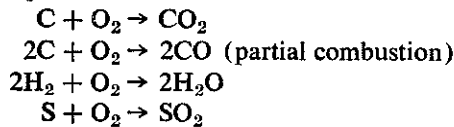
The weight of oxygen required for complete combustion is:

$$W_o = 2.67\,C + 8\left(H - \frac{O}{8}\right) + S$$

where: W_o = weight of oxygen (lb/lb of fuel).

Values of C, O, H, and S are obtained directly from the ultimate analysis for solid and liquid fuels; however, for gaseous fuels a conversion from the volumetric analysis is required.

Because O_2 is rarely supplied in a pure state, but is generally supplied as a constituent of air, it is necessary to include the nitrogen weight to obtain the total products of combustion.

$$W_a = 11.5\,C + 34.5\left(H - \frac{O}{8}\right) + 4.32\,S$$

where: W_a = weight of air (lb/lb of fuel).

In actual practice, an excess amount of air greater than W_a is required.

$$\text{Excess air (percentage)} = \frac{(W_A - W_a)}{W_a} \times 100$$

where: W_A = actual amount of air supplied per pound of fuel.

The volume of air corresponding to W_A or W_a for any air temperature and pressure is found by the gas equation:

$$V = \frac{(W_A \text{ or } W_a)(53.3)(T_a - 460)}{144\,P_a}$$

where: V = air volume (ft^3); T_a = temperature (°F); and P_a = air pressure (psi, absolute).

In the case of gaseous fuel, the weight or volume of air is expressed in terms of cubic feet rather than pounds. The previous equations have been developed on the basis of 1 lb of fuel (gas, liquid, or solid) for which the density of the fuel-gas mixture is needed. If not known, it can be obtained from the molar relations by:

$$D_m = \frac{MW}{359(14.7/P_m)(T_m + 460)/492}$$

where: D_m = density of fuel-gas mixture (lb/ft^3); P_m = gas pressure (psi, absolute); T_m = gas temperature (°F); and MW = molecular weight of gas mixture.

The combustion process does not go to completion at high temperatures. Even while the combustion reactions are proceeding, the resultant products dissociate to a certain degree into other components. Thus, the equilibrium equation,

$$CO + \tfrac{1}{2}O_2 \rightleftharpoons CO_2$$
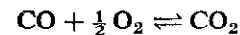
shows that the reaction may proceed in both directions at the same time. At a given condition of temperature and pressure, an equilibrium among the gases is reached so that the amounts of CO, O_2, and CO_2 present will remain constant. The extent of dissociation of the CO_2 will give an indication of the degree of completeness of the combustion. Just as heat is released in the exothermic process of forming the CO_2, much of the heat is absorbed when the CO_2 is broken down into CO and O_2. Thus the dissociation reactions of combustion products are endothermic, and the theoretical combustion temperature can never be attained if dissociation exists.

Heaters

Heaters are divided into two types based upon the method of heat transfer: (1) direct;
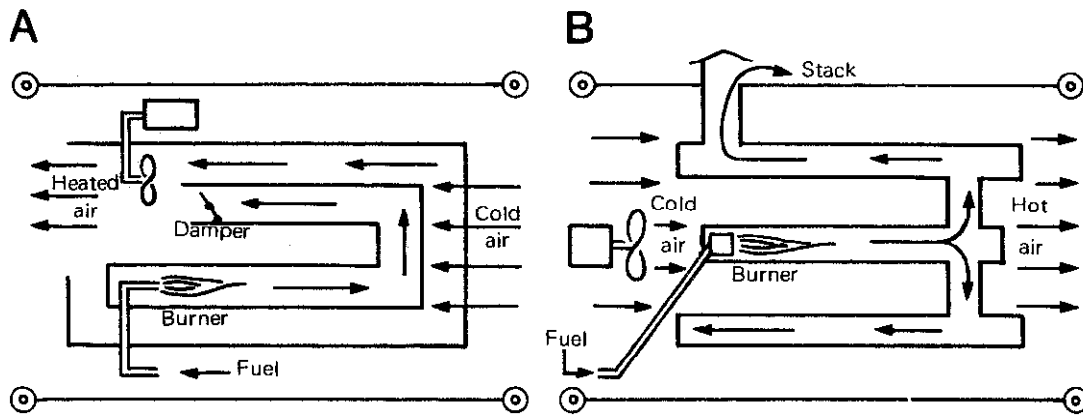
FIG. 65. A. Direct burner in which the products of combustion are mixed with the drying air. B. Indirect burner that uses a heat-exchanger surface to ensure that soot does not get into the drying air.

and (2) indirect. In a direct heater the products of combustion are forced through the product with the drying air (Fig. 65A). The direct heater is less expensive and makes more efficient use of the energy of the fuel; however, there is a greater possibility that the grain may be damaged by smoke. In the indirect heater a heat transfer surface is heated and the air that is used for drying is circulated around the outside of the heat transfer surface and then through the product (Fig. 65B). The products of combustion are removed and not permitted to mix with the drying air.

Types of Burners

There are three kinds of burners used in grain driers: (1) gas; (2) oil; and (3) solid fuel.

Gas Burner

Gas burners operate on the principle that a part or all of the air for combustion must mix with the gas before ignition. A burner is high pressure if the gas is at 350–2800 kg/m² (0.5–40 psi) pressure. Atmospheric burners that use gas at pressures of 5–30 cm (2–12 inches) of water are more popular because of their simplicity. The principle is the same as that of a Bunsen burner. Figure 66 shows a typical atmospheric burner. Gas is a very convenient fuel to use, complete combustion is easily attainable, and it does not emit objectionable odours. However, in general, gas burners are more expensive to operate.

Oil Burners

There are many types of oil burners that can be used to heat drying air. The burners for industrial oils No. 1 and 2 are provided with either a positive gear pump or a pressure tank containing the fuel. The tank is connected to an air compressor to force the fuel through an atomizing nozzle at pressures from 2800 to 7000 kg/m² (40 to 100 psi). The primary air for combustion is provided by the draft of the main blower or by a built-in auxiliary blower. For more complete combustion, some means of controlling the secondary air is sometimes provided. Gravity flow or vapourizing-pot type burners are suited for kerosene or any liquid fuel with an end point not over 316 °C (600 °F). This type of burner is used on many of the driers employed in the Philippines because it is simple and reasonably cheap (Fig. 67). The liquid is metered to the pot by an adjustable needle valve. As the fuel flows out over the bottom of the pot, it is evaporated by radiant energy received from the combustion chamber walls and the flame. The vapours rise in the pot and mix with primary air flowing through the holes in the bottom of the pot. When the burner is operating normally, the fuel-air mixture near the bottom of the pot is too rich to support combustion. The flame
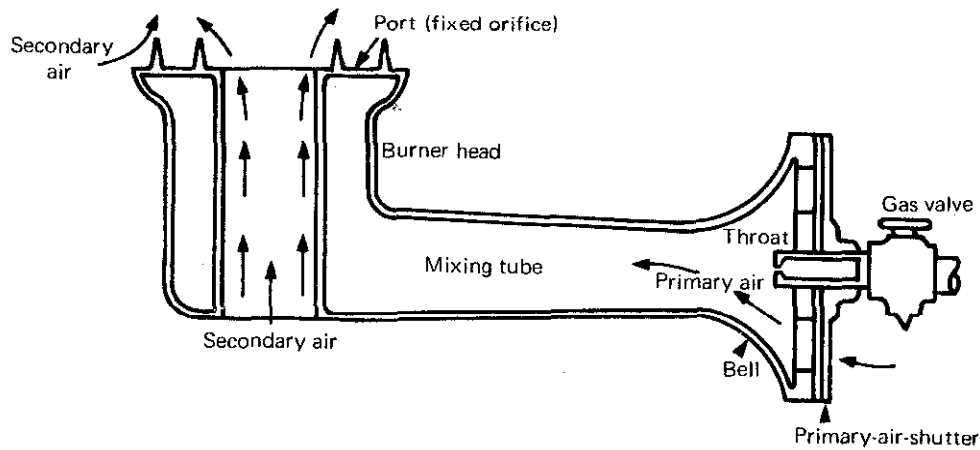
FIG. 66. A typical atmospheric gas burner showing the main parts.
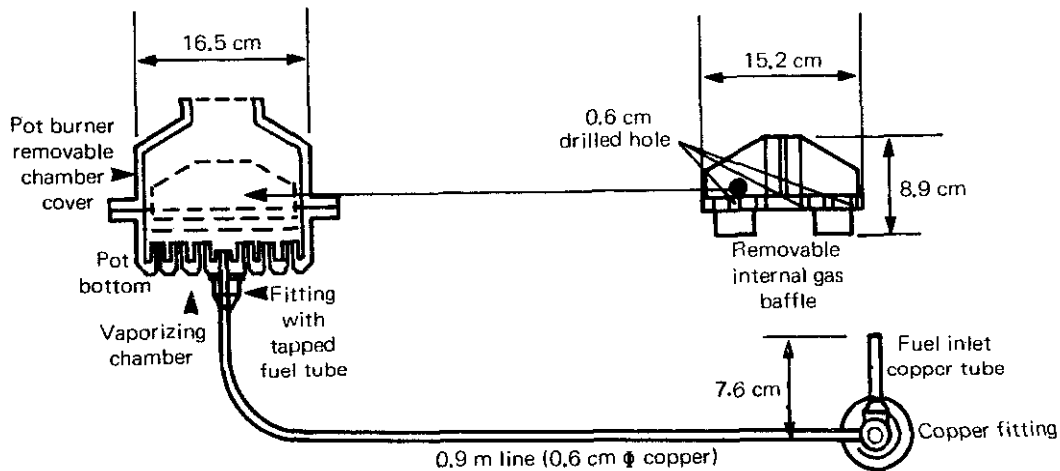
FIG. 67. Section details of kerosene pot burner showing fuel control.

rises to a position above the rim, and at this point enough air is mixed with the vapours to give a good burning mixture.

Burners for heavier oil must use a heat-exchanger surface because the oils produce a lot of soot. Roughly, the heat transfer efficiency is directly proportional to the size of the heat exchange surface. Because of limitations in physical size, heat exchangers sold on the market have a heat utilization efficiency of about 40%. This low efficiency reduces the advantage derived from the low cost of fuel oils.

Solid Fuel Burners

Burners have been designed to burn rice

hull, which is a waste product from milling. Rice hull liberates about 3500 kg-cal/kg (6274 Btu/lb) when burned. About 20 kg of hulls would be enough to dry 1 t of paddy from 20 to 14% moisture content. About 100 kg of paddy would yield 20 kg of hulls. However, temperature control is critical in grain drying, and controlling temperatures in furnaces that use raw fuel is difficult without the use of steam boilers.

Other Possible Heat Sources

Other possibilities worthy of investigation are the harnessing of heat from hot springs and the utilization of engine heat, including
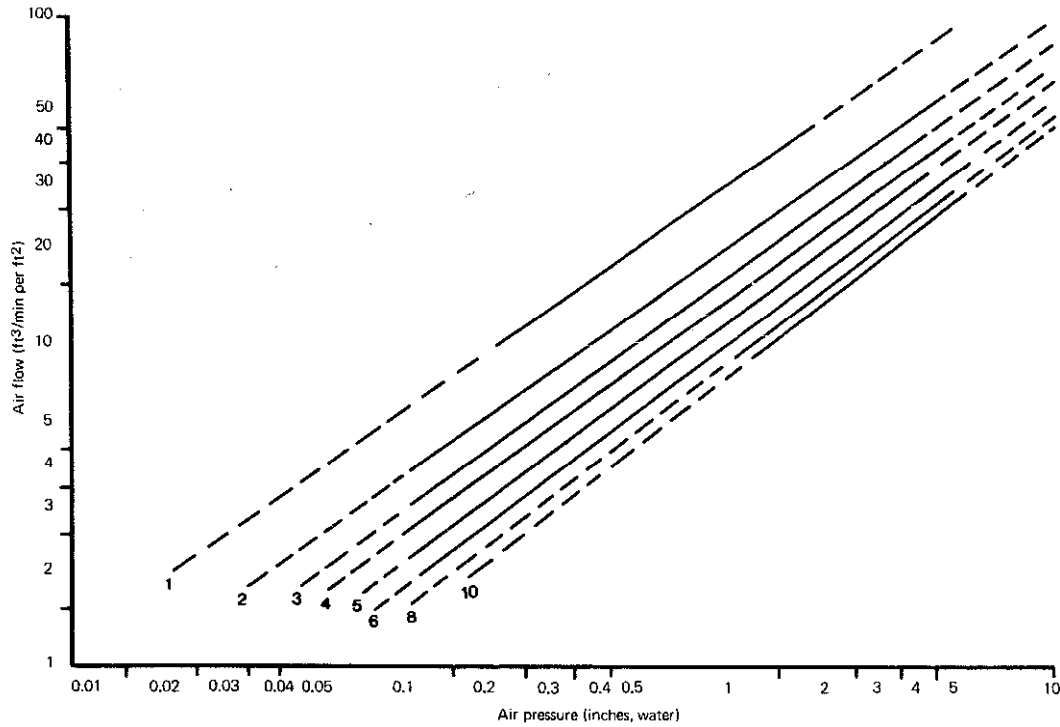
FIG. 68. Air pressure requirements to achieve a desired flow of air through different depths of clean rough rice. Note that broken lines are extrapolated beyond test data reported. Numbers on lines correspond to depth of rice in feet.

exhaust gases of gasoline and diesel engines. Where hot springs may be tapped, the design of the heat exchanger coils is straightforward and should not be a problem. Engine heat and heat from the exhaust gases may be utilized to drive the main blower. Calculations indicate that the energy available from engine heat and exhaust gases is not enough for multipass thin-layer drying; however, it can serve as supplemental heat to reduce the cost of drying. It takes about 8800 g-cal/min (35 Btu/min) to heat an airflow of 28 m³/min (1000 ft³/min) from 30 to 40 °C (85 to 105 °F) at 80% RH.

Blowing the Heated Air

In the drier, the grain pack is dense; therefore, pressure is required to force the drying air through the grain. Pressure requirements are proportional to the desired airflow rate and the thickness of the grain pack. The pres-

sures in grain drying systems are relatively low and are measured as the number of centimetres or inches of a water column that the pressure can support. A grain bed 30 cm (1 ft) deep that needs an airflow rate of 6.5 m³/min per square metre (20 ft³/min per square foot) of bed requires a pressure of 1.3 cm (0.5 inches) of water (Fig. 68). In computing the total pressure requirement, the pressure losses in the manifolds in the entrance to the pressure chamber and in the blower itself must be taken into account. To make allowance for pressure losses, specifications for blower capacity should be increased by 100%. Ordinary room fans cannot be adopted for grain drying purposes because they are designed merely to move large volumes of air at zero static pressure; therefore, special fans must be used. Fans may be placed into one of two general classes: those that operate by centrifugal force, or radial flow, where the flow is perpendicular to the axis of rotation; and those that operate

A

Centrifugal type

Forward curved

Radial

Backward curved

B

Propeller type   Tubeaxial type   Vaneaxial type

guide vane
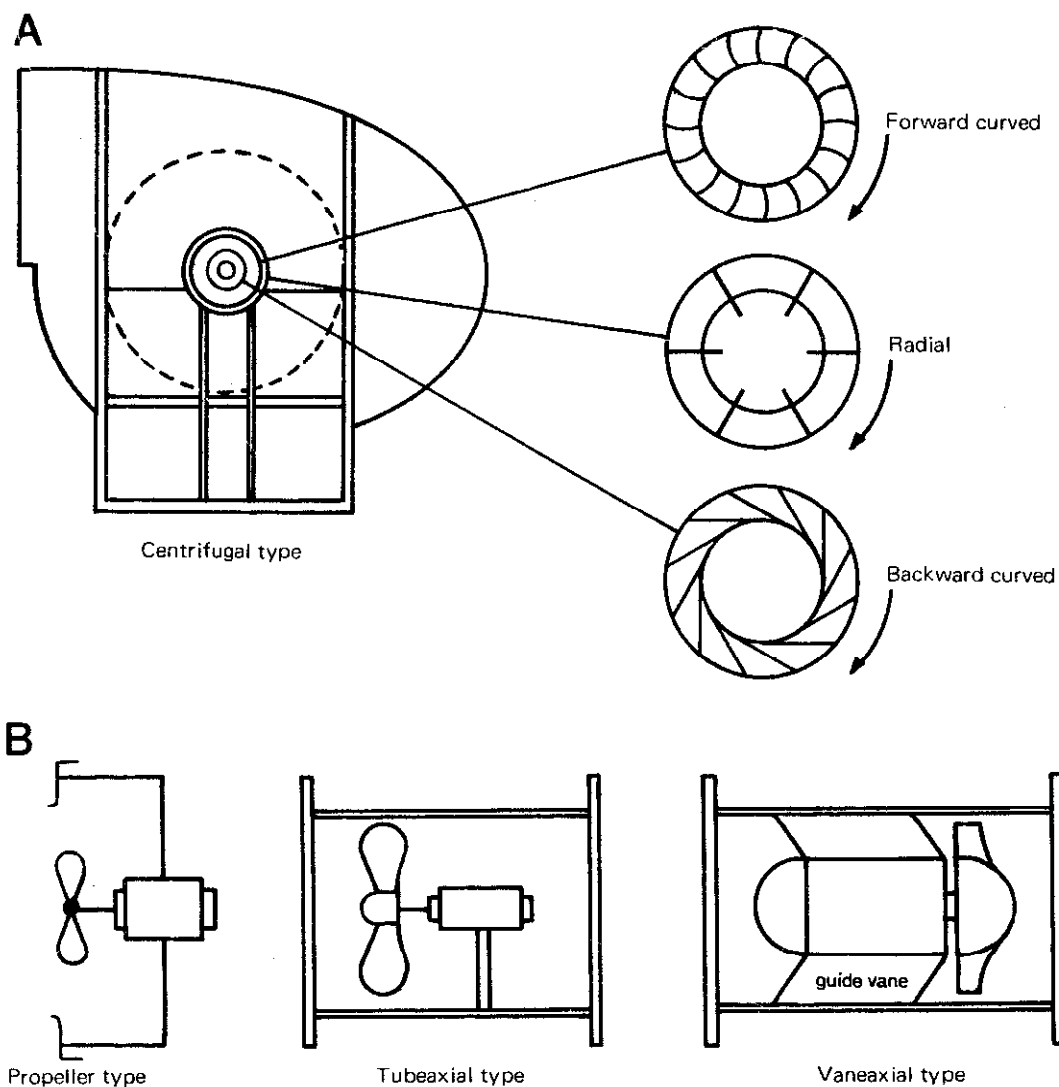
FIG. 69. Different types of fans. A. Centrifugal-type fans illustrating forward-curved, radial, and backward-curved designs. B. Axial-flow fans illustrating propeller type, tubeaxial type, and vaneaxial type.

by axial flow where the flow is parallel to the axis of rotation of the fan blade.

Centrifugal Fans

Centrifugal fans consist of a wheel that is rotated in a spiral housing (Fig. 69A). The three basic types are: (1) forward curved fans, which have 24–64 blades inclined in the direction of wheel rotation; (2) radial blade fans, which have 4–24 blades that are radial elements of the wheel; and (3) backward blade fans, which have 8–16 blades inclined away

from the direction of rotation. These blowers are capable of developing the high pressures required to drive the drying air through the grain mass. The backward curve blowers are preferred because they have more stable operating characteristics, i.e. the power requirement does not tend to overload the drier should there be a change in the load or the bin is emptied. Forward curve blowers may burn out unprotected electric motors.

Axial Flow Fans

There are three distinct types of axial flow

fans (Fig. 69B): (1) propeller fans, which have two or more blades mounted on a hub and set at a pitch of about 15 degrees; (2) vane-axial fans, which have large hubs and short blades, are mounted in a cylinder, and have stationary straight vanes to prevent rotation or swirling of the air; and (3) tubeaxial fans, which are similar to the vaneaxial fans except that they do not have guide vanes.

Propeller fans with multiple blades are used in driers operating at low pressures. Normally pressures of up to 1.9 cm (0.75 inches) of water can be developed with these fans and they are used in small portable drying systems.

Grain-Holding Bins

Grain-holding bins may be designed for either batch-type drying or continuous-flow drying.

Batch Type

Deep-Bed Drying

Deep-bed drying is usually employed in on-the-farm drying, in which case the bin doubles as a storage unit (Fig. 70). The air-distribution system is usually a false floor covered with a screen mesh. Airflow rates per cubic foot of grain are low and are based on the minimum values required to prevent spoilage of the grain in the grain holder. The airflow rates are based on minimum requirements because a large amount of power is required to develop the high pressures necessary to force a large volume of drying air through the grain.

The biggest difficulty in deep-bed drying is that the bottom layers may be over-dried. To minimize this difficulty, drying air with a low temperature must be used. The layer of grain, where the drying air enters, dries down approximately to the equilibrium moisture content corresponding to the temperature and relative humidity of the drying air. A drying front, which moves in the direction of the airflow, is thus established. It is desirable that the drying front moves quickly enough to reach the top layer before moulding occurs. The rate of movement of the drying front is controlled by the velocity of the drying air.
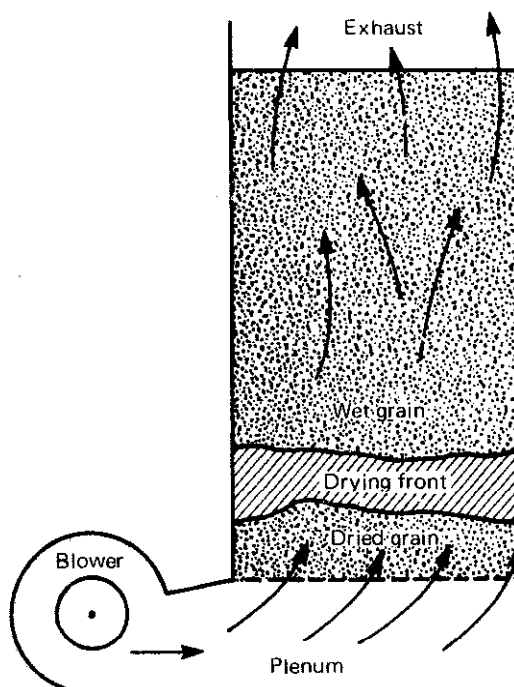
Fig. 70. Deep-bed drier.

Thin-Layer Drying

The thin-layer batch-type drier is similar to the deep-bed drier except that the surface area of the drier is increased and the depth of the drying layer of rice is decreased (Fig. 71). The main advantages of this drier are: (1) the whole batch is dried sooner so there is less chance of spoilage due to moulding; (2) there is less likelihood of over-drying of the grain; and (3) a lower air pressure is required to force the drying air through the rice.

Continuous-Flow Type

These driers are columnar in design. The rice flows by gravity from the top to the bottom of the drier, where it is discharged. The rate of discharge is controlled by metering rollers or oscillating rockers. If the rice flows in a straight path the drier is called a non-mixing type; if the path of the rice is diverted the drier is called a mixing type.
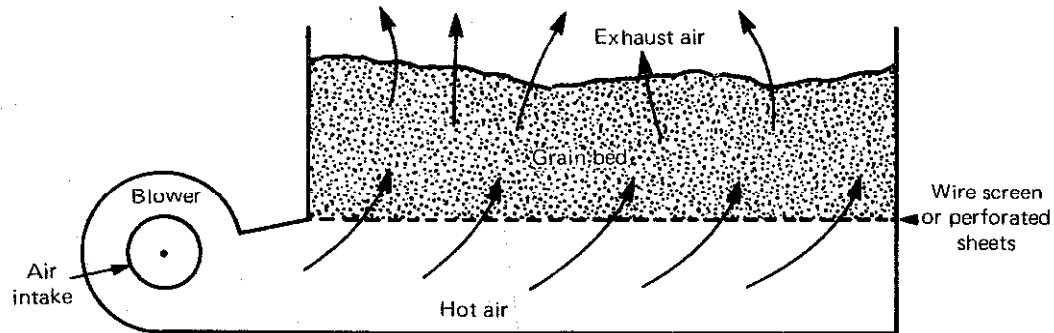
FIG. 71. Flat-bed drier.

Nonmixing Type

Two types of nonmixing driers are shown in Fig. 72 and 73. These driers are simple in design, and the drying takes place between two parallel screens that are usually 0.15–0.23 m apart. Since the grain cannot be blown out, comparatively high air velocities can be used. Because the grain flows straight down the column, the layer of rice closest to the input screen is dried by hotter and drier air than the layer of rice next to the exhaust screen. In this respect it is like thin-layer batch-type drying with the thickness of the layer equal to the separation between the screens. However, in this case mixing does occur when the rice is discharged and conveyed to the tempering and storage bins.

Mixing Type

Baffle Type. This drier is similar in design to the nonmixing-type columnar drier except that it is equipped with sheet metal baffles, which create turbulence and mixing (Fig. 74).

LSU Type. The Louisiana State University drier consists of a vertical compartment in which there are rows of air channels (Fig. 75). The air channels are shaped like an inverted "V." One end of each channel is open and the other end is closed. The rows alternate between hot air intakes and exhaust air outlets, and the alternate rows are staggered to provide mixing action.

In mixing-type driers, chaff and other light materials are blown out with the exhaust air, which improves the quality of the rice; however, if the air pressure becomes excessive

whole kernels will also be removed. As the rice descends in the drier it is mixed so that individual grains are not exposed to only the hottest air, but rather a combination of both hotter and cooler air. Because of this, mixing-type driers generally use higher air tempera-
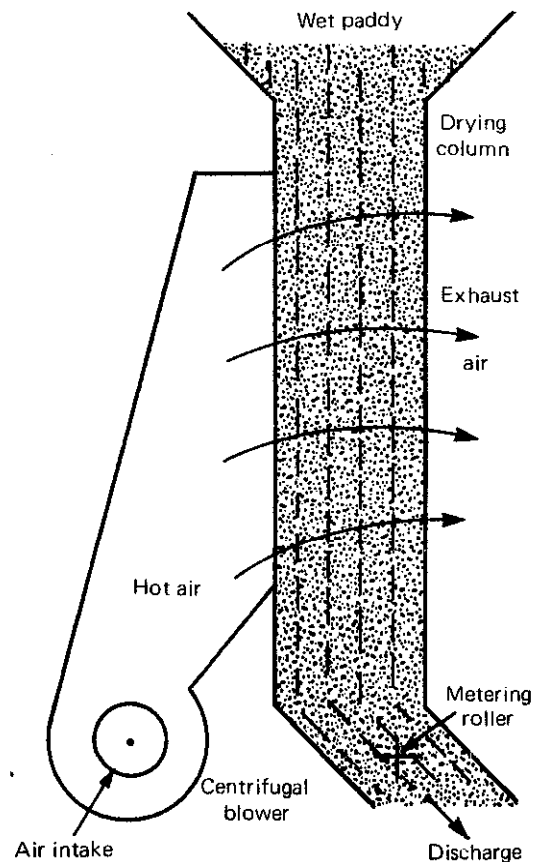
FIG. 72. Nonmixing-type columnar drier.
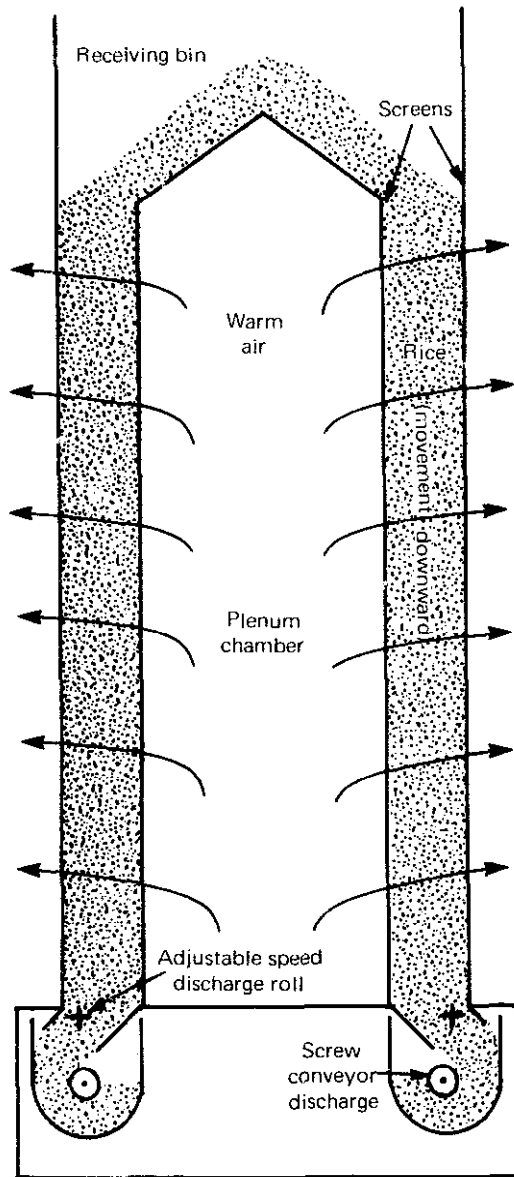
FIG. 73. Nonmixing-type columnar drier.
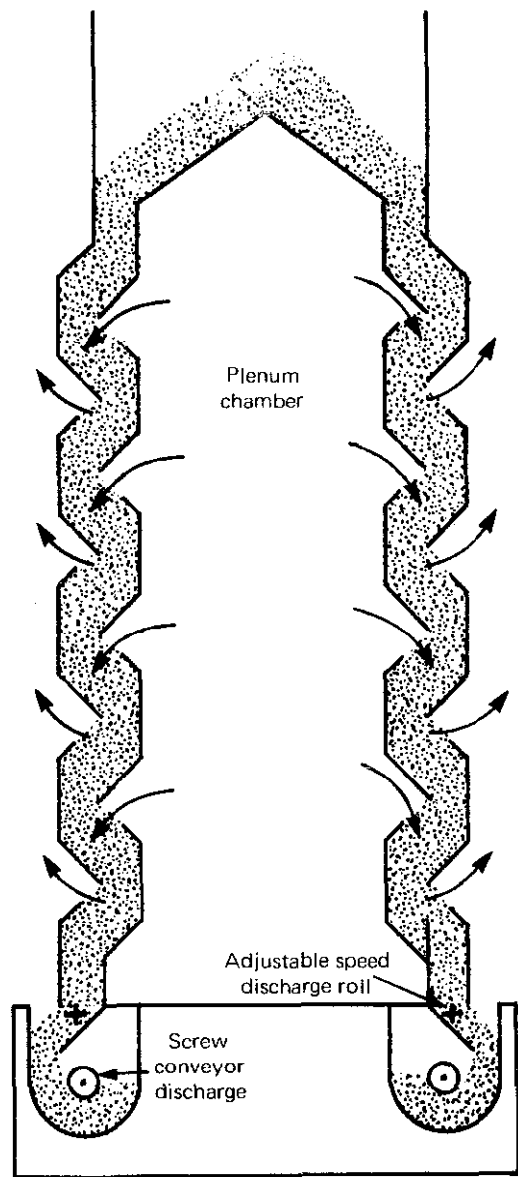
FIG. 74. Mixing-type columnar drier with baffles.

tures and lower air velocities than nonmixing driers.

Multipass Drying

In continuous-flow driers a multipass procedure is used to avoid excessive drying stress (Fig. 77). During each pass, the rice is exposed to the heated air for only a short time (15–30 min) and only about 2–3% of the moisture conten⁺ on a dry weight basis is removed. Between drying passes the rice is moved from the drier to a tempering bin where the moisture content within the grain is equalized. The tempering period usually lasts from 4 to 24 h, and during this time the moisture in the grain slowly moves to the surface. The reduction in the moisture content of rice as a result of multipass drying is shown in Fig. 76. Notice that the moisture content
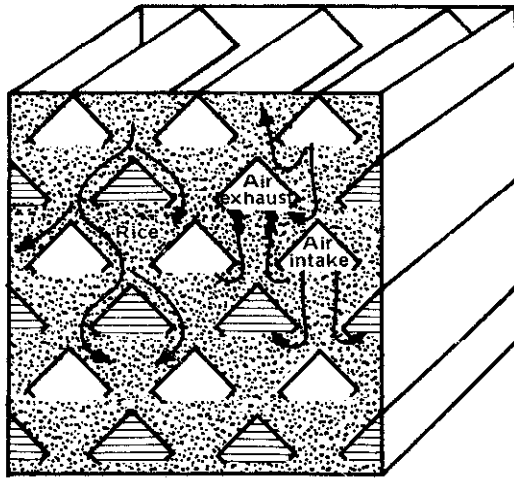
FIG. 75. Pattern of air and rice flow in LSU-type drier.
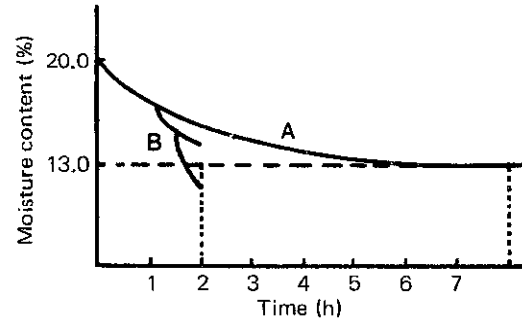
FIG. 76. Reduction in moisture content over time: (A) continuous drying; (B) multipass drying with three passes.
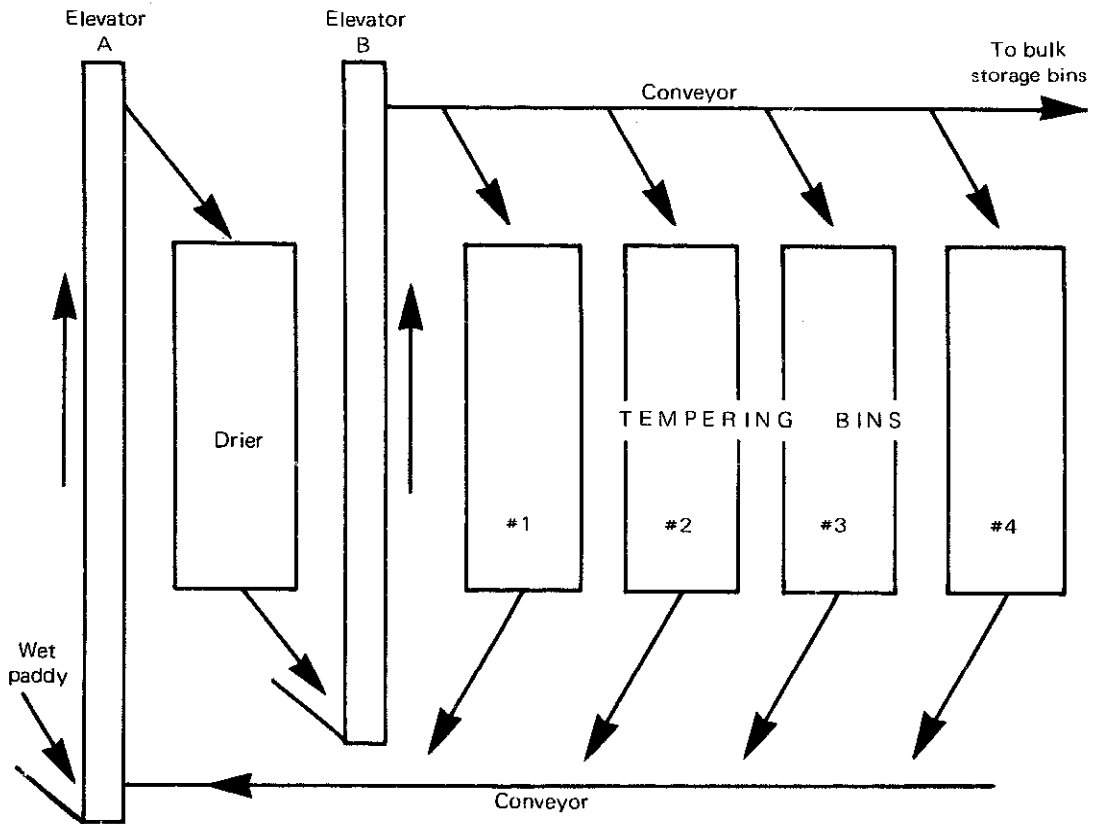
FIG. 77. Direction of flow and equipment required for multipass mechanical grain drying system.

is reduced to a lower level in a much shorter time. The multipass procedure is more efficient because the drier is used only when the kernel surfaces are relatively moist, as a result of tempering.

Figures 78 and 79 show the effects of drying temperature and the number of passes on head rice yield. Head rice yield increases with both an increase in the number of passes and a decrease in the temperature of the drying air. The best drying conditions, therefore, combine a relatively low drying temperature with a large number of drying passes.

Handling of Rice

Handling operations include weighing, sampling, dumping, and conveying. These operations are covered in other parts of this manual.

System of Programming

Proper management of the drying system requires: (1) drying in separate bins designed for drying with hot air; (2) preventing overdrying of part of the product, by using low drying temperatures and as thin layers as possible in a batch system or by regulating the rate of flow and number of passes in a continuous-flow system, to prevent cracking of the grain; (3) determining when the product is dry by using a moisture metre or measuring the time required to dry the grain; (4) cooling and tempering the grain after drying; (5) preventing condensation from accumulating on
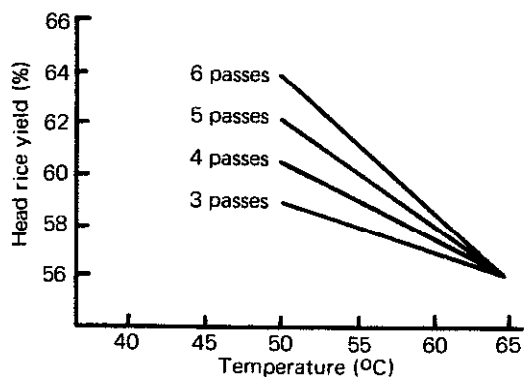
FIG. 78. Relationship between drying temperature and head rice yield.
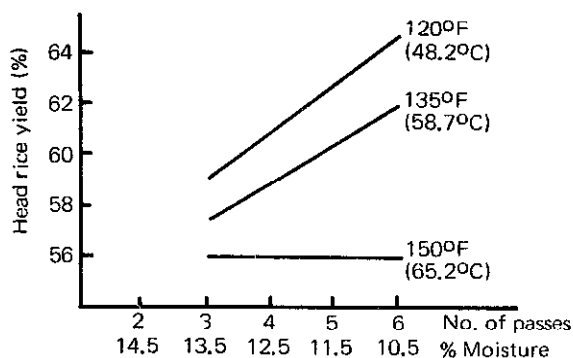
FIG. 79. Relationship between number of passes in drier and head rice yield.

the top layer of grain by providing adequate aeration; and (6) preventing mechanical damage to the product.

Safety

Burner

Burners designed for safe operation should include: (1) a flame control to turn off the fuel supply in case of ignition failure; (2) a high temperature limit switch that will stop the burner but allow the fan to run; (3) a temperature control to prevent overheating the heater; and (4) proper electrical wiring connecting the fan and burner to the electrical circuit. All control systems should be designed to fail "safe."

Installation

A properly designed heater can be used in an unsafe fashion. Safety features of the installation should include: (1) locating the fuel tank and pipes a safe distance from the burner flame; (2) protecting the fuel line from mechanical damage; (3) locating fuel tanks at least 5 m from all buildings; (4) refueling only when the drying unit is not operating or refueling a safe distance away from the drier; (5) separating the drying and storage facilities; (6) keeping batch driers at least 5 m from all buildings; and (7) connecting the burner to the drier by a duct made of flame-proofed canvas or other noncombustible material. — D. B. DE PADUA. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*
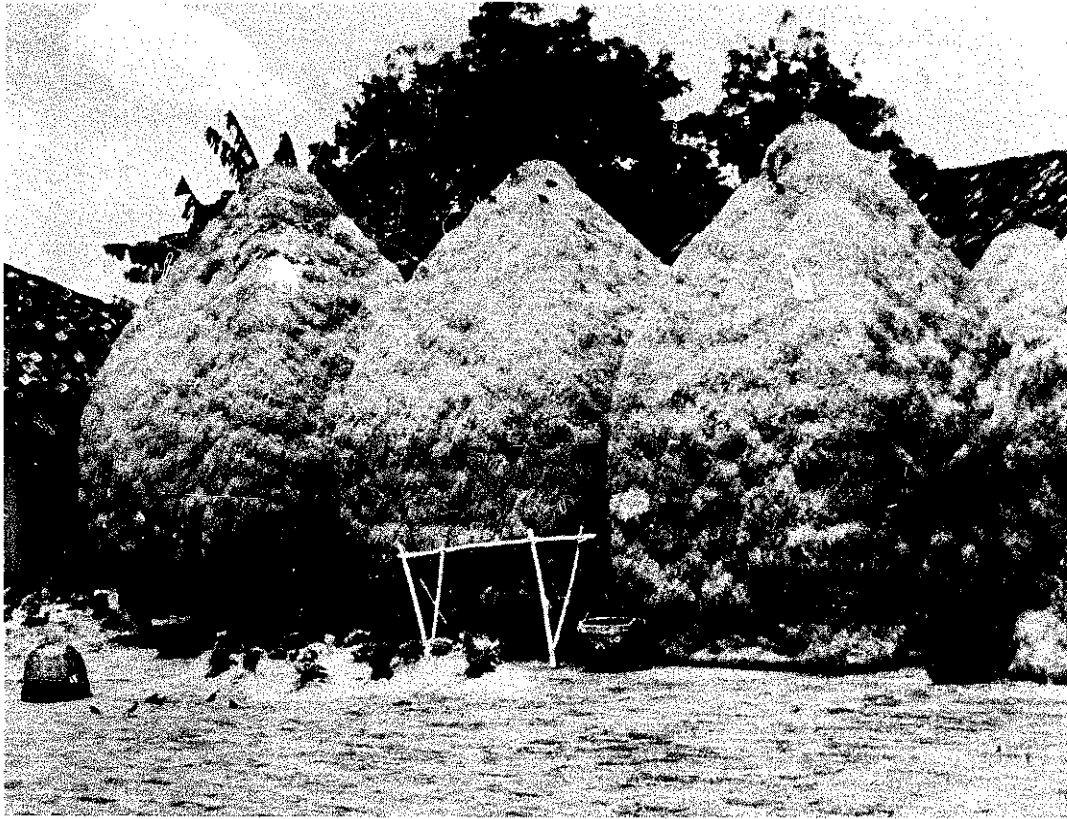
STORAGE

Constraints

Biological Considerations

Atmosphere and Water Relationships

The lower atmosphere of much of Southeast Asia is warm and moist with an average temperature of about 30 °C (85 °F) and an average relative humidity (RH) of 85%. This warm, moist atmosphere is of course subjected to intermittent solar radiation that alters its relative humidity. In certain areas, however, there is a distinct dry season with higher temperatures and lower average relative humidity.

The fundamental measure of air humidity is absolute moisture content, generally expressed as grams of water vapour per cubic metre of air. The water-holding capacity of air increases as the temperature increases. Figure 80 shows that at 10 °C (50 °F) air can accommodate about 10 g of water per cubic metre. If a saturated mass of air is heated from 10 to 38 °C (50 to 100 °F) it has a total moisture absorption capacity of 45 g/m³. In other words, the air contains 10/45 (22%) of the amount of water that it can hold at the saturation point, or its relative humidity is 22%.

In an atmosphere at 38 °C (100 °F) and 22% relative humidity, there is a strong tendency for the air to absorb water; this makes the moisture unavailable for absorption by anything else that is present in the atmosphere. If the same atmosphere (still with 10 g of water per cubic metre) is cooled to 32 °C (90 °F), its relative humidity is 10/30 or 33%. Its tendency to absorb water is reduced and, therefore, the availability of water to substances or organisms is increased.

Figure 81 indicates the decrease in relative humidity, in an atmosphere of unchanging absolute water content, when the temperature is raised. Any organism living in the atmosphere, as it is heated, will experience increasing difficulty in acquiring water because of the increased tendency of the atmosphere to absorb moisture.

The Moisture Requirements of Microbial Saprophytes

The fungi (moulds) and bacteria that cause the spoilage of food are very exacting in their

FIG. 80. Levels of saturation of the vapour pressure (water content) of air at different temperatures.
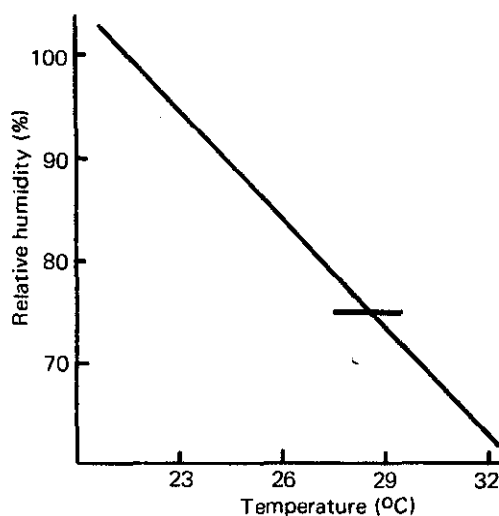
FIG. 81. The variation in relative humidity over a range of temperature in an atmosphere with a constant water content of 21.7 g/m³.

moisture requirements. The moulds, both Phycomycetes and Ascomycetes, generally have a lower limit of about 75% relative humidity for normal vegetative and sexual development. However, certain moulds, like the *Aspergillus* spp., may develop slowly at 10–75% relative humidity. The bacteria of food spoilage generally require a relative humidity of at least 90% for normal development.

Moulds and bacterial spores, where they occur, are resistant to much lower levels of relative humidity. In many moulds and certain bacteria, the vegetative bodies may also be resistant to desiccation. Therefore, if the atmospheric relative humidity is at a suitable level for mould development, it may be necessary not only to suppress moulds but to eliminate them. For instance, if a packed food containing resistant spores or mycelium is opened, but not entirely consumed, the remainder may quickly become contaminated.

The temperature requirements of microbial saprophytes may exceed the range of 10–38 °C (50–100 °F), but at no point in this range will they develop if the relative humidity is unsuitable. At the optimum temperature, which is about 27 °C (80 °F), development is most rapid if the relative humidity is suitable. In most of Southeast Asia it is necessary to contend with the fact that the normal temperature range includes the optimum for microbial saprophytes.

Relative Humidity and Moisture Content Equilibria in Foodstuffs

Most foodstuffs, and many other things such as salt solutions, characteristically lose or gain moisture passively until they are in equilibrium with the relative humidity of the surrounding air. At a particular level of humidity, different foodstuffs have different moisture content equilibria. Figure 82 shows the moisture content -- relative humidity equilibria for milled rice, paddy, and some other products. The practical significance of these equilibria is that, because mould development commences at relative humidities above 70%, it is important to know the equilibrium moisture content at 70% relative humidity of any food that is to be preserved by drying.

Biology

It is generally true that insects assume the temperature of the atmosphere around them; the loss of heat from the body approximately balancing the heat generated by metabolic processes. It is also a general rule that the metabolism of warm-blooded animals decreases (within limits) when the temperature increases; whereas, the metabolism of cold-blooded animals increases.

In insects the extra energy derived from temperature increases is often expressed in adults by more rapid movement and in the developmental stages by more rapid development. Within certain limits, the influence of temperature on insect development follows a pattern similar to that in chemical reactions, i.e. the rate increases as the temperature increases. The main difference is the complete cessation of metabolism at low and high temperatures, which results in death. For each species of insect, somewhere between its low and high temperature limits, there is an optimum temperature for development. Various criteria have been presented to measure this optimum, including: number of eggs laid; percentage viability; preadult development; and adult life span. From the food scientist's point of view, perhaps the most satisfactory criterion is the rate of increase of the population in question. The rate of increase is most useful in anticipating damage that may be caused by an observed infestation, especially when the damage per individual is known (Fig. 83). *Tribolium casteneum*, *Sitophilus oryzae*, and *Lasioderma serricorne* are all serious pests of food in the Philippines.

The importance of relative humidity in insect development is equal to that of temperature; the two are closely related. The retention of water is a ubiquitous problem for small land animals. In insects the loss of water from the body is mostly by evaporation through the cuticle and from the tracheal system. It has been proposed that the evaporation of water from a surface is proportional to the saturation deficiency of the air. In its most simple form the law may be expressed as: evaporation rate = saturation vapour pressure $\times$ (100 -- RH), at a particular temperature. However, some
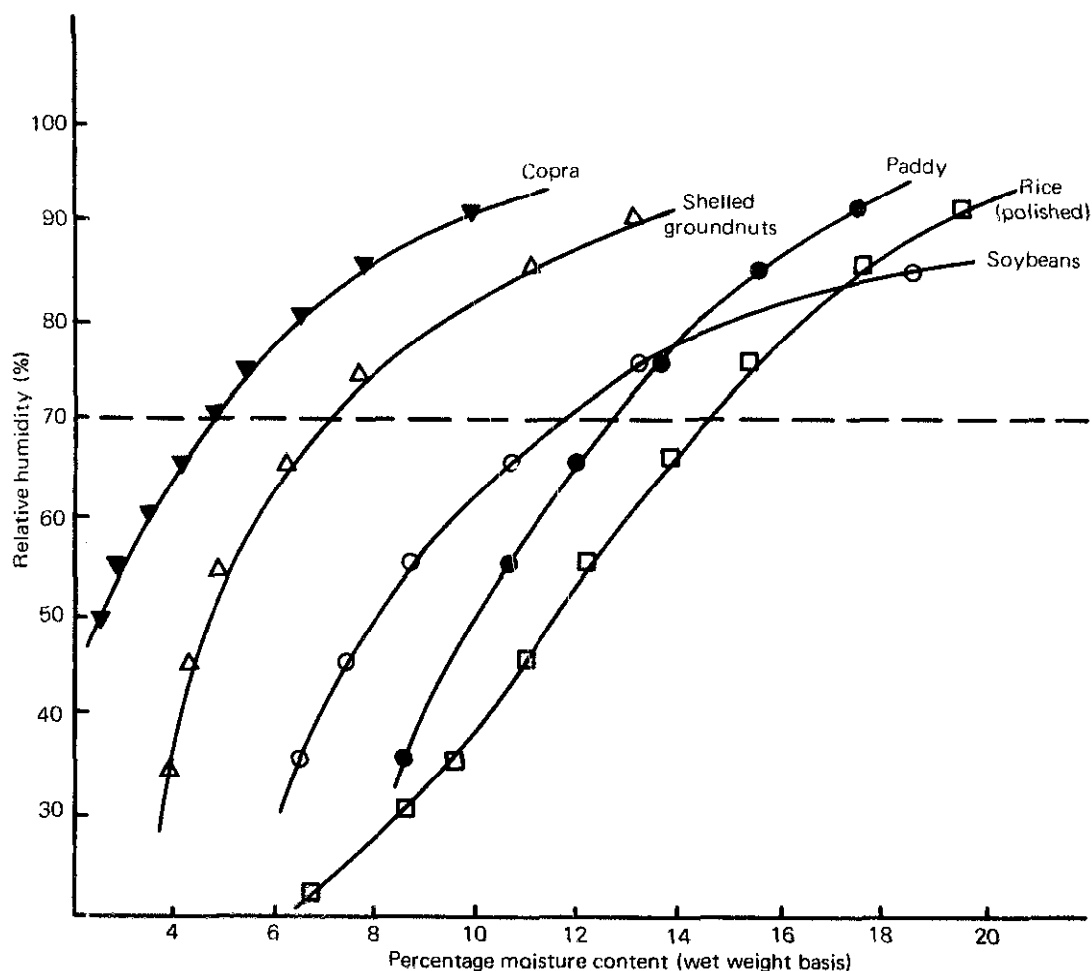
Fig. 82. Moisture content/relative humidity equilibration curves. Each curve has been compiled from results of several workers to present a guide to the moisture content/relative humidity equilibria values, which vary between varieties of the same species of food product. (By courtesy of Miss P. M. Davey, Tropical Stored Products Centre, England).

necessary deviations from this rule must result from: (1) the increase in permeability of insect cuticle with increased temperature; and (2) the increase in water diffusion with increased temperature when the saturation deficiency is the same. The shortening of the development period with increased humidity, at suitable temperatures, has been observed for many insect species.

Figure 84 illustrates the relationship between development period, temperature, and humidity. Saturation deficiency increases sharply with increased temperature, and insect development declines rapidly towards the

thermal death point of a particular species. Therefore, in an atmosphere of constant moisture (relative humidity decreasing with temperature rise), the optimum temperature for development is about the point where the product of development time and saturation deficiency is the lowest (intersection of lines A and B, Fig. 84).

In most of Southeast Asia the optimum conditions for the development of moulds and certain insect pests of food fall within the normal ranges of atmospheric humidity and temperature. It may be deduced that moulds would normally be prolific throughout South-
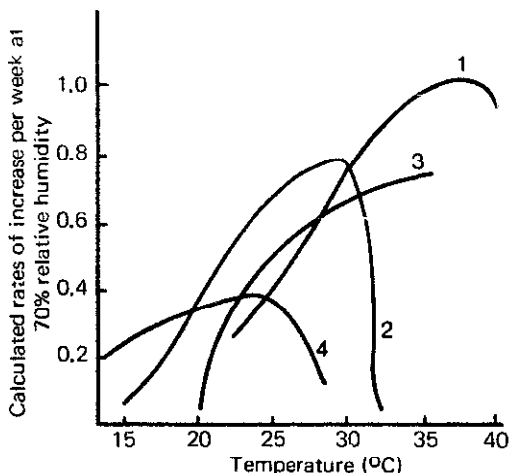
FIG. 83. The influence of temperature on the innate capacity for increase of insect pests of stored food: (1) *Tribolium castaneum*; (2) *Sitophilus oryzae*; (3) *Lasioderma serricorne*; and (4) *Ptinus tectus*.

east Asia except perhaps in the hot, dry seasons that occur in some countries and districts. Figure 83 indicates that the climatic data for Southeast Asia favour the development of *Tribolium*, *Lasioderma*, and *Sitophilus*; however, development of *Ptinus tectus* is very much restricted because the temperature approaches the death point of this species.

As may be expected from the climatic data, the spoilage of foodstuffs by microscopic moulds such as *Mucor*, *Rhizopus*, *Penicillium*, and *Aspergillus* is very common. In certain cases the moulds produce toxic substances, e.g. the production of aflatoxin as a metabolite of *Aspergillus flavus*, and the damage caused to foodstuffs is much more serious than can be calculated from the actual amount of weight lost. Because of the proliferation of moulds, including those producing myco-toxins, it is important to dry and safely store grain very soon after maturation of the crop. This is one of the factors that will increase the demand for mechanical drying in areas where sun drying is not possible. Timely harvesting followed by drying is also very effective in reducing the populations of insect species that attack grain in the field before and about the period of maturity, and that continue their life cycles over the storage period. This is
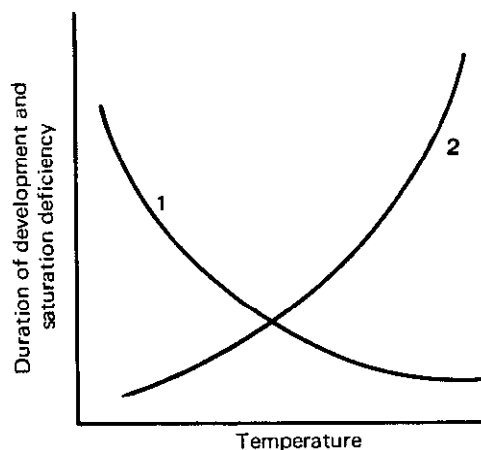

FIG. 84. Generalized chart to show the effect of temperature on: (1) duration of insect development; and (2) saturation deficiency of atmosphere.

particularly true of the grain weevil *Sitophilus oryzae*, which is tolerant of a very large range in moisture content (about 30% down to 9%). Also, the damage caused to mung beans by a number of bruchid weevils, such as *Callosobruchus chinensis*, can also be prevented to a large extent by timely harvesting and drying. This bruchid weevil also begins its attack in the field and continues during storage.

Principles Involved in the Application of Insecticides

It is a simple matter to kill insects in food, but without the proper precautions many undesirable side effects may result. Consideration of the principles involved in the control of insects with chemicals will automatically reduce risks and at the same time ensure the required control. Each practical problem will require individual consideration, and the following notes are simply offered as guidelines.

Residual Toxicity to Humans or Livestock

Many insecticides are toxic to humans as well as to insects. The comparative biochemical aspects of insecticidal action on mammals and insects will be discussed later. For the moment it may be stated that in some

cases there is a wide difference in toxicity; in other cases a dual toxicity but a different basis. For example, pyrethrins are highly toxic for most insects but weakly so to man; DDT is toxic to both. The toxicity is usually expressed as the lethal dose for 50% of the individuals being examined (LD_{50}). The limits of tolerance of insecticide residues in food are expressed as parts per million (ppm). Figures have been published from time to time by various authorities and, at the present time, the International Standards Organization is attempting to create a universal basis for tolerance limits. The first consideration in the use of an insecticide is to ensure that any residues are within the levels of tolerance.

Taint

Even in the absence of residual toxicity, there may in some cases be an off-flavour in the food caused by the insecticide. For example, benzene hexachloride (BHC) may cause a taint in the flesh and the eggs of poultry fed with treated corn, but the amount of BHC present may be less than the accepted tolerance limit.

Effect of Climate on the Insecticide

Many solid insecticides, such as BHC, melathion, and DDVP (2,2-dichlorovinyl dimethyl phosphate) are volatile and, especially at tropical temperatures, may quickly lose their activity. Others, especially pyrethrins, are easily broken down by strong light and by temperatures about 30 °C (86 °F). On the other hand, gases such as methyl bromide are much more effective at higher temperatures.

Differential Toxicity in Insect Life Stages

An insecticide may be highly effective against one life stage (i.e. egg, larva, pupa, or adult) but not against the others. Pyrethrins, 0.5% in oil fog, are highly effective against the adults of the moth *Cadra cautella*, but not against the larvae.

Formulation of the Insecticide

The base that acts as a conveyor for the active ingredient may play an important part in the toxic properties of the formulation. Malathion soon becomes inactive when applied as dust, but it is much more stable when treated with resin to inhibit volatilization. The carrier base itself, as well as restricting volatilization, may have a mechanical insecticidal effect. Light oil often used as a carrier for pyrethrins and other insecticides gives a 20% control of the grain weevil, *Sitophilus oryzae*, when used alone, and a 90% control with the addition of 1.0% pyrethrins. Possibly the female weevil is prevented from laying eggs on the grain surface because it is rendered slippery by a microscopic oil film.

Habits of a Pest in Rel.   Control

An insect in flight m   izing rapidly, may be more susceptible t   particular dose of insecticide than it would be when settled or walking. Being in flight may furthermore make it more accessible. The beetle, *Tribolium casteneum*, and the moth, *Cadra cautella*, are most vulnerable to spraying during their habitual dusk flights.

Parasitic Relationships

Whereas a particular chemical may be found in the laboratory to give a 90% control of a certain pest, it may in practice effect a 100% control on a parasite of the pest that was perhaps unobserved. The practical result might be an increase in the pest population. For example, the moth *Cadra cautella*, has a small hymenopterous parasite; *Bracon hebetor*, that attacks the moth larvae. Although a 0.5% oil solution of pyrethrins is very effective against the parasite, it has little control over the moth larvae. It was found that a spray application at 3-day intervals caused an increase of the pest because of the elimination of the parasite.

Effect of Insecticide on the Pest other than Direct Toxicity

The adult fertilized females of *Cadra cautella*, when knocked down and killed by any one of a large variety of insecticides, involuntarily discharge the eggs they contain. The

eggs are viable in the same proportion as those laid by normal females. Thus, an apparent kill of adults may not give complete control of the pest because the eggs may hatch and the population progress.

An insecticide used indiscriminately, for instance in too low a concentration, may result in the manifestation of a resistant strain of the pest by selection. A 10% initial survival of a pest may result in 100% resistance if the survival is due to an innate resistance of the pest. Several resistant strains of insect pests of stored products have already been found.

Seed Viability

Overdoses of fumigants may result in the loss of seed viability by actually killing the germ. This is most likely to happen in seeds with a high moisture content, because respiration is higher and chemical absorption is greater.

Interrelationship of Pest Species

Where two pests are present, control of one but not the other, if they were in competition, may only result in a dominance of the survivor. Laboratory tests have shown that the application of BHC to maize infested with *Sitophilus oryzae* and *Tribolium casteneum* causes a decrease of the former and an increase of the latter. There is also evidence that this has occurred in practice.

Some Comparisons in the Biochemistry of Insects and Mammals with Special Reference to Selectively Toxic Insecticides

Selective toxicity in medicine is already well known. Penicillin prevents the synthesis of the cell wall in bacteria by blocking the utilization of uridine nucleotide, a biosynthesis that does not occur in mammals. Sulfonamides block bacterial utilization of aminobenzoic acid, which is important to bacterial metabolism but not critical in mammalian metabolism.

In research on insecticides, consideration should be given to the possibility of selective toxicity, especially because there is now evidence of its existence. This is particularly important in countries where food losses are great and where the use of insecticides on foodstuffs appears to be inevitable. The subject is undoubtedly an extremely complicated one, and if it seems, from the extensive acceptance of insecticides, that man is less affected by them than are insects, it is mainly because he receives a smaller dose per unit body weight.

The study of selective toxicity can only proceed from an understanding of the differences and similarities in insect and mammalian metabolism.

Glycolysis

The respiratory quotients of mammals, and many insect species, indicate the use of carbohydrate and fat as primary and secondary fuels. The glycolytic breakdown of carbohydrate to pyruvate involves the formation of phosphorylated intermediates that have been found to have similar occurrence, for example, in the flight muscle of the housefly and in rat muscle:

	Fly	Rat
Adenosine triphosphate (ATP)	37.2	33.6
Adenosine diphosphate (ADP)	1.2	2.4
Phosphagen	10.9	33.7
Adenylic acid	6.9	3.2
Glucose-6-phosphate	7.8	5.2
Phosphoglycerate	20.8	2.9
Inorganic phosphate	15.2	15.3
Other compounds	0.0	3.7
Total:	100.0	100.0

The numbers represent the phosphorus in each compound expressed as the percentage of total acid soluble phosphorus.

Oxidative Metabolism

In mammalian tissue, pyruvate undergoes decarboxylation with the production of acetate that condenses with oxaloacetate and undergoes the Krebs cycle so that the initial carbohydrate is completely oxidized to carbon dioxide and water. The same metabolic pathways have been detected in the tissue of a

number of insect species, including houseflies, bees, and *Drosophila*. Furthermore, the physiological site of oxidative metabolism in mammals, the mitochondria, have their counterpart in the sarcosomes in insect flight muscle.

Amino Acid Metabolism

The amino acids essential to the growth of insects and mammals are similar. Aspartic acid, glutamic acid, alanine, and proline may be synthesized in insects by transamination reactions, and the intermediates of carbohydrate oxidation are the same as the glycogenic amino acids of mammals.

Although these and perhaps other remarkable similarities occur, there appear to be certain differences between the metabolisms of insects and of mammals that may be significant in selective toxicity.

Enzymes

The inhibition of acetylcholinesterases by organophosphorous compounds serves as an example. The enzymes of the housefly, honeybee, and mouse are all inhibited by parathion, but only the enzyme of the housefly is inhibited by the isopropyl analogue of parathion. This suggests that a specific molecular structure of the fly enzyme is different and allows access to the isopropyl analogue. Another enzymic difference is that the phosphagen of insect muscle is arginine phosphoric acid; in mammals it is creatine phosphoric acid. This suggests a different transphosphorylase that may be a point of selective toxicity. It is also conceivable that the enzymes associated with insect metamorphosis, being absent in mammals, may be a point of attack.

The insecticide malathion actually possesses a favourable insect to mammal toxicity ratio that has a biochemical basis. In living tissue malathion is converted to an anticholinesterase by enzymic oxidation. The pathway of P-labelled malathion injected into the hen, mouse, and cockroach clearly shows a selective toxicity. Detoxication and excretion of water-soluble metabolites of low anticholinesterase activity occurs in the vertebrates but not in the insect.

Other biochemical bases for selective toxicity probably exist although no relevant selectively toxic insecticide may yet have been discovered. For instance, insects require a dietary source of cholesteros for normal growth; whereas, in mammals it is synthesized from relatively simple metabolites. The blockage of cholesteros utilization by an antimetabolite in the insect diet is a possibility for selective toxicity.

Control of Insect Pests of Stored Food

Some similarities in the biochemistry of insects and of mammals have been discussed. These similarities should remind the food scientist to exercise caution in the use of insecticides. Also discussed were some possibilities and one known example of selective toxicity in insecticides, based on biochemical differences between insects and mammals.

There is clearly no long-term future for the use in stored food of insecticides that are also toxic to humans. The purpose of these notes is to discuss the types of chemicals and treatments that may be useful and relatively safe for the time being, and other possible methods of insect control that may provide a basis for development in this field.

Killing of Insects by their Ingestion of Poisonous Substances

About a century ago copper acetoarsenite (Paris green) was used as an insect stomach poison to control the Colorado potato beetle. Paris green and other arsenic compounds, fluorine compounds, and various organic compounds are used as insect stomach poisons in agriculture and against domestic insect pests. Although such poisons have been used in food stores, this practice is rapidly disappearing.

Insecticidal Action by Contact of Poisonous Substances with the Insect Integument

The insect cuticle is so permeable to a wide range of chemicals that when applied to the surface of the insect they produce their symptoms in almost the same degree as if they were injected. Insecticides applied to the insect sur-

face may enter the blood stream, nerve centres, or both. Contact insecticides are normally classified as: plant derivatives, e.g. pyrethrins, nicotine, and rotenone; or synthetic organic compounds, e.g. chlorinated hydrocarbons (DDT, BHC), organophosphorous compounds (malathion, DDVP), and carbamates (sevin, isolan).

These contact insecticides are at the present time used extensively in the food industry as: applications to the structures of food stores; space sprays in food stores; applications to packaging materials; and direct applications to foods such as cereal grains, legumes, fruits, root crops, and oil seeds. These insecticides are formulated as solutions, emulsions, dispersible powders, dusts, granules, and resins. They all possess some degree of toxicity to mammals, and quite clearly they cannot be used as direct applications to such finished foods as flour, cereal grains, and meals.

For direct application to unprocessed food, the most useful contact insecticides are those that possess the lowest mammalian toxicity, a secondary consideration being their stability in response to atmospheric moisture, heat, and light. An excessive stability, of course, increases the hazard of residual toxicity, which is probably less a problem in the tropics than in temperate climates. Probably the only contact insecticides that are surviving the competition for direct application to food are pyrethrins, malathion, DDVP, and lindane (pure benzene hexachloride gamma isomer). Carbaryl (sevin), the recently introduced carbamate, may possibly be useful.

Insecticidal Action by the Application of Poisonous Gases to Infested Food in Enclosed Spaces

For treatment of infested flour, grain meals, and other finished food, fumigation with gases such as methyl bromide and phosphine is extensively employed. In the treatment of grain and legumes, fumigation has the special advantage that the intragranular stages of the weevils are killed.

Although fumigated foods may be freed from the fumigant by ventilation, diffusion, or forced extraction, there remains the risk of residual toxicity because the fumigants are to some extent irremovably absorbed into the food. A hot climate provides the advantages of both the well-established increased effect of fumigants at higher temperature and the higher rate of gaseous diffusion.

New and Possible Developments in the Control of Insect Pests of Stored Food

It is excusable to use toxic substances provided: (1) full precautions and scientific applications are adopted; (2) there is economic necessity; and (3) the possibilities for the control of insects without the use of toxic substances have been considered.

Airtight Storage of Grain. In grain storage bins that are *completely* airtight, respiratory exchanges of both the grains and the insects result in a depletion of oxygen and a high concentration of carbon dioxide in the intergranular space. Such an atmosphere is toxic to insects (the lethal factor is depletion of oxygen) and, to a lesser extent, to the grain. If death of the grain is not important, then this method may be useful.

Cooling and Heating. Most insect pests of stored food have low and high thermal death points. When a limited maintenance of these temperatures does not adversely affect the food, a safe method of control presents itself. High temperature is more effective than low temperature. Insect development is generally limited below 10 °C (50 °F) and above 45 °C (113 °F). Heated-air drying of grain is a very effective initial control method against all insect pests of stored grain.

Moisture Relationship. Certain foods, particularly cereals, may be dried to a moisture content too low for the development of pests. A moisture content on a non-fat basis of 8%, corresponding to a relative humidity of about 40% at 25 °C (77 °F), generally excludes grain weevils from development; however, *Trogaderma granarium* may survive these conditions.

Irradiation. Ionizing radiations (alpha particles, beta particles, neutrons, and gamma rays) have all so far been used either experimentally or in practice in insect control. Beta radiation has been used to kill beetles in flour

and in wood and plant tissues on a limited scale. Gamma rays in d sages of about 65 000 R are required to kill storage insects, but they may be sterilized by dosages of about 16 000 R. This is at the present time receiving much international interest from two points of view: (1) the sterilization of entire populations; and (2) the sterilization and release of males of species in which the females mate only once.

Sex Attractants. Many insects have a keen olfactory sense that in many cases guides them to their food. It has also been observed that in some species the females emit "pheromones" that attract the males for the purpose of mating.

Male insects may be attracted by pheromones over distances of greater than a mile. The sex attractant of the silk worm moth has been synthesized recently and found to be biologically active. For example, an effective control of *Cadra cautella*, the tropical warehouse moth, may be conducted by releasing a fog of oil-based pyrethrins into grain stores during the dusk mating flight. The control could perhaps be more economic if a sex attractant could be released to first of all bring the males to a focal point.

Pests of Stored Food

Insects

Of the thirty or so orders of insects, the food scientist should be familiar with at least the Coleoptera (beetles) and the Lepidoptera (moths).

Whereas in temperate climates storage insect pests do not normally occur in the field, in the tropics it is normal for them to begin their attack there. These insect pests can be divided on the basis of whether their larva develop inside the seed or dried root or whether they are free-living within the food.

Larva develop inside the seed or dried root. The pupae occur in a distinct pupal cavity near the surface of the seed or root; the cavity opens to the outside by a distinct window after emergence of the adult. The adults are free-living and lay eggs in a characteristic manner on or just beneath the surface of the seed or root.

Larva free-living within the food. The pupae occur freely (beetles) or in cocoons (moths). The adults are free-living and lay eggs randomly on suitable food.

Some of the common Coleoptera and Lepidoptera are listed in Table 22 according to their mode of life, and some examples of the foods they attack are given.

Rats and Mice

Rats and mice are serious pests of stored grains. They are not only destructive because of the amount of grain they consume but also because they transmit disease. The main three species that cause problems are: (1) the Norway rat (*Rattus norvegicus*); (2) the roof rat (*Rattus rattus*); and (3) the house mouse (*Mus musculus*).

Sanitation. Good housekeeping is one of the most economical and effective ways to reduce rodent problems. Waste grain should be removed; lumber, old screens, and grain sacks should be stored about 50 cm from the floor; old trash and junk should be destroyed; and the grain should be protected with concrete, wire, or sheet metal. Weeds and carelessly strewn debris, which might provide harbourage for rodents, should be eliminated.

Chemical Control. The chemicals used to kill rats and mice are called rodenticides. Rodenticides are usually mixed with baits such as fresh meats, bacon, fresh or canned fish, rice, peanut butter, and melon. A binder of molasses, or vegetable, mineral, or fish oil is often used with dry baits to hold the poison and bait together. An emetic is usually added to the bait to protect other animals although the acceptability of the baits is then reduced. Rats are among the few animals that are unable to vomit. The bait must be mixed as directed because too little will not poison and may result in "bait shyness"; whereas, too much may give the bait a strong taste or odour and increases the danger to man and domestic animals. Extreme caution must always be exercised when handling poisons.

Traps. Two types of traps are commonly used: (1) snap traps; and (2) cage or box traps. In snap traps the bait must be securely fastened to the trigger. Placing cage or box

TABLE 22. Some examples of insect pests and the foods they attack.

Order	Family	Species	Food attack
Larva develop in seed or dried root			
Coleoptera (beetles)	Curculionidae	*Sitophilus oryzae* Linnaeus	Mainly cereal grains
	Bruchidae	*Callosobruchus maculatus*	Mainly beans
	Anthribidae	*Araecerus fasciculatus* Degeer	Mainly dried roots, also maize and dry cocoa
	Bostrychidae	*Rhizopertha dominica* Fabricius	Dried roots and grain
	Anobiidae	*Lasioderma serricorne* Fabricius	A wide range of dried seeds including beans, grain, and cocoa, root crops, and compact meals
Larva free-living within the food			
Coleoptera	Tenebrionidae	*Tribolium castaneum* Jacquelin du Val	Mainly ground grain and meals
		Gnathocerus maxillosus Fabricius	Weevil-damaged grain, legumes, dry cocoa, and oil seed cake
	Silvanidae	*Oryzaephilus mercator* Fauvel	Similar to *Tribolium*
		Cathartus quadricollis Guer	Maize, usually when the moisture content is above 14%
	Dermestidae	*Dermestes maculatus* Degeer	Dried fish, skins, bones, etc.
		Trogoderma granarium Everts	Dried animal products, grain, and oilseed products
	Nititulidae	*Carpophilus* spp.	Usually associated with mould on a wide range of foods
	Cuculidae	*Cryptolestes* spp.	Grain and grain products
	Ostomidae	*Tenebroides mauritanicus* Linnaeus	Similar to *Tribolium* but usually after heavy infestation by other insects
		Lophocateres pusillus Klug	Same as *Tenebroides*
Lepidoptera (moths)	Pyralidae	*Cadra cautella* Walker	Similar to *Tribolium*
	Tineidae	*Sitotroga cerealella* Olivier	Mainly grain and grain products

traps in dark places and covering them with material such as burlap bags will increase catches.

Burrow Gases. This is a supplementary measure for killing rodents and should not be attempted by untrained operators. Calcium cyanide is very effective but is highly toxic and quickly fatal; therefore, extreme care is necessary. Carbon monoxide from automobile exhausts can also be piped into a burrow system.

In tight clay soils, filling burrows with water from a garden hose may drive rodents out so they can be killed with clubs.

Rat Proofing. This consists of changing structural details to prevent the entry of rodents into buildings. The stoppage work, to be economical, should be confined to the most likely points of entry and not to every possible entrance.

Physical Considerations

The progressive approach to grain storage

in the Philippines is concerned with bulk handling and storage systems rather than sack storage. It may be expected that the tendency towards intensified production will be accompanied by: (1) the need to handle larger crops over a limited period of time; and (2) the centralization of storage. The bulk handling and storage of grain offers a number of economic advantages over sack storage: (1) savings in the cost of sacks; (2) reduction in labour costs; (3) better control of losses and quality; (4) reduction in land costs because a given volume can accommodate more grain in bulk than in sacks. The ratio is, for example, more than 10 to 1 when tall silos are used instead of sack storage in sheds; (5) facilitation of national grain policy operations; and (6) simplification of inventory.

Bulk handling and storage installations are not economically sound unless the storage capacity is about 1000 t or more. Capital is depreciated more rapidly with an increase in turnover frequency and this is a factor that contributes to the selection of a storage system. For example, a fully mechanized outdoor silo system may cost US$150/t of static storage capacity compared with US$50/t in a medium-size installation utilizing indoor rectangular or cylindrical bins. These two different systems may be designed in such a way that the technical advantages to be derived from bulk handling, and the overall function, are the same. For equal economic return, however, the frequency of turnover must be three times greater in the concrete silo system. It follows that such high-cost installations are usually regarded as economical only when they are associated with frequent or continuous stock turning operations such as those required for large capacity milling or port handling. However, a government may consider their use for subsidized grain marketing programs that are in themselves of economic and social importance.

Very careful logistic and marketing studies are necessary whatever type of handling and storage system is envisaged.

Before considering the relevant climatic factors, characteristics of structural materials, and the various systems available for handling and storage, it is useful to review briefly the characteristics of bulk grain because they refer to all of the other factors.

Characteristics of Bulk Grain

Certain physical and biological features of a mass of bulk grain are related to any bulk storage system whether it is refrigerated storage, airtight storage, or normal dry-grain storage.

Thermal Properties

Grain is a very poor conductor of heat, its conductivity being similar to first-class insulating materials. This means that any heat generated by the grain itself or absorbed by contact with storage structures (e.g. silo walls heated by the sun) remains localized, dispersing only very slowly from the source. The greatest significance of this is that the locally heated grain develops a high vapour pressure and gives off moisture vapour. This vapour may rise slowly through the bulk due to the convectional airflow created in the intergranular space, or it may maintain the same location, according to air density. In any case, the water vapour will probably condense to liquid water in another part of the silo where heating does not occur, or at the same place when the heat diminishes (e.g. sunset or overcast weather conditions following sunshine). The free liquid water is absorbed into the grain in another cooler part of the grain mass and a deterioration chain is triggered off.

The low capacity of grain for heat transfer can be used to advantage in the technique of chilled grain storage for seed. Once the grain is cooled to a safe level, it can remain cool for long periods provided the storage structures are correctly designed.

Moisture Relationships

Grain has the capacity to absorb or lose moisture according to the humidity of the surrounding atmosphere (intergranular space). One beneficial effect of this feature is the possibility of slow drying when a relatively dry mass of air is forced through a grain bulk.

This ability to give up moisture freely can also be used for evaporative cooling of the grain and is useful in conditioning bulk grain during storage. Conversely, caution is needed to ensure that the moisture in the intake air is not sufficiently high to cause wetting of the grain by absorption (see Table 23).

TABLE 23. The equilibrium moisture content of paddy over a range of relative humidity and temperature.

Temperature (°F)	Relative humidity				
	50	60	70	80	90
80	10	12	13	14.8	17
90	9.3	11	12.5	14.2	16.5
110	7	9.8	12	14	16.2

If dry paddy (say 13% moisture content) is subjected to in-storage aeration from an ambient atmosphere of 27 °C (80 °F) and 90% relative humidity, it will tend to absorb moisture up to the equilibrium level of 17%. At the same temperature a relative humidity of 70% or less is safe.

Biological Characteristics

A bulk of grain may be regarded as a mass of living organisms (the grain itself, moulds, and insects) that consumes oxygen and the reserve food material of the grain and produces carbon dioxide, water vapour, and heat in the same manner as the many other forms of life (Fig. 85).

In certain circumstances (airtight storage) the depletion of oxygen and the increase of carbon dioxide concentrations in the intergranular space can be used to advantage to produce an atmosphere that will retard or prevent the growth of insects and microorganisms. In ordinary bulk storage, however, the heat produced by grain respiration can become a problem if uncontrolled, especially if the grain moisture content is high: grain and mould respiration increases with an increase in moisture content and is very much restricted at low moisture content, e.g. 13% or less.
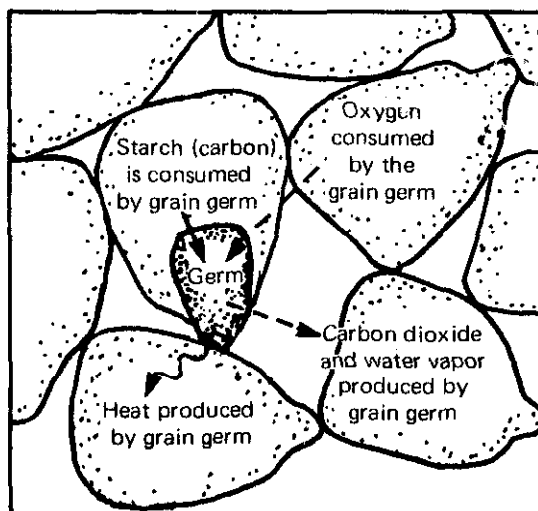
FIG. 85. The intergranular atmosphere, which is initially the same as ordinary air, is modified by the respiratory action of the grain germs, moulds, and insects: oxygen diminishes, water and carbon dioxide increase in concentration, and the temperatures of the intergranular space and the grain rise due to the heat evolved in respiration. The basic expression of this energy relationship is:

12 g carbon + 32 g oxygen =
44 g carbon dioxide + heat
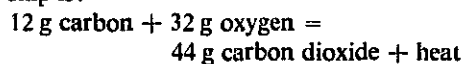
Because respiration increases with increased moisture content, heat production increases and the temperature of the grain mass increases.

Resistance to Airflow

A bulk of grain exerts a resistance to airflow according to the dimensions of the bulk and to the shape and structure of the grain. Although the total intergranular space is fairly constant (30–40%) for all grain types, the configuration of the space is very different and determines the static pressure developed by different grain types for a given rate of airflow within a bulk of given dimensions. For example, shelled maize and soybeans, which have smooth surfaces, are spherical, and are relatively large, present low resistance to airflow. Paddy grain on the other hand, which has a rough surface and is slender and elliptical, exerts a high resistance — the grains being closely applied to each other to form a net-

work of small, predominantly horizontal spaces.

Because the power requirement for forcing a given volume of air through a grain bulk of given dimension is a function principally of air volume and static pressure, it follows that if the volume is the same, the power requirement will be greater for paddy than for maize. The power requirement to provide a bulk of paddy, and maize, of dimensions 10 ft × 10 ft × 10 ft with 2 ft^3 of air per minute per cubic foot of grain, through a flat-bottom aeration floor is:

	Air volume (cfm/ft^3 of grain)	Static pressure (inches of water)	HP required
Paddy	2	3.8	12
Maize	2	1.7	3

The airflow characteristics of sorghum are similar to those of paddy.

During the design and specification of aerated bulk storage, it is clearly necessary to consider the grain types to be handled.

Characteristics of Structural Materials

Since steel and concrete are the most likely materials to be used in the construction of new grain silos, it is necessary to consider their thermal properties.

Steel is a good conductor of heat; therefore, it readily transfers solar heat from the outside to the grain mass immediately inside the silo wall. (This fact should be considered together with the observations on the thermal properties of grain and its significance.) Conversely, steel cools readily at sunset, or in intermittent fair and overcast weather, and then acts as a condensation surface for water vapour produced from the heated grain.

Since steel is the most practical and economical material for silos designed for the ordinary systems of dry grain storage, consideration must be given to necessary factors that compensate for its undesirable thermal properties. These are grain moisture content and aeration. When the moisture content of grain stored in outdoor metal silos is 13% or less, the grain is not so susceptible to an elevation of vapour pressure and the consequent loss of water vapour. Forced ventilation in metal silos is essential to equalize the temperature of the grain mass with the ambient temperature, apart from the need to provide normal conditioning ventilation.

Refrigerated grain storage is not very practical in outdoor metal silos because of the continual heat gain from the exterior.

Concrete has a low thermal conductivity and presents a buffer against the amplitude and the intensity of variations in ambient temperature. Concrete silos are usually more expensive per tonne of storage capacity than steel silos, but their use may be justified in certain cases.

The heat reflectivity of all types of silo can be increased by painting them white.

Weather-proofing is of course essential in both steel and concrete silos. In steel silos this is accomplished by meticulous attention to the sealing and bolting of plates during construction and in concrete silos by the application and correct composition of water barriers.

It is to be noted that concrete is used for the base for steel silos and the same attention must be given to composition and damp-proofing to prevent capillary rise of groundwater.

Basic Requirements for Bulk Grain Storage

The basic requirements for ordinary bulk grain storage are: (1) the grain moisture content must be at the level at which grain respiration is limited; (2) the grain must be free of debris so as to facilitate forced ventilation; (3) a forced ventilation system must be included in the silo design; (4) ventilation must be programmed according to prevailing climatic conditions; (5) ventilation systems must be designed according to the types of grain to be stored; (6) silos must be weatherproof, constructed on firm, water-impermeable foundations, and oriented advantageously with respect to solar radiation; and (7) mechanical conveying systems must be provided.

Review of Storage Methods Available

Aerated Storage of Dry Grain for Long-Term Storage

Paddy, maize, and sorghum having a moisture content of 13–14% can be stored for

long periods in steel or concrete silos that are equipped with a suitable forced-air ventilation system. The functions of the ventilation system are: (1) to replace the intergranular atmosphere; and (2) to equalize the temperature of the grain bulk with the ambient temperature. Silo units (individual bins) of several hundreds to a few thousand metric tonnes are used for this purpose and total tonnages of 1000 and above are normally considered as economic capacity.

The airflow rate for any grain storage is about 0.10 ft^3/min per cubic foot of grain applied at daily intervals for a period of about 15 min during the period of minimum relative humidity.

Aerated Storage of Wet Grain

Grain with a moisture content above 14% can be maintained in good condition for periods of about 2 weeks to 2 months at 29 °C (85 °F) provided adequate ventilation is employed. Grain of 14–16% moisture content requires 1 ft^3 of air per minute per cubic foot of grain daily for a period of about 30 min during the period of minimum relative humidity. Under these conditions, 14–16% moisture content grain can be held safely for 2 months. At this airflow rate, the grain moisture content is reduced only negligibly, but evaporative cooling is adequate. However, if an airflow of about 5 ft^3/min per cubic foot of grain is applied to 16% moisture grain for several hours a day at 70% relative humidity or less, the grain moisture content will be reduced to 14% in several weeks. The grain can then be subjected to reduced aeration as indicated above.

It may be desirable to hold for short periods grain of 16% or more moisture content so as to provide a buffer in the delivery of wet grain into driers. This technique spreads the drying load, maximizes the utilization of drying capacity, and consequently abbreviates the period of capital amortization. Such wet-grain holding is normally carried out in bins of less than 100 t capacity using an airflow of at least 5 ft^3/min per cubic foot of grain for about 3 h per 12 h.

Refrigerated Storage (Chilled Grain Storage)

The application of cooled air (e.g. 4 °C (40 °F)) to bulk grain either dry or semidry (14–16% moisture content) is effective in reducing grain respiration and deterioration to a negligible degree. The cooled air is applied with an ordinary aeration system equipped with a cooling plant.

Airtight Storage

If a filled silo is completely sealed, the grain respiration causes a drastic modification of the intergranular atmosphere — oxygen is depleted and carbon dioxide is increased. The result is that the grain is killed and respiration ceases. Insect and mould development is inhibited or excluded by the modified grain atmosphere but certain yeasts and bacteria may grow if the grain moisture is high (18% or more).

Since this method changes the flavour and milling quality of grain, it is not useful for application to human food grains. It cannot be used for seed grain because the grain is killed. It can be useful for storing animal feed grain for periods of several months, especially because it is not necessary to dry the grain, and the grain is usually required wet for feed blending.

Methods Applicable in the Philippines

Three types of conventional bulk storage with aeration systems would seem to be applicable to the Philippine grain production and marketing patterns, according to location and required capacity.

Bin Storage Systems

These are for installation within existing sack storage buildings or new buildings of a similar type. These indoor silos may be of the rectangular type with flat-floor aeration or of the cylindrical type with cross-flow aeration.

The rectangular bin system offers a number of operations derived from the same installation: (1) holding of wet grain prior to drying; (2) slow in-bin drying from about 18%

moisture content to 14% or less, as a supplement to heated-air drying in continuous flow or batch driers; (3) tempering between heated-air drier passes; and (4) grain unloading using the same aeration system used for in-bed drying and regular conditioning aeration.

The cylindrical system is comparable in its function with the rectangular system except that hoppering is needed for grain unloading and space is not used so efficiently.

These installations are generally suitable for provincial operation up to a capacity of 2000 t. The scale of economy begins at about 1000 t. Capital cost per tonne of static capacity, i.e. tonnes of throughput, is a vital economic factor, as in all storage systems.

Steel Cylindrical Outdoor Silos

The range of size is great and they can be installed economically over a static capacity range of about 1000–10 000 t or more. At 1000 t capacity, the capital cost per tonne for all operations is about US$100 and about US$50 at 10 000 tonnes capacity.

Silo systems of this type may have provincial or terminal application.

Concrete Silo Systems

This system is already used in the Philippines at flour and feed mills and at one rice mill. The economic scale starts at about 10 000 t static capacity with a capital cost per tonne of about US$150 at that level for all necessary operations. Concrete silo systems are generally employed as part of the handling system at high-capacity grain processing installations or port facilities where the turnover is frequent — usually at least four times per year and often as many as twenty. — JOHN RAWNSLEY. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Microorganisms

One of the major problems that confronts the agricultural industry in the Philippines and other developing countries having tropical climates is the proper postharvest handling and safe storage of agricultural commodities such as cereal grains and oilseeds.

The main hazard caused by mishandling and poor storage of grains and other stored products is the loss in quality due to invasion by microorganisms and insects. In the Philippines, the predominant microorganisms usually associated with stored products are fungi or moulds, mainly *Aspergillus* and *Penicillium* types. These moulds occur throughout the world as common contaminants of food, but they are considered to be more serious in tropical areas like the Philippines where high temperature and moisture favour their rapid growth. Although these moulds do not attack actively growing plants, their minute spores may contaminate the outer layers of the seeds, especially at maturity or harvest time. If cereal grains, oilseeds, and other agricultural commodities are not properly dried after harvest they are subject to attack by moulds.

In the Philippines, where rice is harvested by hand, there is sometimes a delay between harvesting and threshing, and often the panicles are heaped in the rice field until they can be dealt with. Such temporary storage of grain with a high moisture content (usually as high as 30%) will lead to development of high temperatures, serious deterioration in the form of discoloration and off-odours, and ultimately, reduced milling yield due to the growth of moulds and other microorganisms. Similarly, if milled rice is stored under damp conditions mould growth will occur. The actual invasion occurs under storage conditions of high humidity (70–75%) and high temperature (25–30 °C). Under these conditions, the spores germinate and penetrate the seed. They attack with ease any section

of the moist seed, and result in mouldy grains. Storage fungi colonies also develop at the site of insect and mechanical damage to the seed.

In a recently concluded survey in the Philippines, samples of different grains, peanuts, soybeans, and copra that were not properly dried always yielded colonies of moulds, mainly *Aspergillus flavus* (Table 24).

Effects of Moulds on Stored Products

Mould growth produces a number of deteriorative effects on grain, grain products, and oilseeds: (1) discoloration and loss of luster; (2) bad odour and off-flavour that make the grain objectionable either as animal feed or food for human consumption; (3) reduced processing quality, for example, it is more difficult to separate starch from protein in wet milling of corn; (4) loss of viability, making the grain unsuitable for planting; (5) loss of competitive position in world markets due to poor quality; and (6) production of highly toxic substances called mycotoxins that poison and kill animals and livestock and possibly also cause health hazards to humans.

Mycotoxins

Mycotoxins are toxic substances produced by fungi, several of which are known to cause specific diseases of animals and man. The first recognized toxic fungi metabolite was the notorious ergot of rye and other cereal grains. Ergot contains a mixture of active substances (primarily ergotamine) that causes mental and physical suffering in man. Present scientific literature reports other mycotoxins that affect animals as well as man (Tables 25 and 26).

Of the many fungal toxins so far reported, few have stirred as much interest as the mould toxin known as "aflatoxin." In England in 1960–1961, 100 000 young turkeys mysteriously died. After an infectious disease was ruled out, it was discovered that what these turkeys had in common was their ration of mouldy peanut meal, which had been imported from Brazil. The meal contained a high population

of the mould *Aspergillus flavus*. Studies revealed that this mould produces several related compounds known as aflatoxins B_1, B_2, G_1, and G_2. The most toxic is aflatoxin B_1 that has a lethal dose (LD_{50}) of 18 μg in ducklings. It has been definitely proven that aflatoxin can cause liver cancer in animals, and it is probably safe to assume that aflatoxin can also cause primary liver cancer in human beings through cumulative consumption of contaminated cereals and other food products, the main ingredients of which are either cereals and/or nuts. Table 27 shows the results of analyses of different foods and native delicacies for aflatoxin content conducted by the Food and Nutrition Research Council of the Philippines (FNRC).

Studies have been undertaken to find means of removing or destroying aflatoxin from foodstuffs. Procedures like autoclaving, use of chemicals, and irradiation have been tried, but these methods have either been unsuccessful or impractical. To date the best means of controlling mould infestation of agricultural commodities is by prevention. This means proper harvesting, drying, storing, and processing.

Some Broad Principles and Practices for Preventing Mould Growth

Environmental factors such as high moisture and temperature, which exist in tropical countries like the Philippines, are the conditions that lead to mouldiness of agricultural products. Consequently, commodities must be dried, without damage, to a safe moisture level soon after harvest and maintained at a low level of moisture and temperature during storage and handling.

Other storage practices are essential. (1) Always thoroughly clean storage premises before refilling. Leftovers may contain insects, moulds, and other microorganisms that will infect new materials. (2) Clean the grain of grain dust, foreign material, and broken kernels before it is stored. This makes the grain less attractive and less susceptible to insect and mould infestations. Do not mix new grain and other bulk agricultural commodities with old stock because organisms that cause quality

TABLE 24. Percentage of *Aspergillus flavus* and aflatoxin content in samples of crops collected in the Philippines, September 14 to October 2, 1970.

Code[a]	Sample description	No. of units cultured	Units yielding *A. flavus* (%)	Aflatoxin B_1 (ppb)
Corn				
B-1	Whole corn on cob, drying yard, rural areas	21	71	343
B-2	Whole corn, shelled, drying yard	20	55	107
C-1	Whole corn, shelled, used in milling procedure	21	14	343
C-2	Corn starch derived from C-1	—	—	14
C-3	Corn gluten meal derived from C-1	25	20	333
C-11	Whole corn on cob standing in fields, improved varieties, over mature, some ears on ground	21	70	929
C-12	Whole corn on cob, drying on cement, rural areas. Mixed varieties	20	70	1074
D-13	Whole corn on cob, wet, stored in sacks in barrio bodegas	20	35	948
GS-5	Corn oil filter from oil refining	—	—	600
Peanuts				
B-4	Peanuts in shell, dry from stored 1970 crop, variety CES-101	20	60	14
CMC-2	Small segregated peanuts sold on market for food use:			
	smooth	20	45	Composite
	wrinkled	20	75	29
CMC-3	Production line "pickouts" removed from stocks:			
	smooth	20	65	Composite
	wrinkled	20	95	986
IS-4	Farmer commercial peanut stock, in bulk storage, dry, 1970 crop, in shell	20	10	257
IS-5	"Pickout" from farmer stock (IS-4) sorted at shelter, shelled	20	0	477
Copra				
C-18	Filter residue from copra oil extraction process and oil clarification	—	—	357
D-10	Crude copra infested with fungi in pile	20	100	314
Sorghum				
B-6	Sorghum, mixed varieties in large moulding pile, very mouldy sample obtained	44	25	208
C-10	Sorghum dry in storage	30	0	0
Rice				
D-7	Mouldy unmilled rice from milling company bodegas	30	0	0
I-2	Rice, exposed in field experiment, improperly dried, variety IR-8-68	40	15	0
Soybeans				
B-3	Soybean, drying on mat	27	16	21

[a]Code letters refer to geographical area in which sample was collected; B—Bacolod; C—Cebu; D—Davao; GS—General Santos; I—Iloilo; IS—Isabela; and CMC—Manila market.

TABLE 25. A partial list of animal diseases attributed to fungi toxins.

Condition	Animals	Fungus source	Food material	Toxic agent
Slobbering	Guinea pigs	*Rhizoctonia legumi-nicola*	Legumes	Slaframine
Trembling and convulsion	Laboratory animals	*Aspergillus* sp. *Penicillium aplopium*	Various foods	Tremorgens (2 or more)
Liver necrosis, cancer, and body hemorrhage	Dogs, fowl, rats, and cattle	*Aspergillus flavus*	Corn, peanuts, sorghum and coconut	Aflatoxins (6 or more
Cerebral necrosis	Equine animals	*Fusarium moniliforme*	Corn	Unknown

TABLE 26. Diverse toxic conditions of man attributed to mycotoxins.

Condition	Fungus source	Food material	Toxic agent
Skin photosensitization	*Sclerotinia schlerotium*	Pink rotted celery	Psoralens
Polyuria	*Rhizopus nigricans*	Millet	Unknown
Bone marrow depression (ATA)	*Fusarium* sp.	Cereal	Not well determined
Hepatitis with hemorrhagic phenomena	*Stachybotrys atra*	Cereal grains	Not well described

TABLE 27. Summary of FNRC analyses for aflatoxin content of different foods (1970).

	No. of samples	Percentage of samples with concentrations greater than 30 ppb	Percentage of samples containing no aflatoxin	Range of concentration (ppb)	Mean concentration (ppb)
(1) Peanuts					
raw	7	0	42.86	0–103	9
boiled	7	14.28	0	trace–103	16
toasted	56	14.28	12.50	0–371	45
brittle					
whole	13	7.69	23.08	0–158	28
diced	6	33.33	16.67	0–74	32
ground	7	42.86	0	6–171	58
sugar coated	15	20.00	46.67	0–35	31
with chocolate	14	42.86	35.71	0–215	73
with tokwa	3	33.33	10	16–68	37
soy peanut	12	16.67	33.33	0–750	115
peanut butter	77	100	0	43–8600	287
(2) Corn					
dried	37	81.08	0	3–398	106
boiled	13	0	23.08	0–20	11
pop (with sugar)	17	0	52.94	0–24	14
pop (with salt)	12	8.33	33.33	0–660	20
canned sweet corn	6	0	33.33	0–9	6
bran	3	1100	0	197–265	242
Corn starch	3	0	66.67	0–trace	
Corn with coconut	17	17.65	17.65	0–143	37

TABLE 27. (*continued*).

	No. of samples	Percentage of samples with concentrations greater than 30 ppb	Percentage of samples containing no aflatoxin	Range of concentration (ppb)	Mean concentration (ppb)
(3) Copra	143	18.88	21.68	0–458	42
copra meal and cake	27	7.40	62.96	0–36	20
coconut products	33	6.06	78.79	0–857	134
(4) Rice					
rice straw	14	0	78.52	0–trace	
rice and sugar	23	0	78.26	0–22	13
rice, sugar, and					
coconut milk	54	5.56	35.18	0–786	39
rice, sugar, and linga	4	0	75.00	0–trace	
pop rice	2	0	50.00	0–3	5
bran	3	33.33	0	28–31	29
pinipig	6	0	33.3	0–6	5
cereal preparation	5	0	0	trace–14	9
binlid	2	0	0	trace–11	11
(5) Tubers					
Camote					
raw	11	27.27	9.09	0–86	27
with sugar and					
coconut	2	0	100		negative
Cassava					
raw	7	14.28	0	4–35	12
with sugar and					
coconut	18	50.00	0	trace–1073	322
Ubi					
raw	6	0	50.00	0	7
with sugar and					
coconut	20	25	35.00	0–443	136
Gabi					
raw	8	0	62.5	0–3	3
Potato					
raw	3	0		0–28	25
Carrot	2	50	0	14–64	39
Radish	2	0	50	0–trace	
Singkamas	2	0	50	0–28	28
(6) Commercial feeds					
(unlabelled)	4	0	(2) 50	0–8	7
Laying mash	6	33.33	0	trace–133	39
Growing mash	13	38.46	0	10–151	47
Starter mash	9	44.44	0	8–129	43
Pigeon mash	5	40	0	11–47	29
Boiler mash	4	50	0	15–171	66
Hog mash	8	62.5	0	12–200	68
Trigo	2	0	0	14–23	19
(7) Mongo					
dried	12	8.33	0	trace–32	9
with coconut	8	37.50	12.50	0–857	332
sugar with flour	5	0	20	0–13	8
sugar sprout	2	0	50	0–trace	

(*continued*)

TABLE 27. (*concluded*).

	No. of samples	Percentage of samples with concentrations greater than 30 ppb	Percentage of samples containing no aflatoxin	Range of concentration (ppb)	Mean concentration (ppb)
(8) Beans (dried)					
string beans	3	33.33	0	trace–96	55
China	1	0	0	8	8
Kadyos	4	0	75	0–4	4
paayap	6	16.67	0	trace–86	15
patani	2	0	50	0–trace	
tapilan	2	0	0	trace–9	5
kidney	10	20	10	0–180	69
chickpea	3	0	0	trace–9	4
canned beans	11	0	0	trace–21	6
(9) Soybean products					
misu	4	0	0	trace–3	
taburi	4	0	0	trace–16	5
tausi	5	0	20	0–28	9
misi	3	0	0	trace–2	
tokwa	8	0	25	0–9	4
(10) Fish					
dried	19	0	0	trace–6	4
smoked	23	0	(10) 43.48	0–9	5
meal	1	0	0	5	5
bagoong	2	0	0	5–7	6
patis (sauce)	16	0	0	trace–7	5
(11) Other nuts					
pili nuts	1	0			
pili nuts with sugar	12	8.33	33.33	0–64	12
kasoy nuts	12	0	58.33	0–7	5
kasoy nuts with chocolate	1	0	0		6
(12) Miscellaneous					
coffee	11	0	100	0	
cocoa (processed)	10	0	60	0–28	12
cocoa raw	1	0	0	17	17

deterioration will most likely be introduced into the new crop. (3) Conduct periodical surveillance tests in bulk-stored agricultural commodities for mould growth and colour appearance. (4) Keep insects, mites, and rodents in check by fumigation or the application of protective sprays. — FLORENDO C. QUEBRAL. *Department of Plant Pathology, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Control Systems

The general requirement for good seed storage is a dry and cool environment. Seed operations located in climatic areas with

high temperatures and relative humidities must have some system of controlling both the relative humidity and the temperature of the air inside seed storage rooms. Sealed storage (vapour-proof containers) has been used for many years in the vegetable seed industry; however, two factors have limited the use of this method for storage of field crop seeds: (1) the cost of vapour-proof containers; and (2) the moisture content of the seed, which must be 2–3% lower than that normally considered safe for seed packaged in non-moisture-proof containers.

Before considering several systems that can be installed to maintain low relative humidities and temperatures, let us consider the basic requirements: (1) a structure must be provided that will keep infiltration of moisture and heat to a minimum; (2) there must be some means of dehumidification (removing moisture from the air); and (3) there usually must be some provision made for lowering the temperature of the air.

Storage Room Construction

The question of how to build a good seed storage room becomes a question of what is the best way to construct a "large container" and make it as airtight as possible. This is necessary to keep the initial cost and the operating expense of the dehumidifying and cooling equipment at a minimum.

For low humidity conditions, it is essential that adequate vapour barriers be included in the construction and that they be installed with the greatest of care, making sure that all joints are properly sealed. Thermal insulation requirements will vary with geographic location. Obviously, the size of the storage area should not be larger than absolutely necessary. If seeds are to be stored in a large warehouse, it is more economical to condition only a small portion of the warehouse rather than to attempt to dehumidify and cool the entire structure.

Dehumidification

Generally speaking, there are two major

categories of dehumidifiers: refrigeration-type, and chemical- or absorption-type.

Refrigeration-Type

The refrigeration-type dehumidifier operates by drawing warm moist air over a metal coil through which a refrigerant such as Freon is circulated. A part of the atmospheric moisture condenses on this cooling coil and is collected in a pan or bucket or is drained off. The cooled air coming from over the coil, which now has a low temperature and a high relative humidity, is reheated by the condenser coil of the refrigeration system; thus raising the temperature and lowering the relative humidity. The water removal capacity of this type of system is dependent on the difference in temperature between the entering air and the cooling coil. Although these units are quite effective at high temperatures they lose efficiency below 21 °C (70 °F) or 50% relative humidity. Heat from the electric motors that drive the compressor and fans add sensible heat to the atmosphere.

Absorption-Type

The absorption-type dehumidifier operates by drawing moist air over a solid drying agent (desiccant) that has the ability to extract and retain moisture on its surface by a phenomenon known as "absorption." The air is filtered and dried to a very low dewpoint in the process, and the desiccant is periodically regenerated by means of heated outside air that vaporizes the moisture and dispels it to the outside of the conditioned space. Continuous operation of these machines is achieved by either using two desiccant beds that switch back and forth automatically, or by using rotating beds of desiccant, a portion of which is always dehumidifying the air while the remainder is being regenerated.

Desiccant dehumidifiers provide maximum efficiency at low temperatures and are able to maintain constant relative humidities even below 10%. A factor that should not be overlooked is that heat is added to the controlled atmosphere although the unit is placed outside the storage room. The latent heat of vapori-

zation of the moisture that is removed is converted to sensible heat. There is also a certain amount of residual heat left in the desiccant after reactivation, which increases the air temperature.

Heat Removal

Because an excessive heat buildup will usually be experienced when either type of dehumidifier is used alone to reduce the relative humidity in a seed storage room, let us consider several means of removing this heat. The most common and familiar method is by using a refrigeration-type air conditioner, which can also be used to "dehumidify." It operates in a manner similar to the refrigerant dehumidifiers except that it has a larger cooling coil area and provides air or water cooling of the condenser coils.

Water after-coolers can be used with a desiccant-type dehumidifier if the sensible heat load of the storage room is not excessive and a supply of cool water is available. Pre-cooling and after-cooling coils that are cooled by a refrigeration system are a most efficient way of removing large amounts of moisture with a desiccant dehumidifier. At temperatures below 10 °C (50 °F), silica gel will remove nearly 90% of the moisture from the airstream; at 38 °C (100 °F) this removal ratio is only about 50%.

Depending upon the temperature, relative humidity requirement, moisture, and sensible heat load, one method or system is usually more efficient than another. Therefore, let us consider eight possible systems for maintaining the required temperature and relative humidity in a conditioned seed storage facility.

Dehumidification System — Type I

As shown in Fig. 86, a refrigeration-type dehumidifier is placed inside the conditioned space. This self-contained unit consists of the following components: refrigeration compressor; motor and fans; and evaporator and condenser coils. The air inside the room is recirculated through the unit until the set relative humidity is reached and a humidity control switch in the electrical circuit shuts the unit
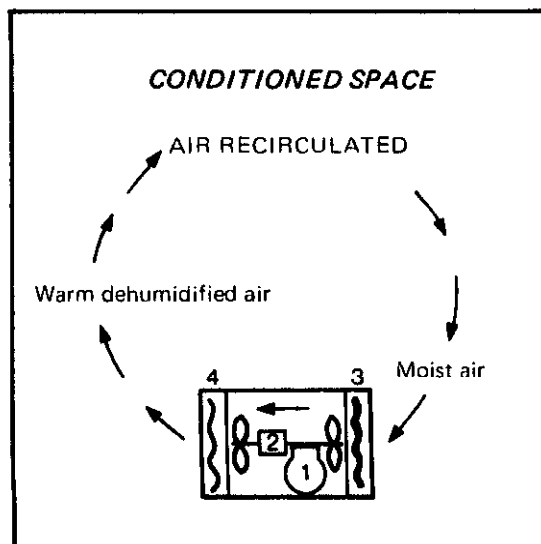
Fig. 86. Dehumidification system – type I: (1) compressor; (2) motor and fans; (3) evaporator coil; and (4) condenser coil.

off. The humidistat will automatically turn the unit on again when the moisture content of the air begins to increase due to infiltration or movement of moisture from the storage product or from other moisture inside the room. This system can be used satisfactorily only in locations where temperature control is not necessary, that is, where the sensible heat increase does not raise the air temperature above safe limits.

Dehumidification System — Type II

Figure 87 shows a desiccant dehumidifier located outside the conditioned space. This self-contained desiccant unit has the following components: desiccant (usually silica gel); heater coils; conditioned air blower; and reactivation blower. The air in the conditioned space, through a closed system, is recirculated through the unit until the set relative humidity is reached. A humidistat, located inside the conditioned space, controls the running of the conditioned air blower. Most desiccant dehumidifiers are wired so that the reactivation cycle continues even though the conditioned air blower stops. This is desirable only when the unit must run most of the time to maintain the relative humidity in the conditioned space;
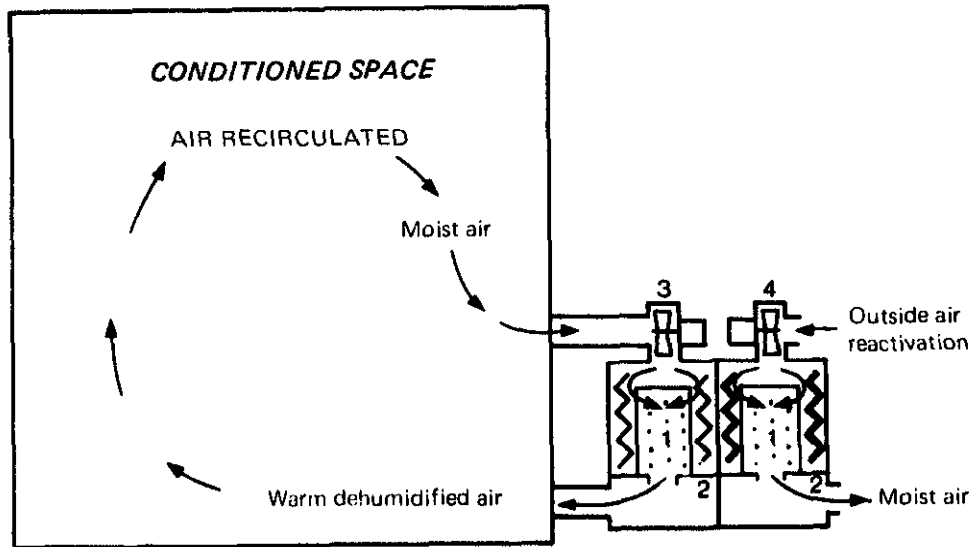
FIG. 87. Dehumidification system – type II: (1) desiccant; (2) heater coils; (3) blower; and (4) reactivation blower.
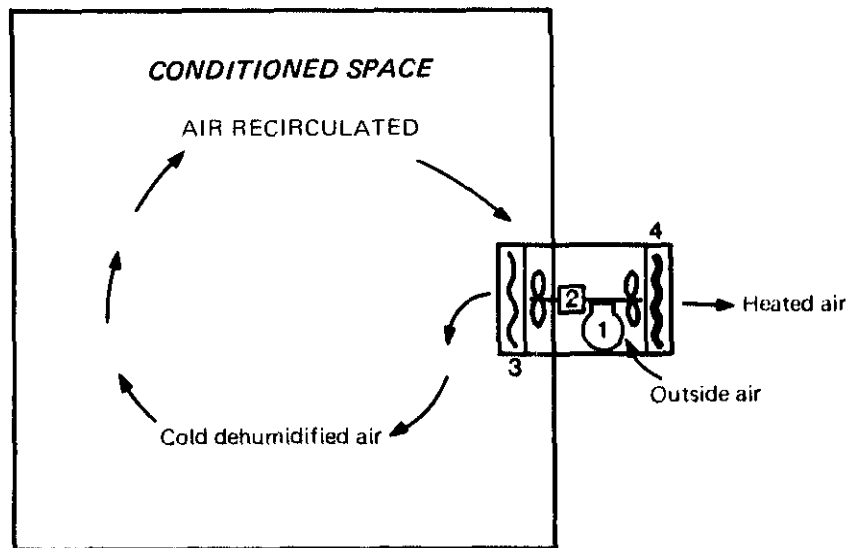
FIG. 88. Dehumidification and cooling system – type III: (1) compressor; (2) motor and fans; (3) evaporator coil; and (4) condenser coil.
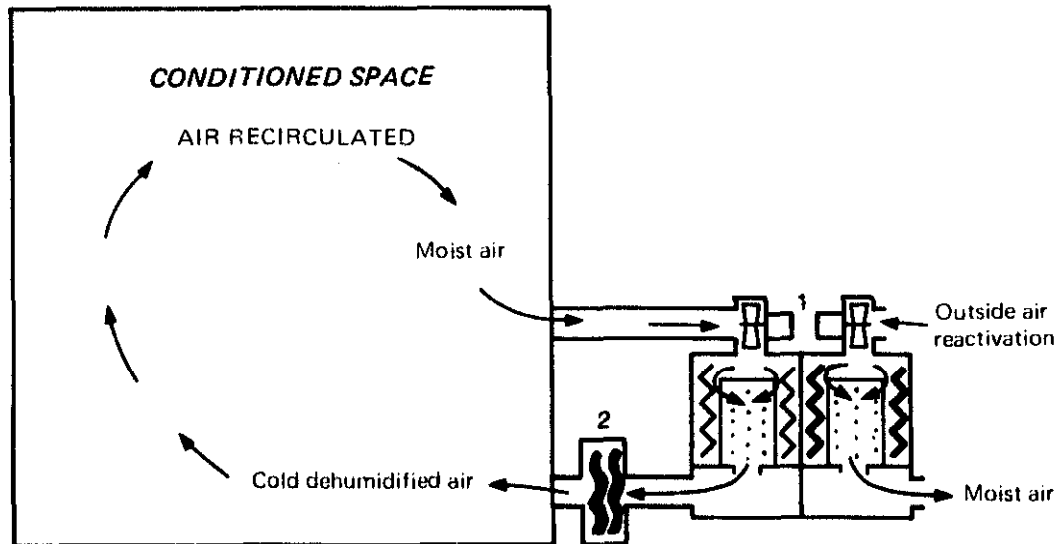
FIG. 89. Dehumidification and cooling system – type IV: (1) desiccant dehumidifier; and (2) water after-cooler.

otherwise, the result is excessive heat and expense. By having the reactivation heaters and fan wired to shut off when the conditioned air blower shuts off and by locating the machine outside the conditioned space, the heat build-up can be kept to a minimum.

electric heater strips are sometimes used to add heat to the air, which keeps the unit running longer. If these heater strips are connected through a humidistat, they can be turned on and off automatically as the humidity inside the conditioned space changes.

Dehumidification and Cooling System — Type III

A conventional-type air conditioner can be used to maintain temperature and relative humidity when the reduction of temperature is necessary for control of the sensible heat load. As shown in Fig. 88, only the evaporator section of the refrigeration unit is placed inside the conditioned space. The air within the conditioned space is recirculated over the cold evaporator coil, where moisture is condensed out of the air. Outside air is drawn over the condenser coils releasing the transferred heat to the atmosphere. The unit is controlled by a thermostat that shuts the compressor off when the temperature of the inside air is reduced to the set level. Because moisture is removed only when the room temperature is too high, sizing of the air conditioner for the sensible heat load becomes critical. For dehumidification, the compressor must run to keep the evaporator coils cold To maintain a more constant relative humidity condition,

Dehumidification and Cooling System — Type IV

The system shown in Fig. 89 consists of a desiccant dehumidifier with a water after-cooler. The water cooler is used to reduce the air temperature as it leaves the desiccant de-humidifier. The size of the after-cooler coil and the quantity and temperature of the water that passes through the coil determine the amount of heat that can be removed. This system is very effective for maintaining low humidities, and temperatures in the range of 5–10 degrees above the water temperature. A magnetic valve can be used in the water supply system to automatically regulate the water flow, and thus keep the air temperature within the set limits.

Dehumidification and Cooling System — Type V

Figure 90 shows a high capacity moisture removal system that utilizes a refrigeration unit
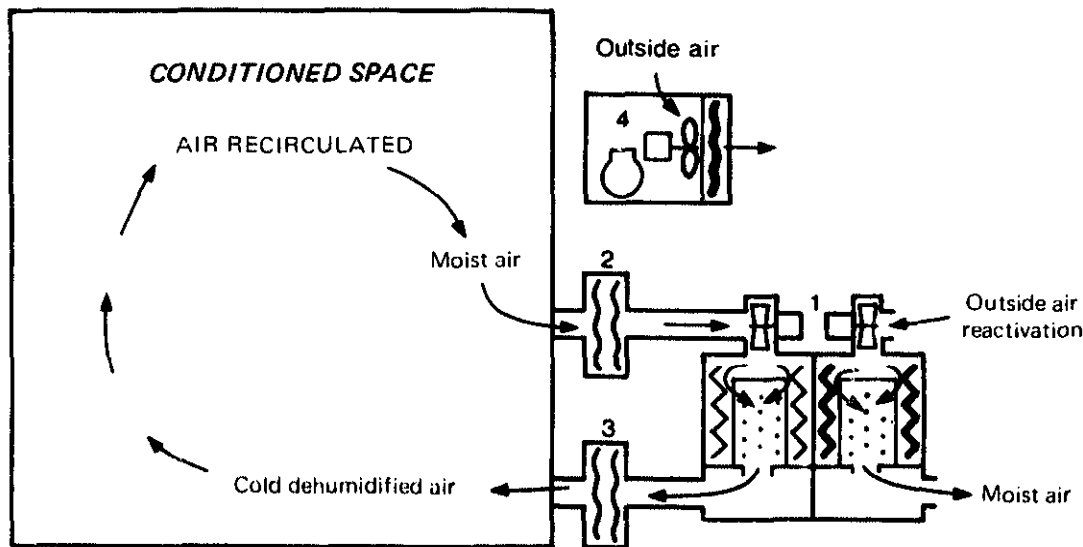
FIG. 90. Dehumidification and cooling system – type V: (1) desiccant dehumidifier; (2) pre-cooling coil; (3) after-cooling coil; and (4) refrigeration unit.

in conjunction with a desiccant dehumidifier. Cooling for the pre-cooling and after-cooling coils is provided by a refrigeration system. Because silica gel can remove nearly 90% of the moisture from air at a temperature below 10 °C (50 °F), the air in the conditioned space is cooled by the pre-cooling coil before it contacts the desiccant in the dehumidifier. In the process of absorption, latent heat of condensation is converted into sensible heat. Because this sensible heat increase may increase the air temperatures as much as 28 C° (50 F°), the after-cooling coil is necessary to reduce the temperature to safe limits. With automatic controls the temperature of both cooling coils can be regulated; thus it is possible to maintain, within close tolerances, low humidities and temperatures inside the conditioned space under a wide range of load conditions.

Dehumidification and Cooling System — Type VI

A simple system for controlling the temperature inside a conditioned space while removing large quantities of moisture at higher temperature is shown in Fig. 91. A self-contained refrigeration-type dehumidifier that is located inside the conditioned space removes the moisture from the air and is controlled by a hu-

midistat. The sensible heat load is handled by a refrigeration unit that transfers the heat to the outside atmosphere. The air temperature inside the conditioned space is kept within set limits by a thermostat that turns the refrigeration compressor on and off. This type of system loses efficiency at temperatures below 21 °C (70 °F) and relative humidities below 50%.

Dehumidification and Cooling System — Type VII

A dual system, as shown in Fig. 92, can be designed to maintain low humidities and low temperatures in the conditioned space over a wide range of load conditions. The refrigeration system will dehumidify (within limits of design) as well as cool the air. It works independently from the desiccant unit; however, in normal operation the two systems complement each other. The desiccant dehumidifier has a much higher moisture removal capacity because cold moist air enters the machine. Under extreme load conditions, the temperature of the air leaving the unit can be high enough to pick up sufficient moisture before entering the evaporator so that a certain amount of water will condense onto the cold coils.

Because either part of the system can lower

FIG. 91. Dehumidification and cooling system – type VI: (1) refrigeration-type dehumidifier; and (2) self-contained refrigeration unit.

FIG. 92. Dehumidification and cooling system – type VII: (1) desiccant dehumidifier; (2) remote refrigeration unit; and (3) evaporator.

the humidity to a certain extent, this dual system offers a safety factor in case of mechanical failure.

Dehumidification and Cooling System — Type VIII

A mechanical refrigeration system, as shown in Fig. 93, can be designed to maintain low humidities as well as low temperatures inside a conditioned space. Because the evaporator coil temperature must be below the dewpoint of the conditioned air at low temperatures and relative humidities, the moisture that condenses out will freeze, forming ice on the coils. Some provision must be made to melt this ice and remove it as water from the conditioned space. In the illustration, a hot-gas defrost system is shown. Using a time

FIG. 93. Dehu
and (

clock, hot dis
compressor i
coil at regula

It should l
system that
below 21 °C
midity is not

FIG. 91. Dehumidification and cooling system – type VI: (1) refrigeration-type dehumidifier; and (2) self-contained refrigeration unit.

FIG. 92. Dehumidification and cooling system – type VII: (1) desiccant dehumidifier; (2) remote refrigeration unit; and (3) evaporator.

the humidity to a certain extent, this dual system offers a safety factor in case of mechanical failure.

Dehumidification and Cooling System — Type VIII

A mechanical refrigeration system, as shown in Fig. 93, can be designed to maintain low humidities as well as low temperatures inside a conditioned space. Because the evaporator coil temperature must be below the dewpoint of the conditioned air at low temperatures and relative humidities, the moisture that condenses out will freeze, forming ice on the coils. Some provision must be made to melt this ice and remove it as water from the conditioned space. In the illustration, a hot-gas defrost system is shown. Using a time

FIG. 93. Dehumidification and cooling system – type VIII: (1) remote refrigeration unit; (2) evaporator; and (3) hot-gas defrost system.

clock, hot discharge gas from the refrigeration compressor is directed through the evaporator coil at regular intervals.

It should be pointed out that a refrigeration system that will function well at temperatures below 21 °C (70 °F) and 50% relative humidity is not composed of standard "comfort" or "cold storage" refrigeration components. Humidity control must, therefore, be built into the coil design and other components of the system. — JAMES M. BECK. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

PARBOILING

Technology

Rice has been used as a staple food since ancient times, and today, more than half of the world's population eats rice as the main food in their diet. Rice is obtained from paddy by milling, which removes the hull and bran (a mixture of pericarp, seed coat, and some of the aleurone layer, Fig. 94). The objective of milling is to get whole grain rice and preserve most of the rice kernels in their approximate original shape. Some varieties of paddy do not yield much head rice (a rice kernel or a piece of kernel having length equal to or greater than 3/4 of the average length of the unbroken kernel) because of their inherent poor milling quality or due to the effects of bad weather or uneven processing conditions. Both preharvest and postharvest factors cause breakage of rice during milling. Preharvest factors include varietal characteristics, agronomical practices, and environmental conditions; whereas, postharvest factors include unevenness in processing conditions during mechanical handling, drying, or storage and the type of milling machinery used and its adjustment.

Even if the proper precautions are used in postharvest processing, some varieties of paddy produce a low head rice yield because of inherent poor milling quality. To counteract this, premilling treatments have been developed in certain parts of Asia, particularly in India, Bangladesh, Pakistan, Burma, Ceylon, Malaysia, and Thailand (Borasio and Gari-

Starch granules (3-8μm)

Starch cell

Void or intergranular spaces

Hull (husk)

Pericarp

Seedcoat

Aleurone layer

Starchy endosperm

Germ or embryo
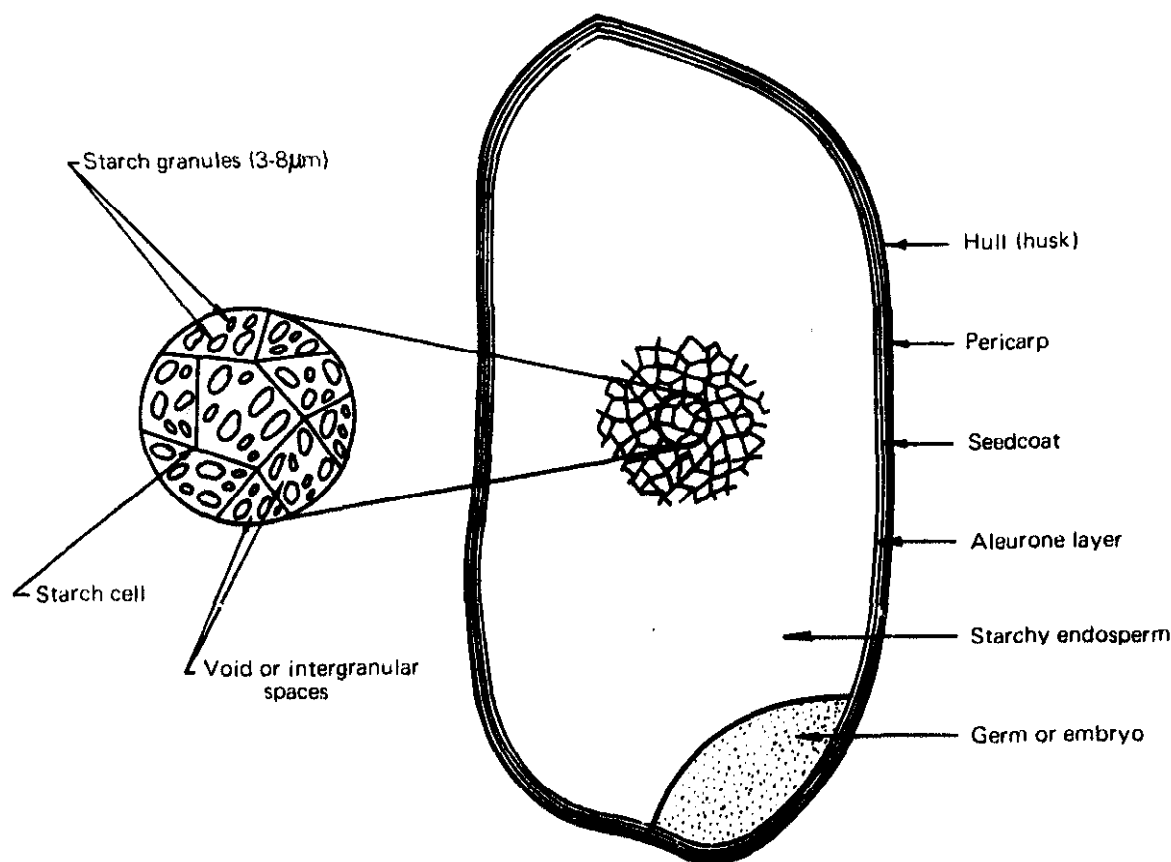
FIG. 94. Diagrammatic representation of the structure of a paddy grain in longitudinal section.

boldi 1965; Jones and Taylor 1933; Jones et al. 1946; Matz 1959; Mazumdar et al. 1960; Roberts et al. 1954; Shivanna 1971).

Premilling Treatments

Because the milling process has long been known to remove much of the vitamins and minerals from the grain, different types of pre-milling treatments of paddy have been devised to improve its milling, nutritional, cooking, and keeping qualities. The rice obtained from milling pretreated paddy is known as parboiled rice; whereas, the rice obtained from milling untreated paddy is known as raw rice or white rice. The different premilling treatments are described below.

Atapa

In the atapa treatment, which was originated in Bengal, India, paddy is soaked in water at room temperature for 24 h and then dried in the sun (hence the name atapa, or sun dried). The dried paddy is then milled by the traditional milling equipment, mortar and pestle, or in a husking mill (huller). During milling many of the grains are broken.

Balam

This treatment, which was also developed in Bengal, India, is slightly better than atapa because the paddy is sprinkled with hot water, which inflates the grain due to sudden thermal expansion. When the paddy is dried in the sun and milled, the hull is easier to remove.

Josh

During the josh (boiling) treatment, developed in Larkhana, Pakistan, the paddy is first sieved to remove the dirt. Large earthen pots filled with cleaned paddy and water are placed on a 15-cm layer of hull that is used as fuel. The pots are then heated, and remain on the fire all night. The next day the water is drained and the paddy is subjected to a second heating in shallow iron pans placed on the fire for 1 h. The paddy is then taken out of the pans and dried in the sun. Sometimes, soaking is done in iron tubes instead of in earthen pots. In this case, the water in the tubes is first heated to the boiling point and the fire is removed. The cleaned paddy is put in the tubes for 8 h. The water is then drained and the paddy is heated in shallow iron pans and dried as described earlier. Because the rice is semi-cooked, the hull easily separates in milling and there is no breakage of grains. In addition, it is claimed that such rice has better keeping quality.

Sela

In this treatment, which was originated in Saharanpur, India, paddy is soaked in water at room temperature for 24–48 h and then gently roasted in hot sand (80–90 °C). Experience is required for judging the correct temperature of the sand and the duration of roasting. The heat supplied should be just sufficient to evaporate the moisture from the wet paddy without causing parching of the rice. The roasted paddy is then further dried in the sun and milled.

Siddha

In the Siddha treatment, originated in Bengal, India, paddy is soaked in water at room temperature for 24 h, boiled for a few minutes, dried, and milled. In this method, rice from over-soaked paddy becomes dark-coloured; rice from over-boiled paddy becomes coarse in appearance; and rice from over-dried paddy shows poor milling quality.

Parboiling

Parboiling is one of the latest well-developed premilling treatments given to paddy to improve its quality. The different modifications parboiling made to the product were considered merely accidental; however, after the

introduction of mechanical milling, parboiling not only survived but even began to spread all over the world because of its economical and nutritional advantages (Gariboldi 1972; Kurien 1964).

Very little is known about its origin; however, since early times paddy has been treated with cold or hot water and dried before hand-pounding or milling. Parboiling may originally have been used merely for a hygienic treatment to clean the threshed grain, or because of its hardening effect and the consequent improvement in milling quality, or a combination of these (Kisan Krishi Yantra Udyog 1972; Kuppuswamy 1972). There is no record of who first discovered the process but there is no doubt that parboiling was being practiced in India long before it was known to other parts of the world (Ghose et al. 1960). Parboiling has been practiced in the United States, Italy, and British Guiana on a commercial scale since 1940 (Matz 1959).

Basic Concept of Parboiling

Before describing the various advantages, disadvantages, methods, equipment, and the quality of parboiled rice, let us first consider the structure of a paddy grain itself. Figure 95 shows cross sections of raw and parboiled rice (International Rice Research Institute 1969). The endosperm, which constitutes the major volume of the rice grain, is mainly composed of polygonal starch granules. The voids or intergranular spaces are filled with air and moisture. The presence of voids, fissures, and/or cracks, developed during maturity, causes breakage of rice during milling. This breakage may be eliminated by gelatinizing the starch, which fills the voids and cements the fissures and cracks.

Swelling of Starch

The starch granules may be swelled by soaking the paddy in water. During soaking, water penetrates into starch granules, forms hydrates by hydrogen bonding, and causes swelling. Starch granules exhibit only a limited

capacity for absorbing water, and swelling in cold water is due to the presence of hydrogen bonds between the amylose and amylopectin fractions of the starch. During hot soaking, energy supplied in the form of heat weakens the granule structure by disrupting the hydrogen bonds; therefore, more surface area is available for water absorption by the starch granules. This permits further hydration and irreversible granule swelling caused by the increase in the number of dissociated water molecules. This phenomenon is called gelatinization of starch. The temperature at which gelatinization takes place is known as the gelatinization temperature and is specific for each variety. At the end of the gelatinization process, the paddy has acquired a moisture content of about 45–50% and must be dried before further processing. (All moisture content valves quoted here are expressed on a dry basis.) The starch in the paddy grain may be gelatinized by either of two methods: (1) the paddy may be soaked in water at or above its gelatinization temperature for a time, which depends on the variety; or (2) the paddy may be soaked in water at or below its gelatinization temperature for some time to facilitate the uniform hydration of the rice kernel, and then heated to produce irreversible expansion and fusion of the starch granules. The heat should be moist, or the soaked paddy will start to dry. The best source of this heat is steam. This method is commonly used in practice.

Chemical Composition of Rice

Chemical analysis of rice shows that most of the nutrients, which are concentrated in the outer layers (bran and polish) of the rice kernel, are lost during milling (Houston and Kohler 1970). This loss of nutrients may be reduced to a certain extent either by consuming shelled or under-milled rice, or by making some of the nutrients present in the outer layers penetrate the kernel, so that they are not removed during milling. The former is not advisable because of consequent digestion trouble; however, if the paddy is soaked in water and subsequently steamed, the water soluble nutrients may be retained to some extent in the kernel.
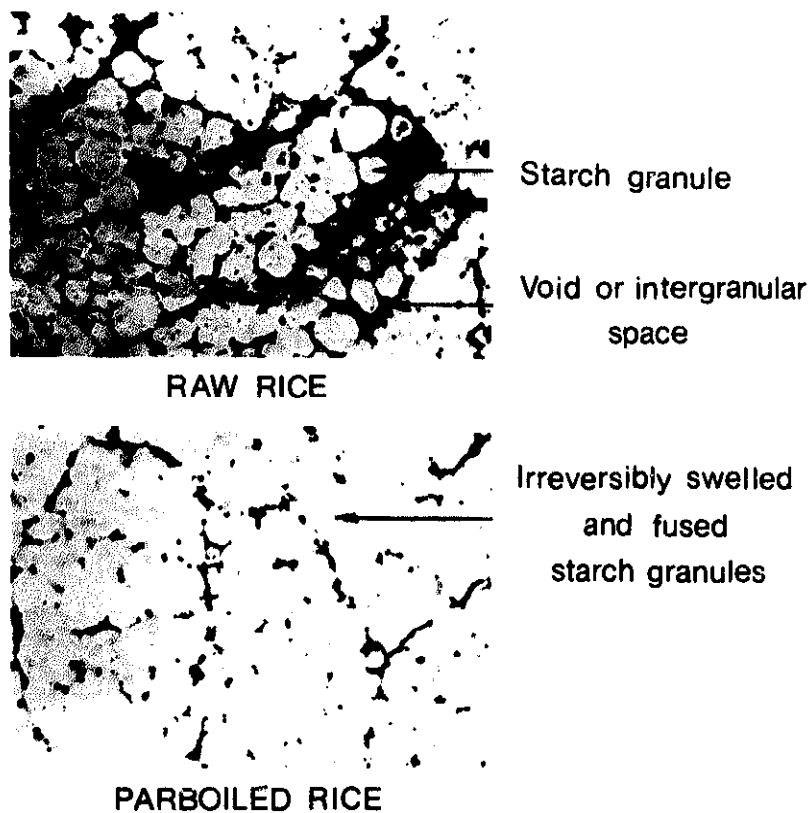
FIG. 95. Cross section of rice endosperm.

It may, therefore, be concluded that to minimize the breakage of rice and reduce the loss of nutrients during milling, the paddy should be soaked, steamed, and dried before milling. This premilling treatment of paddy is known as parboiling. The major objectives of parboiling are to: (1) increase the total and head rice yield of paddy; (2) prevent the loss of nutrients during milling; (3) salvage wet or damaged paddy; and (4) prepare the rice according to the requirements of consumers in certain parts of the world.

Advantages and Disadvantages of Parboiling

The parboiling process, developed by tradition in India and improved by various researchers, provides a unique tool for improving not only the milling quality but also other qualities of paddy. In general, the parboiling process has the following advantages:

(1) shelling of parboiled paddy is easier because the husk is split during parboiling; (2) the extra strength acquired by the rice kernel during parboiling helps reduce the number of brokens; (3) parboiled rice retains more proteins, vitamins, and minerals than raw milled rice of the same variety; (4) parboiled rice, because it is harder, is more resistant to insect infestation during storage compared to raw rice; (5) the loss of solids into the gruel during cooking is less in parboiled rice compared to raw rice; (6) parboiled rice withstands overcooking without becoming pasty; and (7) the bran from parboiled rice contains about 25–30% oil; whereas, raw rice bran contains about 15–20% oil. The heat treatment of paddy during parboiling destroys, to a certain extent, the lipase enzyme that is responsible for the hydrolysis of oil (development of free fatty acids); therefore, the oil is of a superior quality because it has a lower concentration of free fatty acids (FFA).

Parboiling has the following disadvantages: (1) heat treatment during parboiling destroys some natural antioxidants; therefore, parboiled rice develops more rancidity than raw rice during storage; (2) parboiled rice takes more time to cook to the same degree of softness than raw rice, and may develop a taste, texture, and characteristic flavour and colour not liked by many raw rice eaters; (3) because the parboiled paddy has a high moisture content for a long time, mycotoxins that are hazardous to human health may develop; (4) parboiled paddy must be dried from 45–50% to 14–16% moisture for proper milling and storing, which adds an extra drying cost to the total processing cost; (5) shelled parboiled rice is more difficult to polish because it is harder, and consequently the mill throughput capacity is lowered and the milling power requirement is increased; (6) parboiled paddy may choke the polisher because of the higher oil content of the bran; and (7) the parboiling process needs an extra investment of capital.

In spite of these disadvantages, the higher outturn of total rice (about 1–2%) as well as head rice brings in additional profit to the miller and at the same time ensures a lower price to the consumer (Central Food Technological Research Institute 1969). The comparative production cost of parboiled rice using one of the modern methods (Kisan Krishi Yantra Udyog 1972) is presented in Table 28 to illustrate the economic benefits that can be obtained from parboiling. Table 28 shows that the cost of production of parboiled rice is less than that of raw rice. The difference is about 5 paise/kg of rice produced. Nearly 50% of the total paddy produced in India is parboiled; therefore, there is scope for saving approximately Rs. 1000 million annually.

Characteristics of the Paddy for Parboiling

The paddy varieties preferred for parboiling are those that are the most brittle because of the soft structure of their endosperm and those that give a low output after milling because of special conditions associated with cultivation, harvesting, and drying. Varieties

TABLE 28. Comparative production costs for 1 t of raw and parboiled rice (Kisan Krishi Yantra Udyog 1972).

	Cost of raw rice (Rs.)	Cost of parboiled rice (Rs.)
Cost of paddy	500.00	500.00
Incidentals, transport, handling, etc.	12.00	12.00
Depreciation in gunny bags (6 times reused)	6.00	6.00
Charges for drying	10.00	—
Charges for parboiling and drying	—	18.00
Milling charges	23.00	23.00
Total cost:	551.00	559.00
Less realization from by-products:		
Brokens in raw rice (60 kg, @ Rs. 600/t)	36.00	—
Raw rice bran (29 kg @ Rs. 350/t)	8.75	—
Parboiled rice bran (28 kg @ Rs. 450/t)	—	12.69
Net cost of rice realized	506.25	546.40
Cost per kg (raw rice 620 kg and 60 kg brokens; parboiled rice 710 kg)	0.82	0.77
Packaging charge	0.02	0.02
Total cost per kilogram:	0.84	0.79

NOTE: (1) there is a difference in cost of 5 paise/kg of rice produced; and (2) assuming that about 50% of India's rice is parboiled there is scope for saving at least Rs. 50 × 20 × 10^6 = Rs. 1000 million/year.

that are long and slender are usually par-
boiled because they are fragile compared with
short or medium length grains, which stand
up better to the ordinary milling process (Gari-
boldi 1972). Scented and fine varieties, which
have good milling quality, are generally not
parboiled.

Some characteristics of the paddy affect the
final product both quantitatively and quali-
tatively (Gariboldi 1972): (1) the presence of
partially or fully shelled grains, which may be
destroyed or misshapen by the process, cause
the parboiling plant to function irregularly;
(2) the awn and hairiness of the husk may
make the soaking operation difficult because
of the tendency of the grains to float on the
surface of the water, which produces scum
and other waste materials; (3) the pigmenta-
tion of the husk and pericarp may be dissolved
during the soaking and steaming operations
and deepen the colour of the endosperm; (4)
bacterial infestation may cause a partial or
total darkening of the endosperm; and (5)
even minute injuries on the seed, caused either
mechanically or by insects, may lead to partial
discoloration of the parboiled rice.

Parboiling Process

Parboiling of paddy is a hydrothermal pro-
cess that may be defined as the gelatinization
of starch within the rice grain. During the
process, an irreversible swelling and fusion of
starch granules occurs that changes the starch
from a crystalline form to an amorphous one.
As a result of this transformation, the orderly
polyhedral structure of the compound starch
granules changes into a coherent mass (Rag-
havendra Rao and Juliano 1970).

Parboiling of paddy requires three steps:
soaking, steaming, and drying (Fig. 96). In
the soaking process the void spaces in the hull
and rice kernel are filled with water, and the
starch granules absorb water and swell, which
causes an increase in the volume of the paddy
(Ali and Pandya 1974). During steaming,
soaked paddy is exposed to steam heat for a
given duration and the starch present in the
rice kernel is gelatinized. Subsequently, the
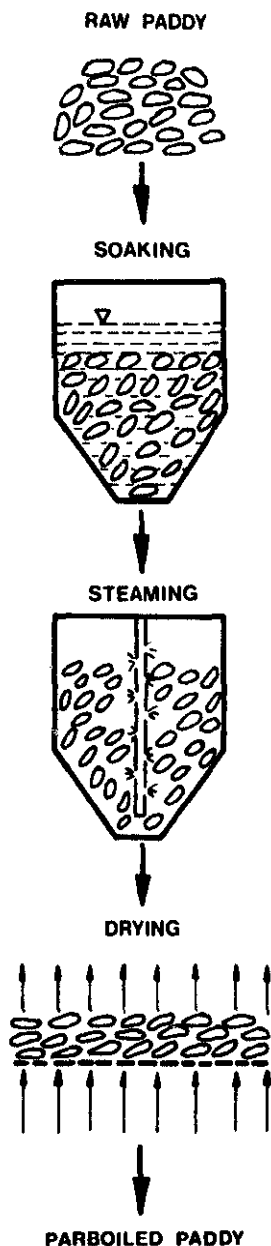
FIG. 96. The three steps required for parboiling.

paddy is dried to 16% moisture content, which
imparts the hardness that the grains require for
milling.

Physicochemical Changes During Parboiling

The most notable change during parboiling
is the gelatinization of starch and the disinte-
gration of protein bodies in the endosperm

(Raghavendra Rao and Juliano 1970). As a result, the starch and protein expand and fill the internal air spaces. The starch granules are closely appressed, which creates strong cohesion between them. Both fissures and cracks present in the endosperm are s d, making the grain translucent and hard and tough enough to withstand milling stresses. This increases the total yield of edible rice and minimizes the number of broken grains.

The colour of the rice changes from white to a yellow or yellowish brown depending upon the different process variables, such as paddy variety, soaking temperature and time, steaming pressure and temperature, and other postharvest factors that will be discussed later. There is little colour difference between raw and parboiled rice after cooking; however, parboiled rice takes a little longer time to cook to the same degree of softness than raw rice of the same variety.

Less protein and starch are lost from parboiled rice into the cooking water (Raghavendra Rao and Juliano 1970). The diffusion and heat-sealing of B-vitamins and other water soluble nutrients into the endosperm during parboiling and the lesser removal of bran during polishing enhance the nutritive value of parboiled rice. The presence of vitamin E is particularly noted in parboiled rice (Borasio and Gariboldi 1965). Slight dextrinization of the starch and destruction of the lipase enzyme occurs during parboiling (Kisan Krishi Yantra Udyog 1972). The presence of dextrins aids in digestion of cooked parboiled rice and contributes to the agglutination and firmness of the cooked product. However, the heat treatment during parboiling causes destruction of some natural antioxidants, and may result in increased rancidity of parboiled rice during storage.

Principles of Parboiling

Theoretically, soaking of paddy can be done at, or below, its gelatinization temperature. The lower the temperature used, the slower is the process of soaking and vice versa (Ali

and Pandya 1974; Bhattacharya and Subba Rao 1966a). However, the temperature should not be more than 75 °C, or the paddy will be cooked. Soaking time can be reduced by subjecting the paddy to vacuum for a few minutes before soaking and/or by soaking under pressure in hot water.

Heat for gelatinization of the starch is supplied by saturated steam. The higher the temperature of the steam and the longer the steaming time, the harder the rice and the darker its colour. Keeping steamed paddy in a heap is equivalent to prolonged steaming and induces the same effect.

Parboiled paddy may be dried in the shade, in the sun, or with hot air. Shade drying takes longer but gives an excellent milling quality. Rapid drying in the sun or with hot air causes higher breakage during milling. In continuous drying, breakage starts as the moisture content reaches about 18% and increases rapidly with further drying (Bhattacharya and Indudharaswamy 1967). Therefore, the most efficient practice would be to dry in two passes, with a tempering period, to a moisture content of about 20%.

Soaking of Paddy

Paddy, being a hygroscopic material, can absorb water both as a vapour and as a liquid, and thereby swells. The process of simultaneous water absorption and swelling is known as soaking, steeping, or imbibition. It is basically a diffusion process. The movement of water into the paddy will continue as long as the vapour pressure inside the grain is less than that of the soak water and will stop when equilibrium is reached.

Two conditions appear to be necessary for soaking: (1) a certain affinity must exist between absorbent and absorbate; and (2) a diffusion pressure gradient must exist between the water vapour of the absorbent and that of the material to be imbibed. The diffusion pressure of dry paddy is practically zero; therefore, when it is immersed in water, a steep diffusion pressure gradient is established and water moves rapidly into the grain.

Mechanism of Soaking

Soaking is the result of different phenomena, such as, molecular absorption, capillary absorption, and hydration (Ali and Ojha 1975a). During soaking of paddy, water molecules first adhere to the surface of the hull and then penetrate through the micropores of the hull into the rice kernel where they may be retained in voids or intergranular spaces due to capillary absorption. Some of the water molecules will be absorbed by starch granules; whereas, others will enter into the lattice of the starch molecule where they will be held as water of hydration. Experimentally, it is very difficult to determine precisely what percentage of the moisture content is held by each of the different phenomena (Mohsenin 1968).

Volume and Energy Changes

There is always a concomitant increase in the volume of paddy with soaking. However, the final volume of the soaked paddy is always less than the sum of the initial volume of paddy and the volume of the water absorbed (Ali and Ojha 1975; Mohsenin 1968). This is due to the fact that some of the absorbed water occupies the minutes spaces in the paddy grain and, therefore, produces no swelling. Moreover, the absorbed water molecules are held with a greater force on the absorbing surface and occupy less space than when in the free state.

The soaking process always results in the release of heat. When water molecules are absorbed a considerable amount of their kinetic energy is lost as heat. The maximum evolution of heat occurs during the initial stage of soaking because a large portion of the water absorbed in the beginning is more firmly absorbed than water absorbed later. However, the actual temperature increase during soaking of the paddy is very small and may be disregarded (Ali and Ojha 1975a).

Amount of Water Absorbed

When soaking paddy, it is generally desirable to know the amount of water that has been absorbed at a particular temperature over a given time. Soaking involves diffusion of water into a swelling medium accompanied by immobilization of diffusion substances. In some cases leaching is also involved.

The relationship between moisture content of the paddy at different soaking temperatures and time indicates a direct relationship between the temperature used and the rate of the process (Fig. 97). Initially, the rate of soaking is very high at all temperatures, but it gradually decreases with increased soaking and tends to zero at soaking temperatures of 30 and 60 °C as shown in Fig. 98 (Ali and Ojha 1975a). However, at temperatures equal to or greater than the gelatinization temperature, following gelatinization of the starch and bursting of the grain, the soaking rate again increases. After some time, the rate decreases and comes to zero when the starch reaches its equilibrium moisture content.

The rapid rate of water uptake at the beginning of soaking is due to three reasons: (1) the hull absorbs water very quickly and becomes saturated; (2) the space between the hull and the rice kernel becomes filled with water immediately after the commencement of soaking; and (3) the capillary action of the shallow pores in the pericarp causes rapid absorption. The slow increase in the moisture content of the paddy after the initial stage of soaking suggests that the absorption of water by the kernel itself proceeds more slowly.

The dependence of soaking rate on temperature may possibly be explained as follows: (1) Air in the pore spaces of the paddy grain, which resists water entry, expands and leaves the pore spaces with the rise in temperature; therefore, water can replace the air in the pore spaces; (2) Water is a dipole compound and is regarded as a polymer of hydrogen bonded water molecules. As the water becomes warmer, more and more of the hydrogen bonds are broken. Therefore, with a rise in soaking temperature, the hydrogen bonds in the water and the hydrogen bonds in the starch granules, which hold the micellar structural units together, tend to dissociate. The smaller dissociated water molecules at a high energy level are, therefore, able to permeate the weakened starch structure and gradually hydrate many of the hydroxyl groups of the
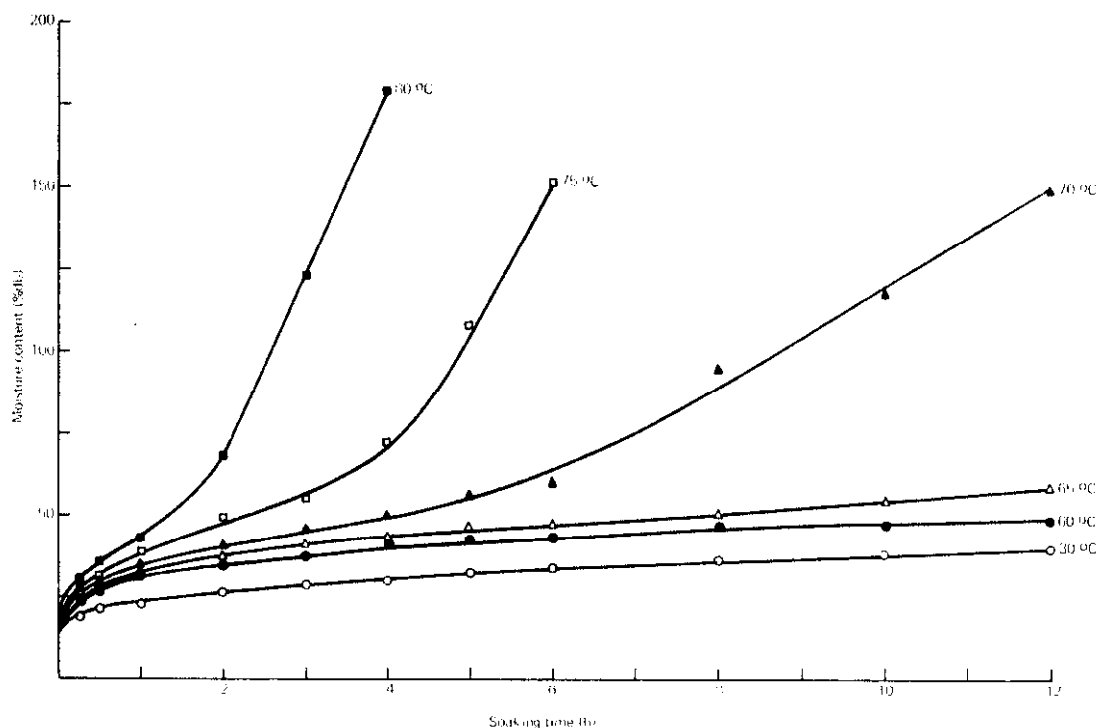
Fig. 97. Soaking curves for IR8 at different temperatures.

starch molecules; (3) Absorption of water by paddy is a diffusion process and depends on a diffusion coefficient that increases with the rise in temperature because of changes in some of the properties of water, such as, vapour pressure, viscosity, density, and surface tension. Therefore, soaking proceeds at a faster rate at higher temperatures and vice versa. Figure 99 shows that the absorption of water by paddy proceeds in two distinct phases. The first phase of soaking continues until the paddy gains 24–45% moisture, depending upon the soaking temperature. The second phase starts after this. Paddy absorbs water very slowly when soaked below the gelatinization temperature (30 and 60 °C) and reaches an equilibrium moisture content (Fig. 100), but at higher temperatures, when the paddy grains reach 40–45% moisture content, the grains start to burst and the rate of soaking becomes very fast. The moisture content of the paddy when the first phase of soaking ends and the second phase starts may be defined as the critical moisture content in soaking. Its

Table 29. Average value of the critical moisture content (dry basis) of different varieties of paddy during soaking at various temperatures (Ali and Ojha 1975a).

Soaking temperature (°C)	IR8	Patnai-23	Sitasal
30	40	40	36
60	45	42	42
65	59	43	45
70	60	45	45
75	60	58	57
80	53	57	52

value depends both on the soaking temperature and the variety of the paddy (Table 29).

Varietal Differences in Soaking Characteristics

The soaking curves of different varieties of
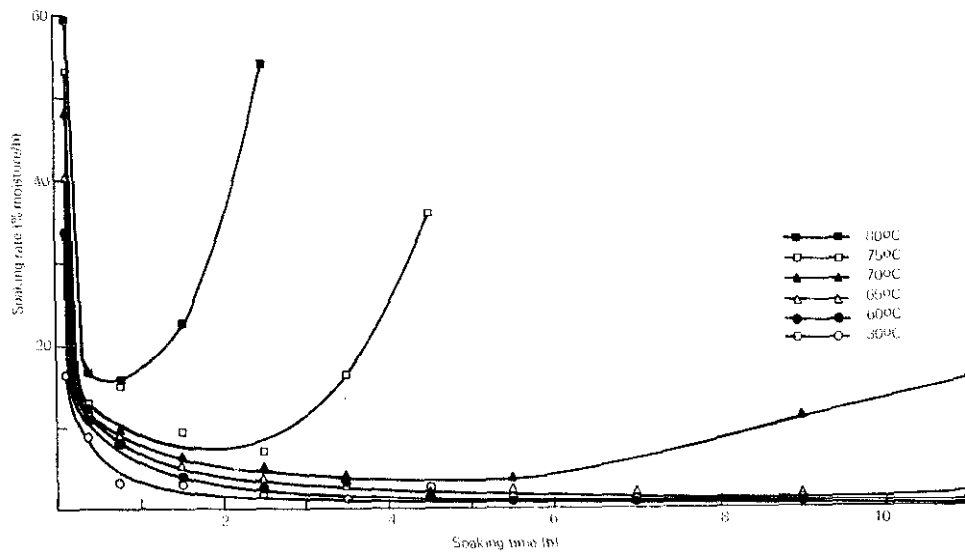
FIG. 98. Soaking rate versus time for IR8 at different temperatures.
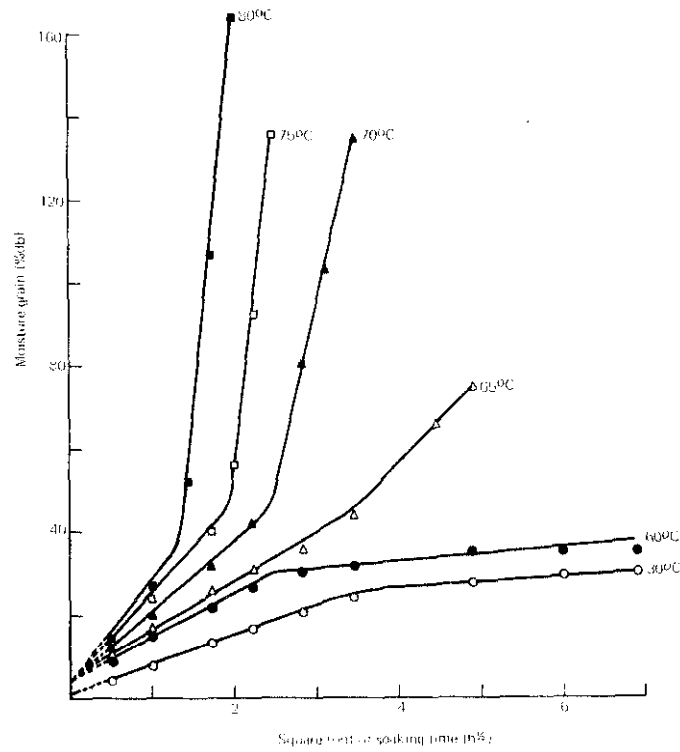
FIG. 99. Moisture gain of IR8 as a function of square root of soaking time at different temperatures.
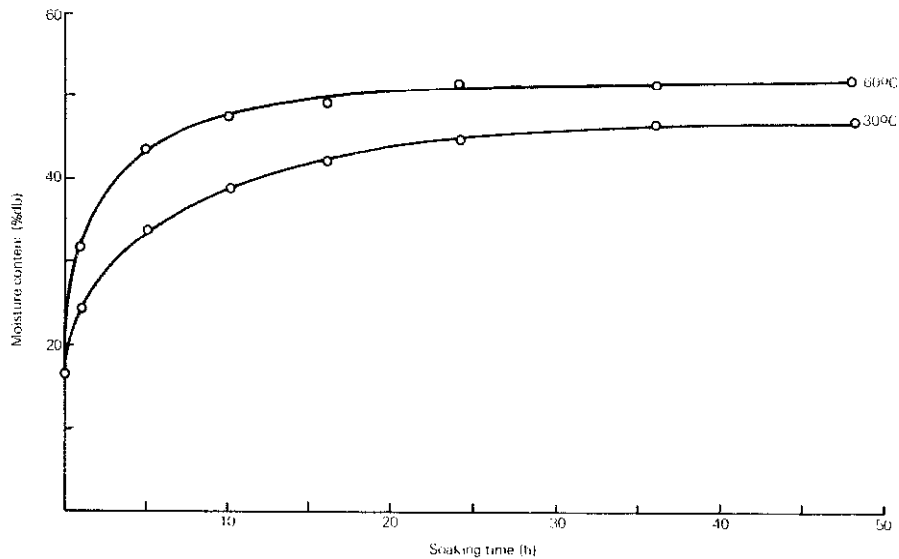
FIG. 100. Moisture content versus soaking time for IR8 at 30 and 60 °C.

paddy are similar to IR8. However, in a study of three varieties, the rate of soaking was IR8, Patnai–23, and Sitasal for all soaking temperatures (Ali and Ojha 1975a). This may be due to differences in the gelatinization temperatures and the physical characteristics of the grains. From the soaking curves it was inferred that the gelatinization temperature of IR8 was in the range of 65–70 °C; whereas, the gelatinization temperature of the other two grains was in the range of 70–75 °C. The soaking rate of paddy shows up varietal differences and indicates the importance of testing the soaking characteristics of each variety.

Initial Moisture Content Versus Water Absorption

Experimental results (Ali and Ojha 1975a) show that the initial moisture content of the paddy does not affect its soaking characteristics. Although differences may exist in the initial moisture content of the paddy, the differences decrease with soaking time. Therefore, after the paddy is soaked for 2.5, 4, and 24 h at temperatures of 80, 70, and 30 °C, respectively, the moisture content of the paddy is practically the same irrespective of the initial moisture content. This shows that a difference of 5–10% in the initial moisture con-

tent of the paddy may not make any difference to the optimum soaking time required during parboiling. Therefore, different lots of paddy with different initial moisture contents can be mixed safely for parboiling without any loss in quality or quantity.

Swelling of Paddy

Soaking of paddy is always associated with an increase in volume. The change in volume of paddy at different moisture contents was calculated by the method of Ali and Pandya (1974). The moisture content of the paddy was increased by soaking it in water at 70 °C, which is the most common temperature used for soaking in the modern methods of parboiling.

The swelling curve (Fig. 101, curve A) extrapolates to zero at zero moisture content and also indicates that the swelling increases at a relatively slow rate up to about 50% moisture content and then increases at a higher rate. The comparatively slow increase in the volume of paddy during the first phase of soaking may be due to two reasons: (1) part of the water absorbed may be utilized in wetting the hull and filling the space between the hull and the pericarp and in filling the pore spaces in the endosperm; therefore, the water pro-
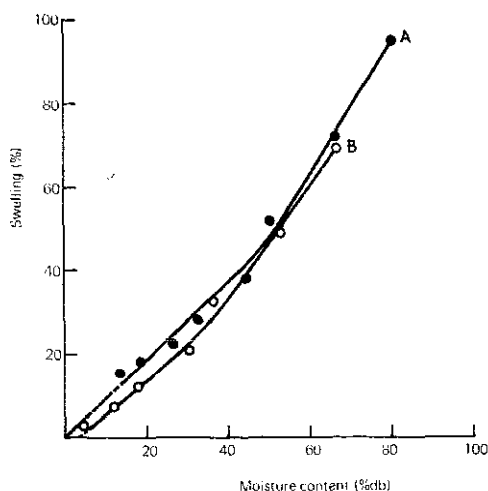
FIG. 101. Relationship between swelling and moisture content for IR8.

duces only a very small increase in the volume of paddy; and (2) a considerable amount of the water is held by molecular absorption and because of this, an absorption compression occurs that causes a decrease in the total volume of the paddy-water aggregate (Mohsenin 1968). The higher rate of swelling above 50% moisture may be due to the bursting of the grain, which exposes more of the kernel area to water and enables the paddy to absorb more moisture. At higher moisture levels, increases in the moisture content of the paddy result in approximately equivalent volume increases (Mohsenin 1968).

When percentage swelling is plotted as a function of moisture gain, by considering the initial moisture content of paddy to be zero moisture gain and by calculating the amount of swelling based on the volume at the initial moisture content, the curve does not extrapolate to zero at zero moisture gain (Fig. 101, curve B). This is contrary to curve A (Fig. 101). This can be explained by considering the paddy grain at zero moisture content to be in a shrunken state. As the moisture content of the paddy increases, the hull and pericarp expand until they reach more or less their normal size, which is their size when the moisture content is in equilibrium with the atmospheric conditions. This moisture content generally varies from 10 to 20%, depending upon the atmospheric temperature and relative humidity. At this stage, further increases of 4–5% in the moisture content may not produce any noticeable swelling because the paddy is at its normal size and resists any change in its dimensions. As the moisture level continues to rise, the paddy swells and increases in size until the hull splits to relieve the stresses caused by the increasing swelling force. After this, the swelling proceeds as explained earlier.

Steaming of the Soaked Paddy

The use of steam for gelatinizing the starch in the paddy grain is preferable to other methods of heating because it does not remove moisture from the soaked paddy, rather it adds moisture by condensation, which increases the total moisture content of the grain (Gariboldi 1972). The other advantages of steam are that its high heat content is applied at constant temperature, it is sterile, and it can be used to produce power before it heats the paddy. During steaming, the following points should be considered (Gariboldi 1972): (1) whether the steam is saturated or superheated; (2) the pressure of the steam, which determines the temperature at which heat is transmitted; and (3) the steaming time, which determines the total heat supplied to the paddy to cause the gelatinization of the starch.

The total amount of heat applied to the paddy is equal to the heat provided by the soaking and steeping water plus the heat derived from the condensation of steam during the steaming operation.

The temperature of the steam has a considerable effect on the colour of the rice although the causes are not yet fully understood. Apart from the spread of colouring pigments contained in the husk and bran, it seems that colouring of the endosperm is caused by absorption of reducing sugars that react with the amino acids, and by fusion of the aleurone layers of the endosperm with the starchy core (Gariboldi 1972). However, by steaming the paddy with nonpressurized steam (at 100 °C), as in the traditional oriental methods, only small variations are found in the colour and quantity of soluble starch and in the amount of swelling of the milled parboiled rice (Gariboldi 1972).

Generally, saturated steam at a pressure of 1–5 kg/cm² is used for steaming the soaked paddy in the different methods of parboiling (Bal et al. 1974). The duration of steaming is dependent upon the quantity of paddy to be steamed. For small batches steaming takes 2–3 min; whereas, larger batches of about 6–8 t take about 20–30 min (Bal et al. 1974). It has been reported that splitting of the husk can be taken as an indication of completion of the steaming process (Agrawala 1963; Central Food Technological Research Institute 1969; Ghose 1963; Jones and Taylor 1933; Jones et al. 1946; Mecham et al. 1961) although it is not a necessary condition and the paddy can be properly parboiled without any splitting of the husk (Bal et al. 1974).

The steam requirement per tonne of paddy parboiled in a modern parboiling plant using steam at a pressure of 4–5 kg/cm² is about 120 kg for soaking, 60 kg for steaming, and 20 kg in losses (Bal et al. 1974; Central Food Technological Research Institute 1969).

Drying Characteristics of Steam-Parboiled Paddy

Drying of steam-parboiled paddy is essential for proper milling and storing, but it is different from drying raw paddy because the steamed paddy has a high moisture content (45–50%) and is hot. The main aim of the drying process is to reduce the moisture content to 14–16% without causing cracks or stresses in the rice caryopsis, which may lead to breakage during milling.

The manner in which this excess moisture is removed is of considerable importance. If the moisture is removed at a very slow rate, microorganisms will grow and partially or fully spoil the parboiled paddy. On the other hand, if drying is done rapidly and continuously, cracks may develop and the rice will break during milling. However, if parboiled paddy is uniformly dried by any means (shade, sun, or hot air), practically no breakage will occur. Improper drying conditions may result in as high as 100% breakage; therefore, parboiled paddy should be dried with great care.

It has been reported (Bhattacharya and Indudharaswamy 1967; Central Food Tech-

nological Research Institute 1969) that drying of parboiled paddy in the shade will give less than 1% brokens; however, if the same paddy is dried rapidly in the sun or by hot air to the same moisture level, enormous breakage (20–100%) may occur. It is, therefore, the rate of drying that is the main factor that controls the breakage of rice.

When parboiled paddy is dried rapidly, a steep moisture gradient develops between the surface and the centre of the kernel. This sets up a stress, and at a certain stage the kernel relieves the stress by cracking. These cracks are irreversible and set up lines of weakness, along which fractures easily occur under the mechanical stresses of milling. This behaviour is also observed in the drying of raw paddy.

During drying, two points are of great importance. First, breakage does not occur throughout the drying process. It occurs only when the moisture content reaches and then crosses 18% (Bhattacharya and Indudharaswamy 1967), no matter how fast the drying (Fig. 102). After that, breakage increases sharply. Second, the cracks do not develop during drying, but over a period of 2 h after the drying has been terminated (Bhattacharya
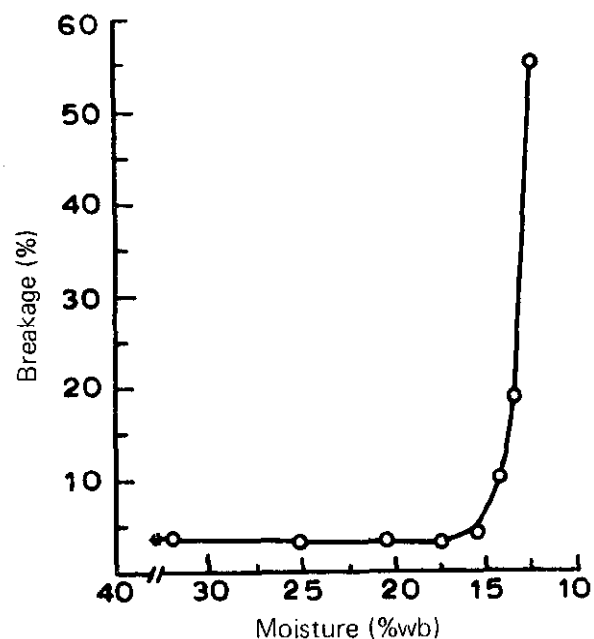
Fig. 102. Change in milling quality of parboiled paddy during continuous drying in an LSU drier.

and Indudharaswamy 1967). Drying of parboiled paddy should be done in two passes to avoid the breakage of rice during milling, although some successful experiments have been carried out in which the parboiled rice was dried until the moisture content was low enough for milling (Bhattacharya and Indudharaswamy 1967; Rama Rao and Bal 1973). In actual practice the two methods that are commonly used are sun drying and mechanical drying.

Sun Drying

Drying of parboiled paddy in a drying yard using the sun's energy is widely practiced by both conventional rice mills and small scale farmers. Through experience and practice over the decades, the process has been developed into a highly skilled and efficient method of large scale drying in spite of major drawbacks, such as, dependence on weather conditions and inherent losses during the drying operation (Bhattacharya and Ali 1970).

In India, as well as in most of the Asian countries, drying is carried out on large paved yards attached to the rice mills. A large number of workers constantly turn and mix the paddy with a number of indigenous wooden implements to achieve rapid and uniform drying.

The paddy is normally steamed in the evening and kept on the drying floor in equally spaced heaps of about 2 quintals (200 kg). Early the next morning, the paddy is spread to a thickness of 2–3 cm on the drying floor with a wide wooden board. After spreading, the paddy is continuously and systematically stirred and turned: (1) the spread paddy is raked into long ridges 20–30 cm high by the wooden spade to turn the paddy; (2) the paddy is thrown in either direction from the ridges to distribute the paddy uniformly over the drying area; (3) the paddy is spread by feet and then combed and stirred by a spiked plank that levels the paddy layer uniformly over the drying floor; and (4) the uniformly levelled paddy is turned by foot.

During these operations, the grain is continually mixed; therefore, each grain gets approximately equal exposure to the sun.

These operations are repeated until the paddy is evenly dried to a moisture content of about 18–20%. Then the paddy is heaped and covered with mats or with thick caps made of straw and tempered for about 2–3 h. The tempered paddy is again spread and dried for about 1–2 h in the evening to complete the drying to 14–16% moisture content. The dried paddy is heaped on the drying floor, covered with straw caps or a tarpaulin, and left in the yard overnight. The next morning, the paddy is put into gunny bags and transported to the rice mill.

In hot and dry weather the paddy dries in a few hours, while in cold, cloudy, or humid weather it may take 2 days. During the night, or when rain comes, the paddy is heaped and covered. Depending on its size, a mill can handle 20–100 t of paddy this way every day (Bal et al. 1974).

Figures 103 and 104 show the general nature of moisture removal from the grain during sun drying. The total drying time is about 6–7 h during summer, and about 9–10 h during winter due to shorter day length and weaker radiation from the sun. The effect of tempering may be distinctly seen in Fig. 103. The grains are tempered for about 2–3 h after 5 h of drying in the sun. There is a steep increase in the moisture content of the grain after tempering because of migration of moisture from the inside to the surface of the grain.

Figure 104 shows the rate of moisture removal with respect to drying time. This curve is similar to the one obtained for hot air drying and shows two distinct zones of drying: (1) a zone of constant rate drying, which is limited to just 1 h of drying and a zone of first falling rate of drying (C–D); and (2) a zone of second falling rate of drying (D–E).

Grain temperature closely follows floor temperature (Fig. 105). The grain temperature was approximately $2 C°$ lower than the floor temperature, and the maximum grain temperature observed was 36.5 °C. High grain temperatures can cause cracks in the kernel; however, it appears that the parboiling process hardens the rice kernel so that the high grain temperature during the drying process does not produce cracks in the kernels.

The milling quality of parboiled paddy is not
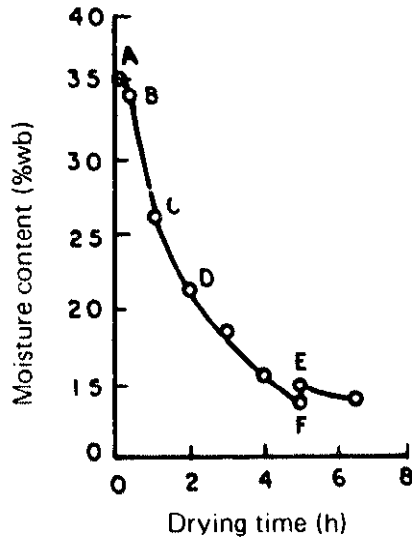
FIG. 103. Variation of moisture content of paddy with drying time (sun drying): AB = heating period; BC = constant rate period; CD = first falling rate period; DE = second falling rate period; and EF = tempering for 2.5 h.
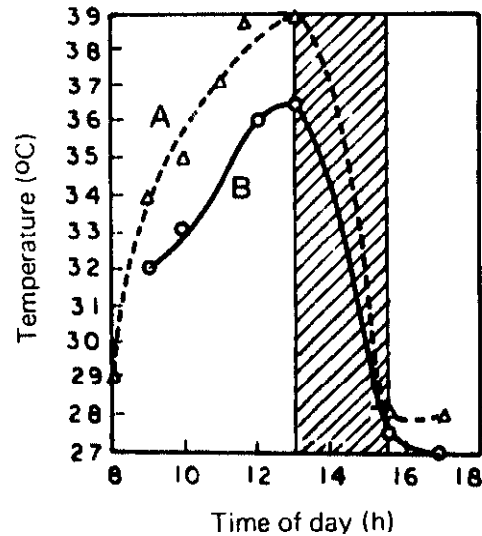
FIG. 105. Variation of grain temperature and floor temperature with time of day (sun drying): tempering from 13:00 to 15:30; A = drying floor temperature; and B = grain temperature
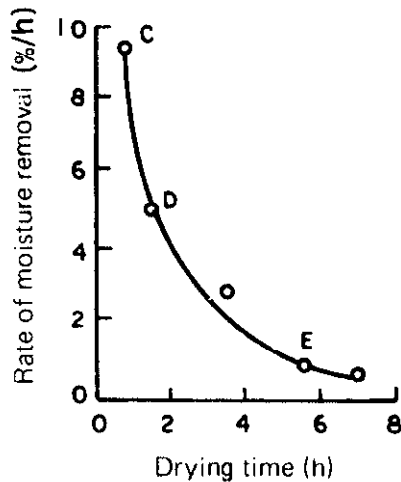

FIG. 104. Variation of drying rate with drying time (sun drying): CD = first falling rate period; and DE = second falling rate period.

affected by sun drying. A total yield of 72.5% and a head yield of 69% are the average figures for milling quality of parboiled paddy. Therefore, sun drying seems to be an effective means of drying parboiled paddy wherever facilities for the process are available. Further improvements in both techniques and facilities, which

are based on scientific studies, are desirable to make this method more effective.

Case studies conducted by the Rice Process Engineering Centre at various commercial rice mills have shown that the total time required to dry parboiled paddy is 8–10 h in summer and 13–15 h in winter (Bal et al. 1974). They have also indicated that one female labourer can comfortably handle about 1 t of paddy during the drying operation. From these studies, the cost of drying was calculated to be about Rs. 9–10/t of dried paddy. They assumed that about 0.2% of the paddy was lost to birds, rodents, and insects and corrected for this loss in their estimate of the drying cost.

Mechanical Drying

Mechanical drying of parboiled paddy is of quite recent origin. Hot air is forced through the grain, which evaporates and carries away the moisture. Louisiana State University (LSU) continuous flow driers are usually used for drying parboiled paddy. The air is heated by an oil burning furnace or a steam heat exchanger. In India, most of the rice mills are now using the husk as fuel for generating the steam. The steam generated by burning the

husk obtained during milling is sufficient for the parboiling and drying operations (see "Estimate of Heat Required for Parboiling").

Very little research has been done on the drying of parboiled paddy; therefore, the present method of mechanical drying is based on the cumulative experience of the engineers and operators who operate the mechanical driers under different processing conditions. Presently, the drying of parboiled paddy is done in two passes that are separated by a tempering period. Each pass requires 0.5 h to load the drier, 2 h to recirculate the paddy while the hot air is blown through it, and 0.5 h to unload the drier. During the first stage of drying, the moisture content is reduced from about 50 to 25%. This is followed by 8–10 h of tempering to equalize the moisture within the kernels. The tempered paddy is then dried to 14–16% moisture during the second pass.

Most of the moisture in freshly parboiled paddy is surface moisture. The rate of removal of surface moisture from the grain is dependent upon the evaporating capacity of the drying air, which increases with temperature. However, after removal of the surface moisture, the rate of moisture removal is considerably reduced and depends upon the rate of moisture migration from the centre of the grain to its surface, which depends on the characteristics of the grain. Therefore, an increase in the temperature of drying air at this stage does not increase the drying rate. Unlike drying raw paddy, it is possible to use very high temperatures to dry parboiled paddy because of its increased hardness. To achieve faster moisture removal, drying air at a temperature as high as 120 °C is being used in commercial parboiling and drying plants (Bal et al. 1974). Due to the very high cost of the fuels (furnace oil) used for heating the air, astronomical figures for the cost of drying parboiled paddy (Rs. 50–120/t of paddy) have been reported (Bal et al. 1974). From the results of field experiments conducted by the Rice Process Engineering Centre, a combination of drying air temperatures has been determined to ensure optimum performance of the mechanical drier. To remove the bulk of the surface moisture during the first drying pass, the temperature of the drying air is kept at 95–100 °C. However, during the second drying pass, when moisture from the inner part of the grain is to be removed, the temperature of the drying air should be kept at 75 °C because a higher temperature will not increase the drying rate but will only result in an increased heat loss in the exhaust air.

Methods of Parboiling

The methods of parboiling may be classified into three groups (the name in parenthesis indicates where the method was developed or is being studied):
(1) Traditional methods
    (a) Single boiling
    (b) Double boiling
(2) Modern methods being used
    (a) CFTRI method (Indian)
    (b) Jadavpur University method (Indian)
    (c) Converted process (American)
    (d) Malek process (American)
    (e) Avorio process (Italian)
    (f) Cristallo process (Italian)
    (g) Fernandes process (Surinam)
(3) Modern methods under study
    (a) Brine solution method (Indian)
    (b) Kisan continuous method (Indian)
    (c) Pressure parboiling method (Indian)
    (d) RPEC method (Indian)
    (e) Sodium chromate method (Indian)

Traditional Methods

The traditional process consists of soaking in water at room temperature for 24–48 h or more, steaming in kettles, and drying in the sun. A flow diagram of a traditional parboiling plant is shown in Fig. 106.

Single Boiling Method

Paddy is soaked in ordinary water for 24–72 h and then transferred to cylindrical iron kettles for steaming in small batches under atmospheric pressure. The parboiled paddy is then dried in the sun before milling.
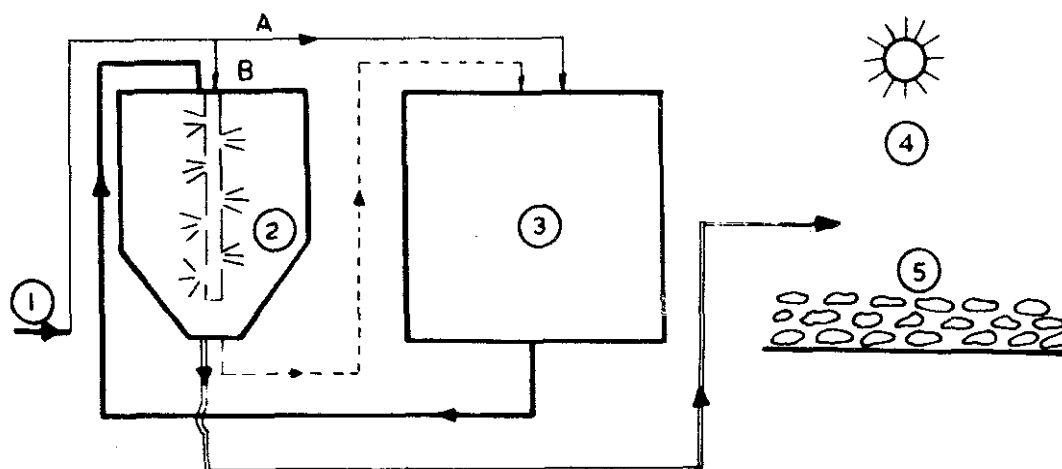
FIG. 106. Flow diagram of a traditional parboiling plant: (A) raw paddy goes to soaking tank directly (in single boiling method); (B) raw paddy goes to steaming kettle for first steaming and then to the soaking tank (in the double boiling method); (1) raw paddy; (2) steaming kettle; (3) masonry soaking tank; (4) sun; and (5) drying yard. Flow path of paddy: ———raw paddy; – – – first steamed or hot paddy; ▬▬▬ soaked paddy; and ═══ parboiled paddy. Note: handling of paddy is done by manual labour.

Double Boiling Method

In this method, steam is injected into the raw paddy in the steaming kettle before soaking. This hastens the soaking process. The hot paddy raises the temperature of the soak water to 45–50 °C, which reduces the soaking time to 24 h. Thereafter, soaked paddy is steamed as in the single boiling method. Sometimes, the soak water itself is heated to about 50 °C before the raw paddy is dumped into it. In this case, the first steaming of the raw paddy is not required.

The traditional method of parboiling has the following disadvantages: (1) during prolonged soaking, fermentation starts and the paddy acquires a smell; (2) it is conducive to the development of mycotoxins, such as alfatoxins, which are known to be quite harmful to humans; (3) in the process of drying, loss due to manual handling and consumption by birds, rodents, and insects occurs and may amount to about 1.5–2.0%; (4) sun drying is quite uncertain and is dependent on bright sunny weather; (5) sometimes an entire batch of parboiled paddy is spoiled because of delayed drying; (6) unhygienic conditions exist as a result of people treading on the paddy and contamination by dust and birds; (7) it re-

quires a large area of land for drying; and (8) its labour requirement is high.

The main hazards that can be expected in traditional methods are the retention of a fermented smell in the parboiled rice after milling and the possible development of mycotoxins. However, parboiled rice is always good in other aspects. The modern methods being used in different countries have been very successful in overcoming the above limitations.

Modern Methods Being Used

CFTRI Method

This is one of the modern methods of parboiling paddy employed in India, Pakistan, and Ceylon. It was introduced by the Central Food Technology Research Institute (CFTRI), Mysore, India, in the mid-fifties. Large scale adoption of this method and production of parboiled paddy were started with the introduction of mechanical driers (LSU-type) in modern rice mills during the past few years. At present a few hundred thousand tonnes of paddy are parboiled in India by this method.

Parboiling tanks are filled with clean water that is heated to a temperature of about 85 °C by passing steam through the coils inside the

tank (Fig. 107). Sometimes, hot water is prepared in a separate hot water tank before it is pumped into the parboiling tanks. The second process saves time and increases the capacity. Paddy is dumped into the hot water as quickly as possible. In a fully automatic system the paddy is lifted by an elevator and dumped into the parboiling tanks for soaking. The resulting temperature of the paddy-water mixture in the tanks stays at about 70 °C. The soak water can be recirculated into the hot water tank to maintain a constant temperature of 70 °C. After letting the paddy soak for 3–3.5 h, the soak water is drained and the water discharge valve is left open to remove the water that condenses during steaming. Soaked paddy is exposed to steam heat by letting steam at a pressure of about 4 kg/cm^2 through the open steam coil. Splitting of the husks usually indicates completion of the parboiling process. After the steaming is complete, the paddy is removed for drying by opening the bottom door. If a mechanical drier is to be used, the parboiled paddy is conveyed to the drier by a conveyor and an elevator. If the parboiled paddy is to be sun dried, it is transported to the drying yard either in push carts or in baskets. Mechanical drying is preferable to sun drying because it saves space and minimizes the cost of production.

Before the paddy is fed into the parboiling unit, it is desirable to remove chaff, dirt, and other impurities by passing the paddy through a cleaner. Greater cleanliness can be achieved by washing the paddy in a separate tank before it is dumped into the parboiling tanks. In this operation, even light chaff and heavy stones can be separated from the paddy.

The CFTRI method of parboiling has the following advantages over the traditional method of parboiling (Central Food Technology Research Institute 1969): (1) there is a reduction in soaking time to 4 h, which considerably reduces the processing time and increases production; (2) the bad smell is entirely eliminated; (3) most of the microorganisms originally present will be destroyed because the paddy has been soaked in hot water and steamed; (4) the turnover of capital investment on the paddy is faster; (5) the rice can be prepared on short notice depending upon
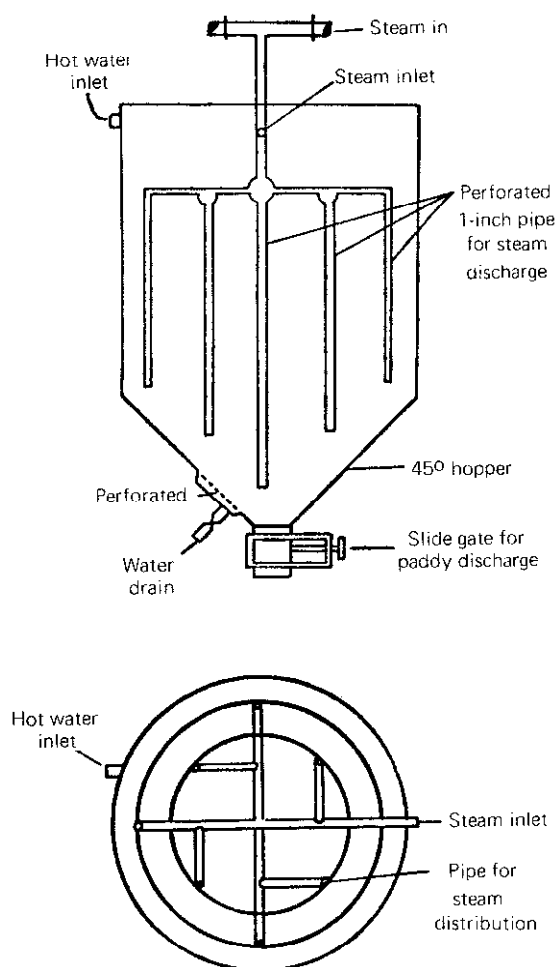
FIG. 107. Inside details of a parboiling tank (not to scale).

the market demands; (6) a yellow colour can be easily obtained in the rice to suit the needs of customers; (7) there is a reduction in labour charges; (8) the water requirement of this method is smaller than the cold soaking method because frequent changes of soak water are not necessary; (9) the yield of rice is reported to be slightly higher; (10) bran obtained from paddy parboiled by the CFTRI process is more stable than bran obtained from the traditional method; and (11) rice millers who have used this process claim that paddy parboiled by the CFTRI method is easier to shell and suffers less breakage during milling than paddy produced in the traditional method.

The size of the parboiling plant depends on the daily requirement for parboiled paddy by

the rice mill. For example a 2 t/h rice mill needs a parboiling plant with a capacity of 48 t/day and a 4 t/h rice mill requires a plant with a capacity of 96 t/day.

During parboiling, the water requirement is about 1.25 times the weight of paddy to be parboiled and the requirement for steam is about 200 kg/t of paddy (Central Food Technological Research Institute 1969).

Table 30 lists the main equipment required for parboiling plants with capacities of 12, 24, 48, 96, and 120 t/day capacity. The flow diagrams of these plants are shown in Figs. 108–111.

FIG. 108. Flow diagram of a 12 t/day parboiling plant: E = elevator; PBT = parboiling tank; D = drier; TB = tempering bin; and RM = rice mill building with receiving bin.

Jadavpur University Method

At Jadavpur University, India, studies were carried out to improve the method of parboiling by both batch and continuous techniques. The various operations of the integrated process include mechanical methods for soaking, steaming, cooling, and drying. These studies resulted in a reduction in the time required for soaking to 2.5–3 h depending upon the age and size of the paddy grains. The temperature of soaking varies from 65 to 70

TABLE 30. Equipment required for parboiling plants of different capacities (Radhey and Wimberly 1970).

	Capacity of the parboiling plant (t/day)				
	12	24	48	96	120
Receiving bin (t)					
Number	1	1	1	1	1
Capacity	12	24	48	96	120
Elevator (t/h)					
Number	1	1	2	2	2
Capacity	12	24	24	32	40
Holding bin (t)					
Number	—	—	1	1	1
Capacity	—	—	24	32	40
Parboiling tank (t)[a]					
Number	1	2	4	6	6
Capacity	7.5	7.5	7.5	6.7	8.3
Belt conveyor (t/h)					
Number	—	—	1	1	1
Capacity	—	—	24	32	40
Drier (holding capacity) (t)					
Number	1	1	1	1	1
Capacity	6	12	24	32	40
Tempering bin (t)					
Number	2	2	2	3	3
Capacity	6	12	24	32	40
Boiler capacity (kg/h)	300	600	1200	1600	2000

[a]Parboiling tanks are 25% larger than the tonnage capacity to allow for swelling during soaking.
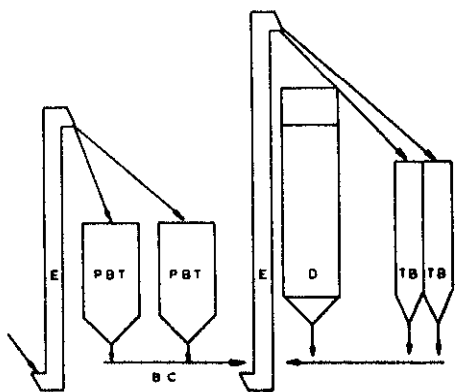
FIG. 109. Flow diagram of a 24 t/day parboiling plant: E = elevator; PBT = parboiling tank; BC = belt conveyor; D = drier; and TB = tempering bin.
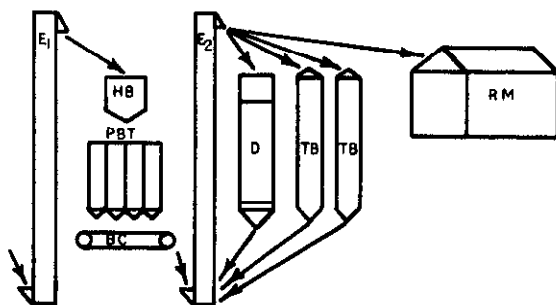
FIG. 110. Flow diagram of a 48 t/day parboiling plant: E = elevator; HB = holding bin; PBT = parboiling tank; BC = belt conveyor; D = drier; TB = tempering bin; and RM = rice mill.
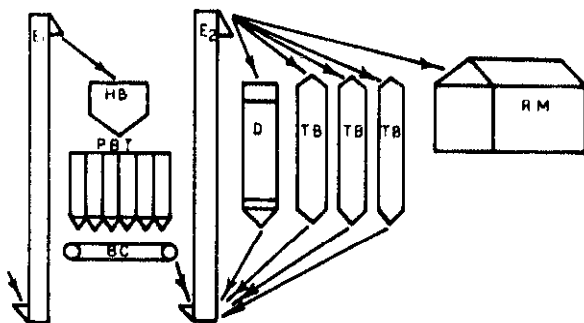
FIG. 111. Flow diagram of a 96 or 120 t/day parboiling plant: E = elevator; HB = holding bin; PBT = parboiling tank; BC = belt conveyor; D = drier; TB = tempering bin; and RM = rice mill.

°C according to the size of the grain. Moreover, the two steps of soaking and steaming are done in the same vessel. The steaming time is reduced to 3–5 min. The short time of soaking and the elevated temperature eliminate the possibility of fermentation during this operation and, therefore, reduce the chance of development of any off-flavour in the rice product. A flow diagram of the process is shown in Fig. 112.

In the batch process, the parboiling tank (soaker-steamer tank) is cylindrical, has a conical bottom, and is equipped to discharge the paddy after the soaking and steaming operations. The tank also has perforated steam pipes or coils for open steaming. In this process, the paddy is soaked at elevated temperature, gelatinized by exposure to open steam for 3–5 min, immediately cooled to room temperature by a continuous mechanical method, dried in a continuous rotary drier, and conditioned before it is milled (Ghose 1963).

The continuous soaker-steamer consists of a long semicircular jacket with suitable arrangements for paddy feeding and transportation and for the discharge of soaked and steamed paddy. The soaking and steaming operations are done in separate sections of the combined equipment. Heating is done either by condensing flowing steam in the jacket at low pressure or by passing hot water through the jacket. Provisions are also made for the continuous addition of soak water at elevated temperature.

The parboiled paddy is cooled by allowing it to fall through a cup and cone type vertical cooling tower, which has a counter current air draft. This operation appears to be essential to prevent browning of the rice during drying.

The rotary drier is composed of a long cylindrical rotating shell with a number of steam tubes and longitudinal lifter flights placed inside the shell. There is also an arrangement for blowing hot air through the unit; therefore, the parboiled moist paddy is simultaneously dried indirectly by steam in the tubes and directly by hot air.

The dried paddy discharged by the drier carries an appreciable amount of heat and care must be taken to allow the paddy to cool slowly. This is done by keeping the paddy in a
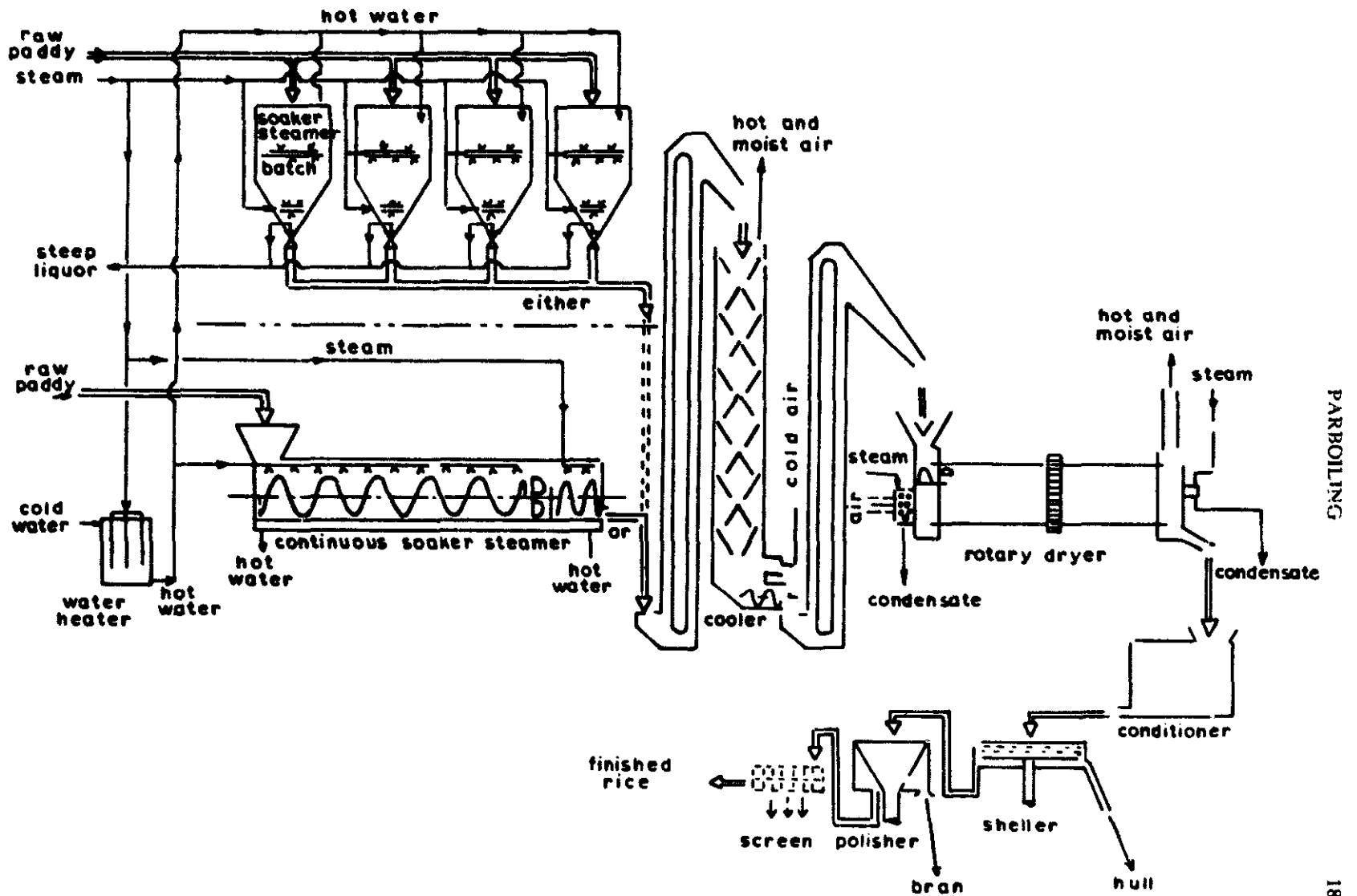
FIG. 112. Flow diagram of Jadavpur University method of parboiling paddy.

closed chamber so that the heat is distributed evenly and the moisture content becomes homogeneous throughout the kernel. This process is called aging or conditioning the dried grain.

This parboiling method has nearly the same advantages as the CFTRI method over the traditional method. In addition, the Jadavpur University method has two more advantages: (1) the process is continuous; and (2) the parboiled rice produced by the process is lighter in colour because the steamed paddy is cooled before drying.

Converted Process

This process, which was initiated in 1941–1942, was the first American parboiling process. The product is obtained by a complete gelatinization of the entire kernel. The parboiled product has an amber colour, is completely vitreous throughout. and has no white starchy centre.

Soaking in an autoclave begins with deaeration of the paddy by vacuum. This facilitates saturation and softening of the grain in water. A pressure treatment is applied to the soaking water in the autoclave that in combination with the vacuum reduces the soaking time to less than 3 h.

After soaking, the paddy is cooked in a rotary steam-jacketed autoclave. Applied vacuum then frees the grain of excessive water and the steam pressure is held at less than 1 kg/cm^2 for about 1 h. Final drying is carried out in the same autoclave by applying vacuum and heating with steam.

Malek Process

This method was perfected a little later than the converted process. The amber coloured parboiled paddy is prepared by successive unit operations that leave the grain remarkably hard. The paddy is steeped in tanks filled with hot water for 3–6 h. It is then cooked by the injection of steam into a vertical cylindrical autoclave that has a truncated cone bottom and is provided with charging and discharging ports or valves at the inlet and outlet, respectively. The paddy is moved in and out

of the autoclave by gravity.

Drying is performed in two stages: (1) in a steam-heated rotary cylindrical drier; and (2) in a forced hot air columnar drier at low temperatures.

Avorio Process

This fully mechanized and automatic parboiling process was patented in Italy in 1936. The paddy is steeped in baskets that are mechanically submerged by an endless chain conveyor in a tank of continuously circulated and aerated hot water.

The duration of steeping is controlled by regulating the speed of the baskets in the tank and the total immersion time varies between 50 and 60 min depending upon the rice variety. After steeping, the paddy is cooked in pressure autoclaves containing rotating perforated cylinders that permit steam to be injected into the paddy, which reduces the cooking time to 15–20 min. The steam pressure depends upon the temperature and duration of the operation and varies from 0.5 to 1.0 kg/cm^2. Special valves or ports control loading and unloading of the autoclave.

Drying of the steamed paddy is preceded by a cold air cooling operation. The cooled paddy is then passed through a series of columnar hot-air driers using air at 45–50 °C.

This process, which is well controlled in all phases of the operation, produces a parboiled rice with a high head rice yield, excellent cooking characteristics, and an amber colour.

Cristallo Process

The paddy is first subjected to a special cleaning in water to eliminate the trash and imperfect grains. The cleaning takes place in an open tank in which hot water of controlled temperature is circulated.

Steaming and drying are performed in the same rotary auto-pressure autoclave with vacuum. The steam-jacketed autoclave is also equipped with a mechanism for uniform distribution of steam in the autoclave. The operation is well controlled and produces a range of products depending upon the varieties processed and the market demands.

Fernandes Process

This process was patented in 1952. The steeping, steaming, and drying operations take place in three similarly constructed cylinders. Each of the horizontal cylinders rotates and has an internal helical conveyor for movement of the paddy. At the centre of the rotary cylinders and extending along their length is a perforated tube. This tube carries hot water for steeping in the first cylinder, steam for cooking in the second, and hot air for drying in the third cylinder.

Modern Methods Under Study

Brine Solution Method

This is a modified CFTRI method (Shivanna 1971). The modification and other developments were done at the Research and Development Laboratory of the Modern Rice Mill at Tiruvarur, India, in the latter part of 1969. The main advantage of this method is a reduction in the drying time resulting from a reduction in the moisture content of the parboiled paddy.

In this method, a 15% brine solution (specific gravity about 1.10) is circulated for 10–20 min through hot paddy that has been soaked at 65 °C and has acquired a moisture content of nearly 45%. The paddy is then steamed at a pressure of 3–5 kg/cm^2 for 15–20 min. During steaming, paddy loses moisture and dries to a moisture level of about 30%. The parboiled paddy produced by this method requires only 2 h of mechanical drying (85–90 °C air temperature) to bring its moisture content to 14–16%.

It is claimed that the salt withdraws moisture by osmosis and does not enter the paddy. The percentage of salt reported on the rice is negligible (0.03–0.05%). The paddy does not open during the steaming operation and the brown rice remains free of dirt, dust, or other foreign matter. Opening of the husk along the beam is a unique feature of all methods of parboiling. Although nonopening of the paddy is a distinct disadvantage in this process, it may affect the efficiency of the sheller to a small extent.

Kisan Continuous Parboiling Method

Considering the need for modernizing the existing parboiling units and the scope for introducing more plants in India, a simple, cheap, and versatile unit has been designed to operate on a continuous basis (Kisan Krishi Yantra Udyog 1972; Kuppuswang 1972). A hexagonal tank with 12 compartments is filled with hot water into which paddy is discharged from an elevator head. These compartments are filled in a sequential order starting with No. 1, and leaving an interval of 15 min between successive compartment fillings. By the time the 12th compartment is filled, the first one is ready for steaming. By opening the discharge gate, water and paddy can be taken to the dump pit below the tank. This pit has a perforated floor plate that permits the drainage of water. From this pit a screw conveyor, with a capacity of 2 t/h, removes the soaked paddy for steaming. Because each compartment contains only 0.5 t, the pit is emptied in 15 min. However, at the end of the 15 min period, the paddy in the second compartment is emptied into the pit to continue the operation. Therefore, a series of batches emptied from the hexagonal tank continually feeds the parboiling unit. The size and ratings of the batches can be modified to suit individual requirements. The steaming cylinder is a simple device in which the paddy flows vertically down an annular chamber as a horizontal flow of steam radially heats and gelatinizes the grain. The size and speed of the paddy flow can be varied as desired.

This unit can be operated both as a continuous parboiler and as a batch system. The steaming unit can serve as a paddy drier if hot air is used instead of steam. Because it is possible to dry some other cereals in the drier during the off-season, it is a versatile piece of equipment that can be optimally utilized throughout the year.

The escaping steam from the parboiler is used to heat either the water tank or the paddy soaking tank. If a steam heat exchanger is employed to produce hot air in a mechanical drier, steam from the parboiler may be used in the heat exchanger.

Pressure Parboiling Method

This method was developed at Tiruvarur, India, in the latter half of 1969 (Shivanna 1971). The principle of the method is the penetration of moisture into the paddy in the form of water vapour under pressure, which causes gelatinization of the kernel. The paddy is soaked for nearly 40 min at a temperature of 85–90 °C and then steamed under pressure for 18 min. The air entrapped inside the rice kernel is driven out by the penetration of water vapour; therefore, the presence of white bellies in the resultant rice is avoided. It is claimed that the whole parboiling operation is completed in 1–1.5 h. The rice obtained by this method has a pleasing, slightly yellowish, uniform colour and is expected to have a great demand in many parts of India. The main advantages are a reduction in soaking time, an increase in shelling efficiency (nearly 80% of the paddy hull splits during steaming), and an increase in milling outturn because the grains are resistant to breakage. Increases in the fat content of the bran after milling and in the storage life of the grain have been observed. The process should be easy to convert to a continuous one, and has the potential to be introduced even in small size mills as a replacement for the traditional parboiling system.

RPEC Method

Parboiling of paddy is a process of gelatinization of rice starch in situ, which requires moisture and heat (Ali and Ojha 1975b; Ali and Pandya 1974). Moisture and heat can be supplied to the paddy by soaking it in water that is at or a little above the gelatinization temperature of the starch, instead of supplying moisture and heat in two different operations, namely soaking and steaming, as is presently done in conventional and modern methods of parboiling.

Therefore, to determine if parboiled paddy could be produced by supplying moisture and heat simultaneously, studies were carried out at the Rice Process Engineering Centre (RPEC), Indian Institute of Technology, during 1970–1973. The method consists of soak-

ing the paddy in water, at or a little above the gelatinization temperature of the starch, for a suitable period, which depends upon the paddy variety. During soaking, the paddy absorbs moisture and heat and the parboiling process is completed.

The milling quality of the paddy produced by the RPEC method is similar to the quality of paddy parboiled by conventional methods, and after milling both rices look alike. The degree of gelatinization of the starch in hot-soaked parboiled rice was slightly less than in parboiled rice produced by conventional methods; however, this reduces the optimal cooking time. This is a great advantage because it reduces cooking costs and saves fuel for other purposes. Both of the parboiled rices, when optimally cooked, have nearly the same swelling indices.

The production of parboiled rice by hot soaking would be more economical than conventional and modern methods of parboiling because it eliminates the steaming operation; therefore, the boiler, which is one of the most costly items in a parboiling plant, can be eliminated. The water for soaking the paddy can be directly heated by a suitable husk or coal furnace.

Sodium Chromate Method

To try to control putrefactive changes and minimize the loss of dry matter during cold soaking, an extensive series of studies was carried out using a variety of additives in the soak water at the Paddy Processing Research Centre (Subrahmanyan 1972). It was observed that oxidizing agents were useful because they donated small doses of oxygen to the medium as they were required. Although more systematic work is needed to identify the mechanism of their action, the available evidence suggests that they react with the substances that are responsible for the foul odour, retard the action of putrefactive microorganisms and other organisms that lead to the loss of material from rice kernel, and do not affect the viability of paddy.

The process consists of soaking paddy in a 0.05% sodium chromate (Na_2CrO_4) solution for 40–48 h. This controls putrefactive

changes for 3 days. The other operations, i.e. steaming and drying, are done in the usual way and no extra costs are involved. There is absolutely no smell in the soaked paddy, resultant rice, or bran.

Using this method, it is claimed that a net saving of Rs. 6–8/t of paddy may be expected in the cost of operation. If this technique was combined with the brine solution method, an additional saving of Rs. 6/t of paddy would result.

Sequence of Operation for a Modern Parboiling Plant

To maximize the use of a processing plant and its machinery, a process analysis of all the unit operations is used to determine the sequence of the various operations and the utilization efficiency of the handling equipment (Bal et al. 1974). Preparation of the sequence diagram requires the application of various systems engineering principles. Table 31 gives the various unit operations of a parboiling process.

Using Table 31, a detailed flow process chart was prepared (Table 32). The flow process chart is the first step in preparing an optimum sequence diagram of a given system. This chart illustrates the interaction of one operation or event with the others, in a sequential manner, and describes the events and the individual time requirement of each event. This assures that the operations do not overlap, and helps to decide what equipment and machinery is required for the process.

A sequence diagram is a time schedule of product movement through the processing plant, with respect to the equipment and machines, that is expressed in the form of a histogram. This diagram is made with the help of the flow process chart (Table 32). Figure 113 shows a sequence diagram of a modern parboiling and drying plant. This sequence diagram is applicable to the equipment listed in Table 38 and represents the sequence presently followed in modern rice milling plants.

Effect of Parboiling on the Milling, Nutritional, and Cooking Qualities of Rice

During raw rice milling, several factors are generally recognized as probable causes of breakage of rice. Cracking or checking of the kernel is known to be one factor, because delayed harvesting, threshing, and too rapid

TABLE 31. Details of unit operations in parboiling and drying process.

Operation	Time required	Remarks
(1) Cleaning of raw paddy to remove dirt, dust, stones, chaff, and other impurities	—	Time of operation depends upon the amount of foreign material
(2) Soaking of clean paddy in hot water keeping the temperature of the paddy-water mixture constantly at 70 °C (recirculate water if required to maintain temperature)	3.5 h	
(3) Steaming the soaked paddy, after draining the steeping water, by injecting saturated steam at a pressure of 4 kg/cm^2	20–40 min	Time for steaming depends on quality of paddy to be steamed and capacity of the boiler
(4) First drying pass, paddy is recirculated in drier and 95 °C air is blown through the paddy	2 h	
(5) Tempering of paddy in tempering bin to equalize moisture	8 h	
(6) Second drying pass, paddy is recirculated in drier and 75 °C air is blown through the paddy	2 h	

TABLE 32. Flow process chart for 4 t/h paddy parboiling and drying system: V indicates vertical transportation distance; ○ operation; → transportation; □ inspection; D delay; and ▽ storage.

Process description of existing method	Chart symbols	Distance moved (m)	Unit time (h)					Man-h	Power (kWh)	Remarks
			Oper.	Insp.	Trans.	Delay	Storage			
Cleaning	○							1.00	5.00	
Inspection of foreign matter	□							0.02		Parboiling process starts
Loading parboiling tank	→	5 V			0.50			2.00	1.00	
Parboiling consisting of soaking paddy at 70 °C for 3.5 h and steaming for 0.5 h	○		4.00					4.00	6.00	
Delay in parboiling operation due to filling of soaking water and draining the water	D					1.00				
Inspection of parboiled paddy	□			0.02				0.02		
Unloading paddy from parboiling tank and loading it in the drier	→	10 V			0.50			0.50	1.00	
Delay in starting the burner and blower of the drier	D					0.08				
Drying pass I	○		2.00					2.00	10.00	
Unloading the drier and loading the tempering bin	→	5 V			0.50			0.50	1.00	
Tempering	▽						8.00			
Unloading the tempering bin and loading drier	→	10 V			0.50			0.50	1.00	
Drying pass II	○		2.00					2.00	10.00	
Unloading drier to the rice mill storage	→	10 (5 V)			0.50			2.00	1.00	Parboiling process ends
Temporary storage before milling	▽						Unspecified			

drying conditions that all favour cracking always increase the number of brokens. Immature and chalky kernels are considered to break relatively easily. Moisture content and infestation likewise appear to be contributing factors, as are the shape and hardness of the kernels. Rice varieties with short hard grains are usually considered to be the most resistant to break-

age. The type and design of the milling machinery influences milling results (Bhattacharya 1969; Bhattacharya and Subba Rao 1966). Rice breakage is related to milling conditions, particularly the prevailing relative humidity and temperatures and the extent of milling (Bhattacharya 1969).

Progressive milling of raw and parboiled
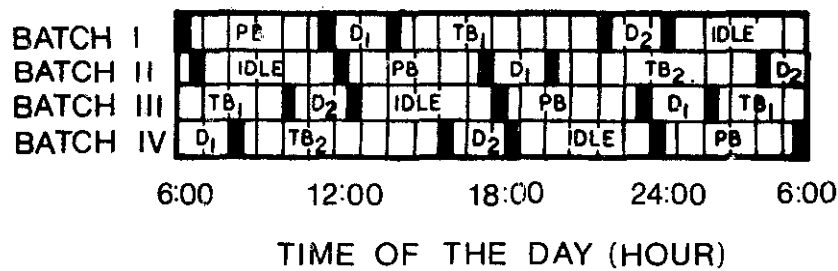
FIG. 113. Sequence diagram for a 4 t/h modern parboiling and drying plant: PB = parboiling; TB_1 = tempering bin 1; TB_2 = tempering bin 2; D_1 = drying pass 1; D_2 = drying pass 2; and ■ = loading and unloading.

rice shows that most of the breakage occurs during shelling (Desikachar et al. 1967; Raghavendra Rao et al. 1967). The grain that remains unbroken after shelling produces few brokens when separated and polished. Two facts indicate that breakage is mostly related to cracked and immature kernels: (1) brokens practically disappear after shelling; and (2) the total number of brokens in the sample is closely related to the total loss in head yield (Bhattacharya 1969).

The parboiling process is known to reduce rice breakage, and the improvement in milling quality is usually attributed to either greater hardness of the parboiled grain or to the healing of cracks. It has been established that cracks, incomplete grain filling, and chalkiness are completely healed during the parboiling process, apparently because of realignment and cementing of the grain constituents after starch gelatinization. Improvement in milling quality is evidently related to this phenomenon, and ideally, breakage should always be negligible after parboiling.

The most beneficial effect of parboiling is an increase in the head yield of paddy that has very poor milling quality either because of varietal characteristics or because of bad postharvest processing operations. There is a slight increase in the head yield of paddy that has good milling quality; however, in this case the net increase in the total yield of rice as a result of parboiling is fairly small.

During polishing, both the percentage* of polish and breakage increase with time, but parboiled rice takes longer than raw rice to attain the same degree of polish (Fig. 114). Both raw and parboiled rice can be polished

to 4–5% in a relatively short time; however, prolonged polishing is necessary to obtain higher levels of polish. This indicates that the outer bran layers are easier to abrade than the inner aleurone and endosperm layers (Raghavendra Rao et al. 1967). Breakage during polishing is lower in parboiled rice than in raw rice; however, parboiled rice requires three to four times as much abrasive load as raw rice to attain the same degree of polish (Raghavendra Rao et al. 1967). The effect of increasing the degree of polish on the breakage of raw and parboiled rice is shown in Fig. 115. Breakage during polishing increases steadily in the case of both raw and parboiled rice although the increment is more rapid in raw rice (Raghavendra Rao et al. 1967).

Removal of bran colour during polishing is faster in parboiled rice (especially red varieties) than in raw rice (Raghavendra Rao et al. 1969). The bran colour may be extracted from a 2-g sample of rice, polished to different degrees, by an alkaline methanol solvent (Raghavendra Rao et al. 1967). Loosely adhering bran is first removed by washing and decanting with 10 ml of water. The colour is then extracted by boiling the rice for 10 min in two successive 25-ml lots of 5% sodium carbonate solution. Twenty millilitres of methanol are added to the combined extract to prevent turbidity. The colour of the filtrate is measured in a photoelectric colourimetre at 420 mμ (No. 42 filter). The amount of bran colour extracted from shelled rice is taken as 100, and the amount of bran colour removed at any degree of polish is determined by measuring the residual colour in the rice. It has been noticed that parboiled rice needs to be slightly less polished
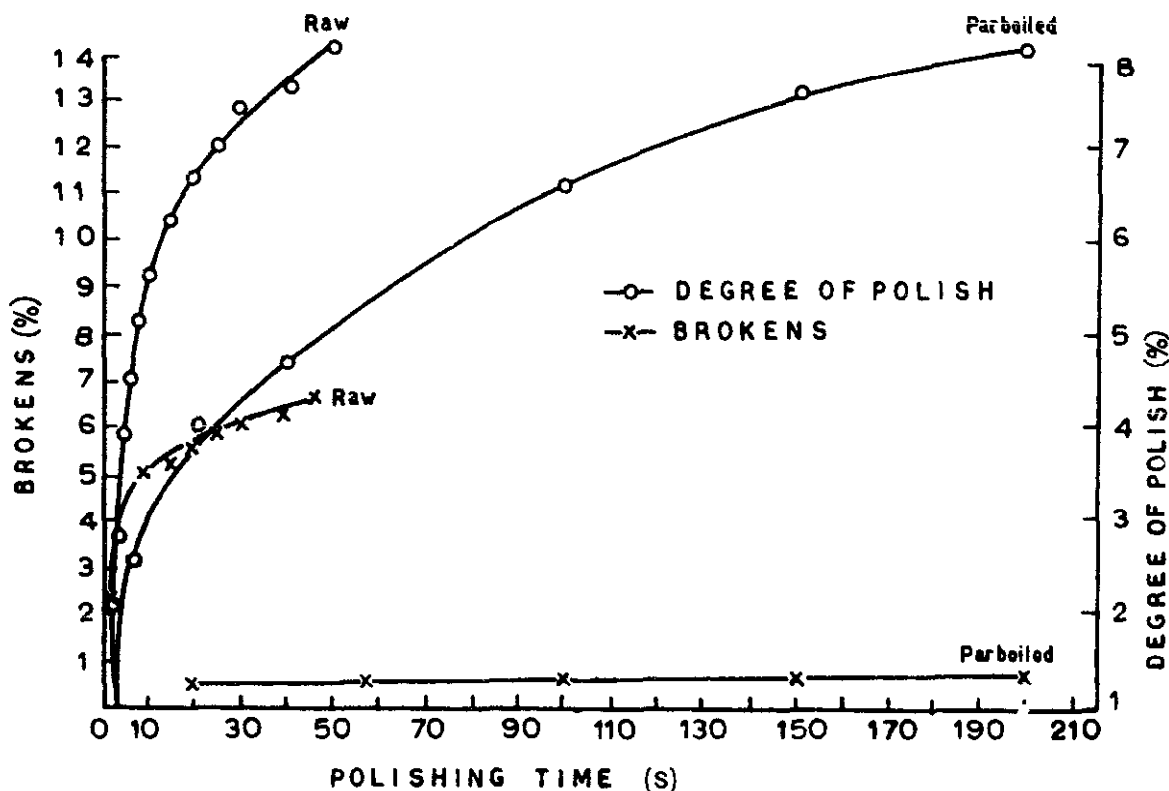
FIG. 114. Effect of length of time of milling on breakage and degree of polish of rice.

than raw rice to have the same minimum consumer acceptability. Figure 116 shows that to achieve an equal degree of surface bran removal, parboiled rice must be subjected to less polishing than raw rice (Raghavendra Rao et al. 1967). For instance, for 80% bran removal, the level of minimum consumer acceptability, parboiled rice must be polished to about 3%; whereas, raw rice must be polished to about 4%.

Bran from parboiled rice can be peeled off as flakes, and it contains less starch and more oil than raw rice bran. This shows that parboiling not only facilitates dehusking but also helps in the separation of surface bran without the loss of endosperm, although both a high abrasive pressure and a longer time may be required for polishing.

The amount of bran sticking to the rice is determined by the abrasive or scouring force used and the polishing time. The former controls the amount of bran scoured; whereas, the latter determines the amount of bran sieved through the perforations of the screen. The

use of a high abrasion force with a short polishing time helps to remove more bran from the rice, but does not allow sufficient sieving time. If the polishing operation is prolonged after removal of the polishing load, the sticking bran gets brushed and sieved through the screen (Desikachar et al. 1967; Raghavendra Rao et al. 1967). In a commercial rice mill, the difficulty caused by sticking bran can be overcome by using a large number of polishing units so that sufficient brushing and sieving time is permitted. High moisture content enhances the tendency of the bran to stick to the rice; however, by running the machine longer with no extra load and increasing the sieving time, this difficulty can be eliminated.

It is pertinent to point out that the problem of bran stickiness is serious only in the milling of parboiled rice, and not in the milling of raw rice. Histological studies have shown the presence, in parboiled rice, of oil globules that are damaged and burst; in raw rice, the oil appears as roundish globules. Smearing of oil at a level of 0.5% on the surface of rice increases bran
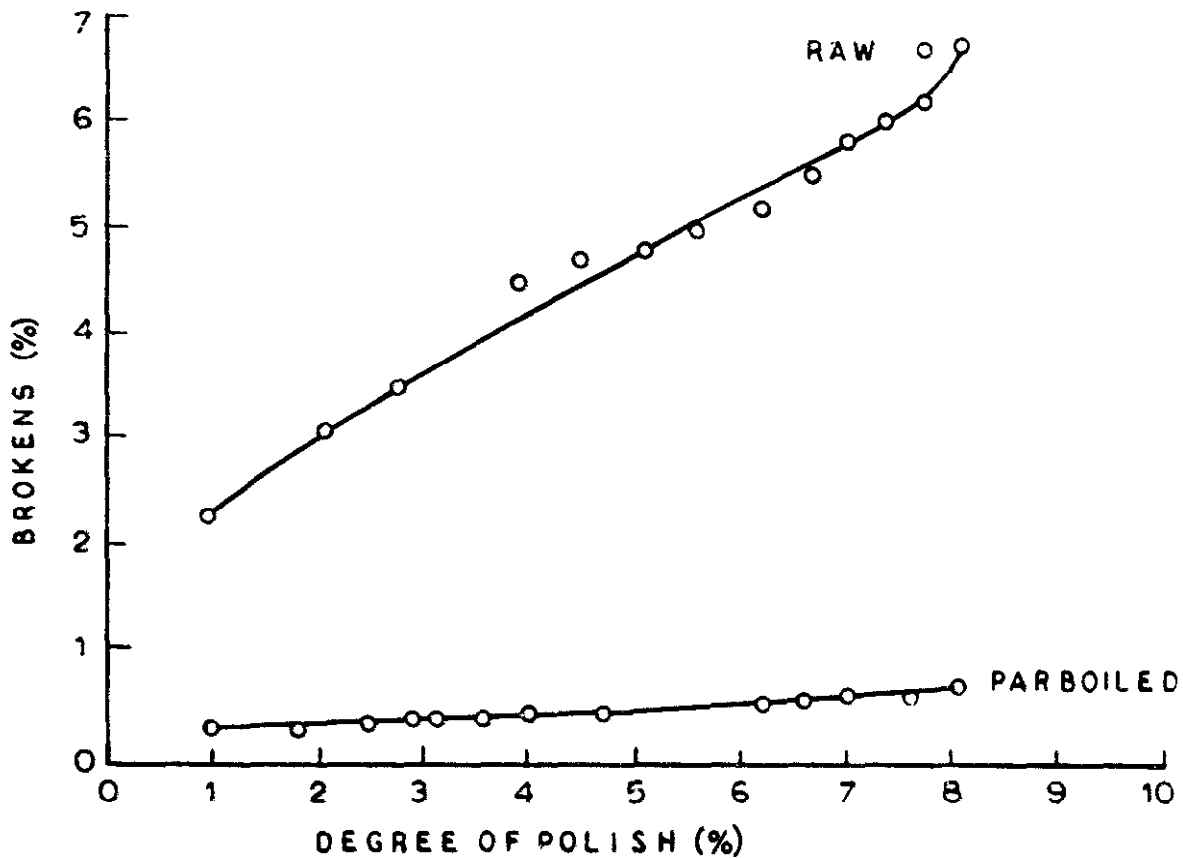
FIG. 115. Percentage of breakage at different degrees of polish of Ratnachudi rice.

stickiness in both raw and parboiled rice (Mahadevappa and Desikachar 1968b; Raghavendra Rao et al. 1967).

Parboiling restores the milling quality of both damaged raw and parboiled paddy. Parboiling is an excellent tool for salvaging the milling quality of paddy that has been inadvertently damaged by sun, rain, or faulty drying or paddy that contains a high proportion of immature kernels, which would otherwise be extremely fragile and would fragment during milled (Bhattacharya 1969; Battacharya and Subba Rao 1966a).

If the degree of polish is restricted to the level required for minimum consumer acceptability (80% of bran colour removed), parboiling increases the total yield by 1–1.5% and the yield of marketable rice by about 3.5%. Marketable rice is rice that does not contain brokens smaller than one quarter the size of the original. The profits obtained from the increased yield of rice by parboiling are

almost neutralized by the increased processing costs. Therefore, parboiling will fetch profits only for those varieties that suffer high breakage in the raw state and cannot be milled economically.

Effect of Parboiling on the Nutritional Value of Rice

An average chemical composition of rice is shown in Table 33. It indicates that the concentration of nutrients in the bran is higher than in either raw or parboiled rice. Because bran is an admixture of the outer layers of the rice kernel, it appears that most of the nutrients are present in the outer layers of the shelled rice (Tables 34–36). Table 36 shows the approximate losses of important nutrients during milling (FAO 1954).

The loss of nutrients during milling is reduced to a certain extent by parboiling. It has been claimed that parboiled rice contains more
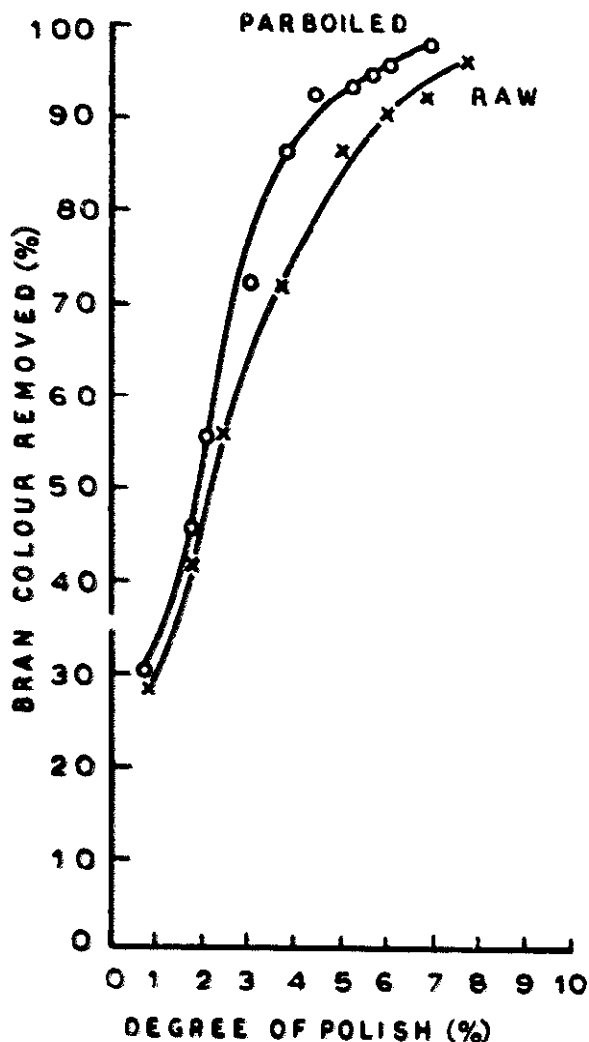
Fig. 116. Percentage of bran colour removed at different degrees of polish of red (kar) rice.

vitamins, proteins, and minerals and loses fewer nutrients during cooking than raw rice. The high nutritive value of parboiled rice may be due to: (1) the diffusion and heat sealing of vitamins and other nutrients into the endosperm; and (2) the low degree of polish required for consumer acceptability, which means that less bran and nutrients are removed.

Parboiled rice contains less oil or fat compared to raw rice because the soaking operation brings about certain enzymatic changes that release oil from the combined state in which it is present in the rice kernel; subsequent steaming causes the oil to move to-wards the periphery of the kernel, which is removed with the bran during milling.

Effect of Parboiling on Cooking Quality of Rice

The cooking quality of rice may be expressed with respect to: time of cooking; swelling capacity; expansion ratio; colour; solids in gruel; and pastiness.

Time of Cooking

Raw rice cooked in boiling water needs about 15–20 min to become fully cooked; whereas, parboiled rice requires 30–40 min to be cooked to a comparable degree of softness. Raw rice cooked beyond 20 min continues to absorb water, but the grains lose their shape, become almost flat, burst along the ventral line of fusion, and become pasty (Kurien et al. 1964; Mahadevappa and Desikachar 1968a).

Swelling Capacity

This is the ratio of the final to the initial volume or weight of the rice. The water absorption capacity, as reflected by the swelling ratio, is significantly lower for parboiled rice than for raw rice cooked for the same period. However, samples of raw rice and parboiled rice cooked to an equivalent degree of softness show that parboiled rice can absorb more water without losing its shape (Mahadevappa and Desikachar 1968b). Raw rice cooked for 15 or 20 min has a lower swelling ratio than parboiled rice cooked for 30 or 40 min, respectively. Semiparboiled rice has a swelling capacity between that of raw and parboiled rice.

Expansion Ratio

This is the ratio of the dimensions of the cooked and uncooked rice. The expansion ratios both along the length and breadth of parboiled rice are lower than the ratios for raw rice cooked for the same period (Mahadevappa and Desikachar 1968b). At an equivalent stage of softness, the parboiled

TABLE 33. Composition of rice and its milling products (Houston and Kohler 1970).

| | Water (%) | Protein (%) | Fat (%) | Ash (%) | Carbohydrate | | Minerals and vitamins (mg/100 g) | | | | | | | |
					Total (%)	Fibre (%)	Calcium	Phosphorus	Iron	Sodium	Potassium	Thiamine	Riboflavin	Niacin
Brown	12.0	7.5	1.9	1.2	77.4	0.9	32	111	1.6	9	214	0.34	0.05	4.7
White fully milled (common)	12.0	6.7	0.4	0.5	80.4	0.3	24	94	0.8	5	92	0.07	0.03	1.6
White fully milled (waxy)	13.2	5.6	0.9	0.5	79.8	0.3	36	100	2.0	10	130	0.07	0.04	2.0
Enriched, all types	12.0	6.7	0.4	0.5	80.4	0.3	24	94	(2.9)	5	92	(0.44)	(—)	(3.5)
Long grain, parboiled	10.3	7.4	0.3	0.7	81.3	0.2	60	200	(2.9)	9	150	(0.44)	(—)	(3.5)
Long grain, precooked	9.6	7.5	0.2	0.2	82.5	0.4	5	65	(2.9)	1	—	(0.44)	(—)	(3.5)
Rice bran	9.7	13.3	15.8	10.4	50.8	11.5	76	1386	19.4	trace	1495	2.26	0.25	29.8
Rice polish	9.8	12.1	12.8	7.6	57.7	2.4	69	1106	16.1	trace	714	1.84	0.18	28.2

NOTE: Values in parentheses for iron, thiamine, and niacin are based on minimum level of enrichment specified in standards of identity. Those required for riboflavin are presently not in effect.

grain has expanded more along the breadth than raw rice. Differences in expansion along the breadth are significant; those along the length are not.

Colour

Parboiling changes the characteristics and appearance of the milled rice, but when cooked by boiling, the kernels are almost as white as raw rice.

TABLE 34. Comparative percentage distribution of thiamine and niacin in rice (Central Food Technological Research Institute 1969).

	Thiamine	Niacin
Pericarp, seed coat, and aleurone layer	34.50	85.50
Outer endosperm	4.30	7.80
Inner endosperm	3.70	4.50
Embryo	10.80	0.60
Scutellum	47.00	1.60

TABLE 35. Weight and protein content of successively removed fractions of shelled rice (Houston and Kohler 1970).

Kernel weight removed	Total cumulative weight removed	Protein in fraction	Amount of total protein in fraction	Total cumulative amount of protein removed
4.52	4.52	16.24	8.36	8.36
5.60	10.12	21.01	13.41	21.77
5.54	15.66	19.64	12.39	34.16
5.88	21.54	17.37	11.63	45.79
5.56	27.10	15.05	9.53	55.32
6.32	33.42	12.38	8.91	64.23
4.88	38.30	10.12	5.63	69.85
3.12	41.42	8.60	3.05	72.90

TABLE 36. Approximate percentage losses of important nutrients during milling (FAO 1954).

	Losses during milling (% of total)
Protein	15.0
Fat	85.0
Calcium	90.0
Thiamine	80.0
Riboflavin	70.0
Niacin	68.0
Pantothenic acid	62.0
Pyridoxine	56.0

Solids in Gruel

The loss of solids into the gruel is greater in raw rice than in parboiled rice because the starch is gelatinized in parboiled rice. Semi-parboiled rice has an intermediate amount of loss.

Pastiness

Parboiled rice cooks more flaky than raw rice because of gelatinization. Storage or ageing of the rice also improves this characteristic (Desikachar et al. 1969; Desikachar and Subrahmanyan 1959).

Parboiled rice grains, after cooking, appear larger than cooked raw rice grains of the same variety and give the impression that they are coarse, bold-grained strains (Mahadevappa and Desikachar 1968a). This could be due to differences in the time needed for cooking, the water absorption capacities, and/or changes in the dimensions of the grains as a result of parboiling. Because parboiling and the subsequent gelatinization harden the grain, it needs a longer time to cook to a soft consistency and swells more during this period without disintegration. The intrinsic water absorption rate of parboiled rice is low. Raw rice, on the other

hand, imbibes water more quickly and loses its physical structure, because of dispersal of the cell contents, when it is cooked beyond 20 min. The visual appearance of the grain depends on the ratio of its length to its breadth or thickness. The relatively greater expansion of parboiled rice along its breadth after cooking gives it a characteristic short and plump appearance (Mahadevappa and Desikachar 1968b).

Effect of Processing Conditions on the Quality of Parboiled Rice

The process of parboiling involves soaking and steaming, which cause swelling, and drying, which causes contraction. Incomplete shrinkage during drying may also cause an overall change in the dimensions of the grain. The average breadth of parboiled rice is greater than raw rice of the same variety. Microscopic examination shows rounding of the germ tip of the milled parboiled rice grain (Mahadevappa and Desikachar 1968a,b). This may account, in part, for a slight shortening in the length of the grain due to parboiling. The slightly lower degree of polish generally given to parboiled rice may be responsible for the slightly greater breadth of the parboiled rice grain.

The soaking of paddy in hot water at 60–65 °C significantly reduces the swelling capacity of the rice. The steaming operation that follows the soaking further reduces the swelling ratio; the longer the steaming period, the lower the swelling quality of the rice. The rate of decrease in the swelling quality, as a result of steaming, is observed to be greatest in a first 10–15 min of steaming. Although an increase in the period of steaming might harden the grain and result in a higher yield of head rice during milling, the swelling quality of the rice would be adversely affected.

The combined severity of the heat treatments during parboiling is clearly the main factor that determines the cooking quality and colour of parboiled rice. Soaking at a relatively low temperature (below 70 °C) for the minimum time required, using a minimum degree of steaming, and quickly cooling the steamed paddy are thus necessary if a parboiled rice

with soft cooking quality and little colour is desired. Quick cooling after parboiling may be the most important factor in industrial scale operations. The reverse conditions are necessary to produce a hard rice with a lot of colour. However, there are some indications that steaming has relatively more effect on the cooking quality; whereas, soaking temperature has more effect on the colour (Bhattacharya and Subba Rao 1966b).

Discoloration during parboiling is chiefly due to nonenzymatic Maillard-type browning that can be inhibited by bisulfite; however, other factors also seem to be involved. The effect of soaking temperature and time, and steaming pressure and time on the whiteness of parboiled rice are shown in Fig. 117 (Jayanarayana 1965). A part of the bran is embedded in the endosperm during soaking and steaming. This bran layer will undoubtedly add to the colour of the rice, and the colour itself will be darkened by the Maillard reaction because the bran is rich in free sugars and amino acids. The husk pigment may also contribute colour by diffusion into the endosperm or by absorption into the grain if the grain splits during soaking. The husk pigment has been found in many grains during soaking. In many

0	50	60	70	80	90	A
0	1	2	3	4	5	B
0	0.25	0.75	1.25	1.75	2.25	C
0	10	20	30	40	50	D
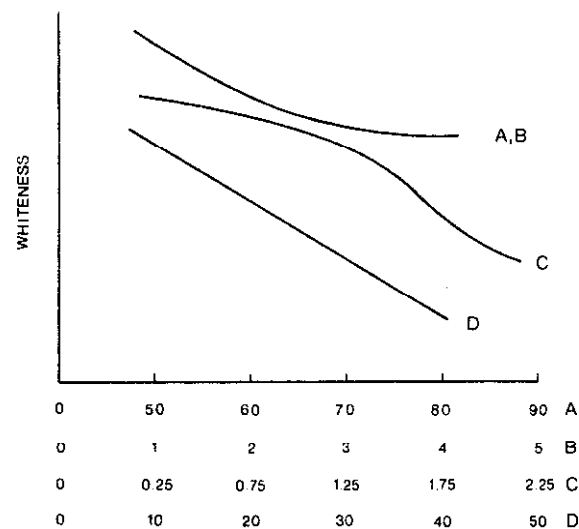
FIG. 117. Effect of processing variables on the colour of parboiled rice: A = soaking temperature (°C); B = soaking time (h); C = steaming pressure (kg/cm²); and D = steaming time (min).

varieties of paddy this pigment is appreciably soluble in hot water and is readily absorbed by milled raw rice if it is cooked in the husk extract. These two factors may partly explain the strong colour inducing effect of high temperature soaking.

The pH of the soaking medium also has an effect on the colour of parboiled rice. Discoloration increases on either side of pH 4.5 (Jayanarayana 1965).

Changes in Parboiled Rice During Storage

Parboiled rice may be stored in open or sealed containers. During storage, changes occur in moisture content, colour, composition, and oil fraction.

Moisture

The moisture content of rice stored in the open soon becomes equal to the moisture level of the surrounding air. The rice loses moisture faster and to a greater extent as the storage temperature is raised; therefore, the moisture content becomes different from samples of the same rice kept in closed storage.

Colour

Parboiled rice has a light to medium amber colour. The colour of dry whole-grain parboiled rice may be measured on the Hunter colour and colour-difference metre. Colour differences, E, are calculated from the measurements, using colour values of the original rice samples as standards (Houston et al. 1956).

Colour changes of parboiled rice are marked by a slight initial increase followed by little or no change over a period of about 1 year at room temperature (25 °C) in either open or sealed storage (Fig. 118). Rice exposed to light darkens slightly more than rice in the dark. At 38 °C colour differences again show an initial rise (Fig. 119). Little change takes place until about 4 months, and then progressive darkening begins and continues. During this phase rice in sealed storage becomes browner than rice in open storage. At 60 °C (Fig. 120) the
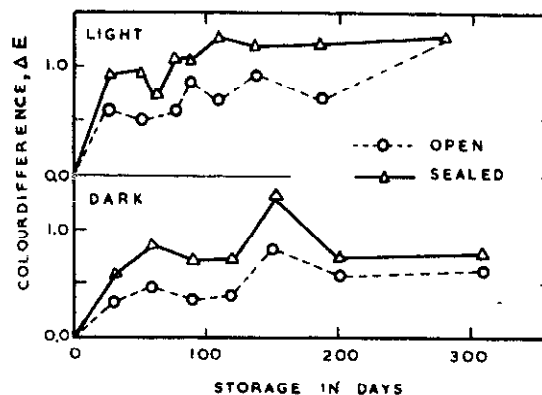
FIG. 118. Colour changes of parboiled rice at 25 °C.
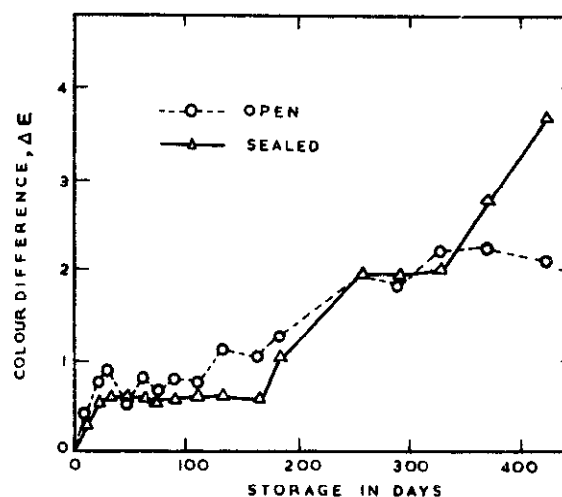
FIG. 119. Colour changes of parboiled rice at 38 °C in the dark.
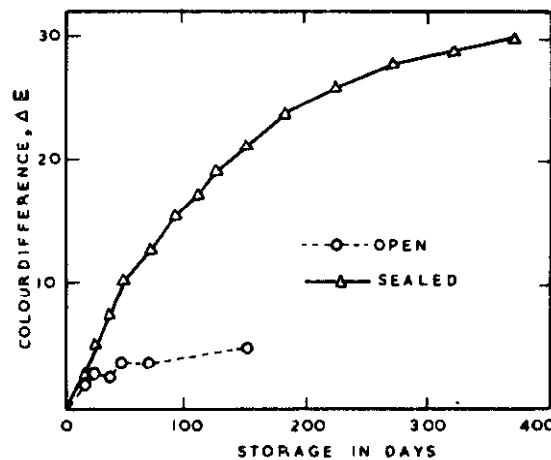
FIG. 120. Colour changes of parboiled rice at 60 °C in the dark.

distinction between open and sealed storage becomes significant. Open storage samples soon dry down to about 3% moisture content and show a moderate, gradually decreasing rate of browning. Sealed storage rice, with the original moisture content, continues to darken and finally becomes a deep mahogany brown.

Compositional Changes

Sulfur dioxide added during parboiling inhibits browning but does not delay rancidification and it gradually disappears during storage (Houston et al. 1956). Because the sulfur dioxide disappears more rapidly in sealed storage it does not evaporate. The losses of reducing sugars are about the same at 25 and 38 °C, but at 60 °C losses increase appreciably. These losses are also greater in closed storage, which is consistent with colour development. A reduction in the amount of available amino nitrogen also occurs.

Deteriorative Changes in Oil Fraction

Oil may be present as less than 1% of the grain, yet have marked effects on acceptability because of rancidity development. Both hydrolytic and oxidative rancidity may occur: hydrolytic action is favoured by high moisture content; oxidative action is favoured by low moisture (Houston et al. 1954).

Changes in the oil fraction of stored parboiled rice have been used as criteria for loss in quality. Rancidification and nonenzymatic changes in the oil of stored parboiled rice may be measured by peroxides, monocarbonyl compounds, and free acids.

Open Storage in Dark

In open storage, values for peroxides, monocarbonyls, and free acids remain low during an induction period, then rise markedly at or just before the time when a rancid odour is detected (Fig. 121–123). Peroxides and monocarbonyls then decrease to low residual values and rancidity disappears. Free acid values remain at the high level or continue to increase slowly. The monocarbonyl maxima occur at about 1 year at 25 °C, at about 1 month at 60 °C, and at about 1 week at 82 °C.
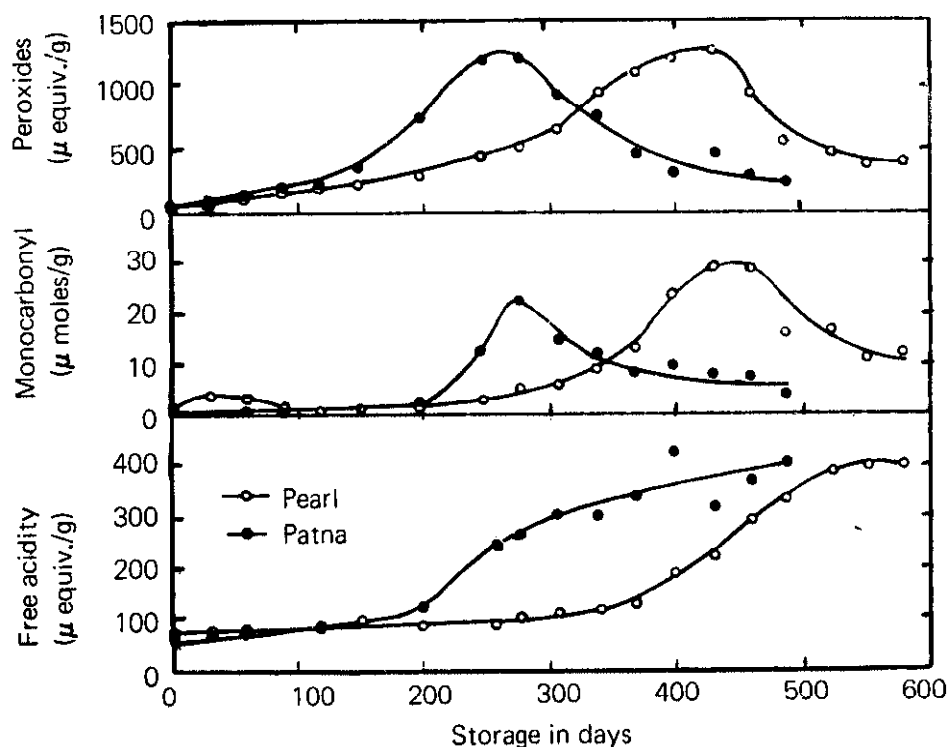
FIG. 121. Changes in the oil during open storage in the dark at 25 °C.
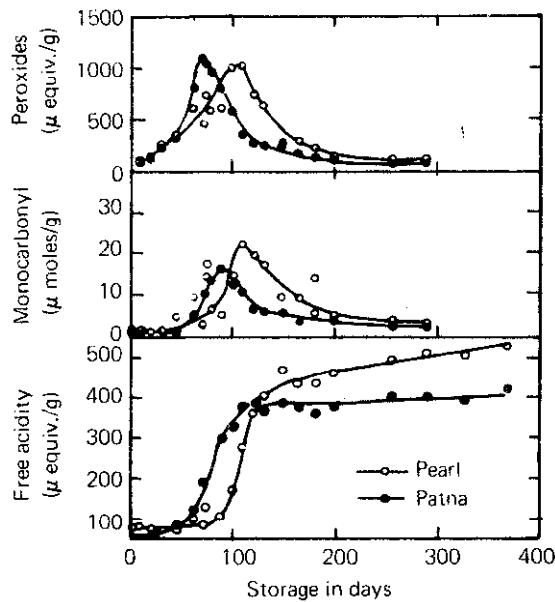
FIG. 122. Changes in the oil during open storage in the dark at 38 °C.
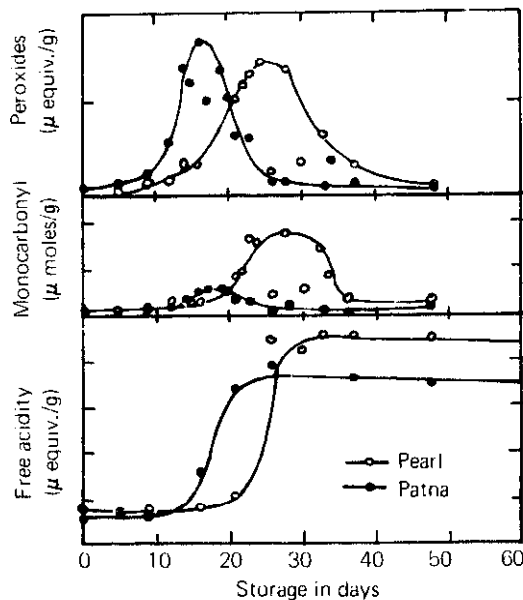
FIG. 123. Changes in the oil during open storage in the dark at 60 °C.

Sealed Storage in Dark

In closed storage at 25 and 38 °C peroxide and monocarbonyl changes are similar to those for open storage although the induction peri-

ods are longer. At 60 °C no rise is shown. Free acidity increases linearly for considerable periods at all three temperatures (Fig. 124–126).

Storage in Light

Light has a considerable effect in reducing the storage life of parboiled rice maintained at room temperature (25 °C). Rancidity starts during storage if the storage area is well lit (Houston et al. 1954, 1956). The differences between samples in open and in sealed storage are apparently less than the differences found between samples kept in dark storage conditions.

Studies have shown that the storage life of parboiled rice is dependent not on variety but on processing treatments. Therefore, it is possible to modify both the keeping quality and the appearance of the commercial product by varying the manufacturing process.

Estimate of Heat Required for Parboiling

To calculate the total heat required for parboiling a tonne of paddy, the following assumptions were made: (1) paddy moisture increases from 16 to 50%; (2) bulk density of paddy = 580 kg/m^3; (3) porosity of paddy = 50%; (4) temperature of water for soaking = 90 °C; (5) initial paddy temperature = 25 °C; (6) paddy-water mixture temperature = 70 °C; (7) paddy temperature just after soaking = 65 °C; (8) paddy temperature just after steaming = 100 °C; (9) heat lost while steaming = 20%; and (10) specific heat of dry paddy = 0.4 Kcal/kg-°C.

Soaking Operation

The total water required for the soaking operation is

$$W = Wd \, (m - m_0) + Wp$$

where: W = weight of water (kg); Wd = weight of paddy (kg); m = final moisture content (%); m_0 = initial moisture content (%); and Wp = weight of water required to fill the pore spaces (kg).
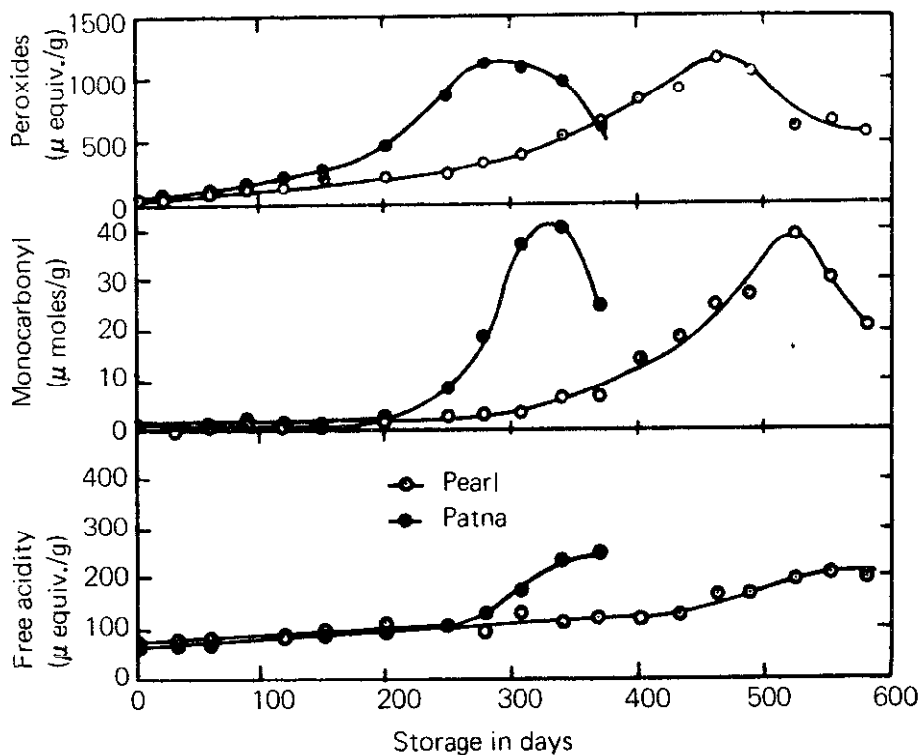
FIG. 124. Changes in the oil during sealed storage in the dark at 25 °C.
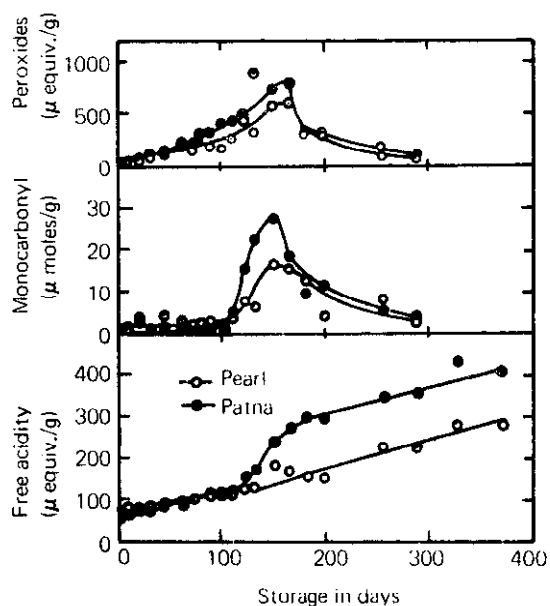
FIG. 125. Changes in the oil during sealed storage in the dark at 38 °C.
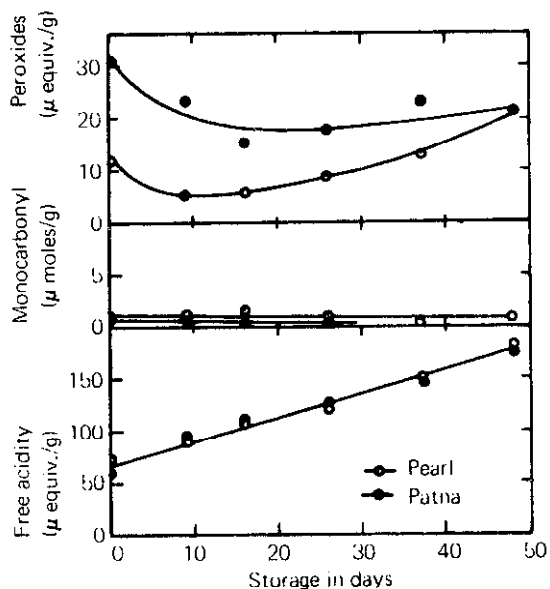
FIG. 126. Changes in the oil during sealed storage in the dark at 60 °C.

For one tonne of paddy,

$$W = 1000 (50 - 16) + 0.5 \times \frac{1000}{580} \times 1000$$
$$= 340 + 862$$
$$= 1202 \text{ kg}$$

Adding 10% extra to account for losses during the operation, the total amount of water required = 1202 + 120
= 1322 kg.

The amount of heat (Kcal) required to raise the temperature of the water from 25 to 90 °C = 1322 × (90 − 25) = 85 930 ≃ 86 000 Kcal.

Steaming Operation

The heat gained by paddy during the steaming operation is

$$E = w_p \times C_p \times T + w_x \times C_w \times T$$

where: E = heat gained by paddy during steaming (Kcal); w_p = weight of dry paddy (kg); C_p = specific heat of dry paddy (Kcal/kg-°C); T = temperature difference between the steamed and soaked paddy (C°); w_x = weight of water in soaked paddy (kg); and C_w = specific heat of water (Kcal/kg-°C).
Therefore, E

$$= 667 \times 0.4 \times (100 - 65) + 333 \times 1$$
$$\times (100 - 65)$$
$$= 267 \times 35 + 333 \times 35$$
$$= 9345 + 11655$$
$$= 21\,000 \text{ Kcal}$$

Adding 20% extra for the heat losses during steaming, $E = 21\,000 + 4200 = 25\,200$ Kcal.

Drying Operation

Assumptions: (1) moisture to be removed = 50 to 16% (2) total drying time = 4 h; (3) holding capacity of the drier = 7 t; (4) airflow rate = 350 m³/min; (5) average atmospheric air temperature = 25 °C; and (6) drying air temperature = 80 °C.
Heat required to raise the air temperature from 25 to 80 °C is

$$Ed = A \times d \times C \times t$$

where: Ed = heat required to raise the air temperature (Kcal); A = airflow rate (m³/h); d = density of the air (0.865 kg/m³); C = specific heat of the air (0.24 Kcal/kg-°C); and t = temperature rise (C°).
Therefore,

$$Ed = 21\,000 \times 0.865 \times 0.24 \times (80 - 25)$$
$$= 21\,000 \times 11.42$$
$$= 239\,820$$
$$\simeq 240\,000 \text{ Kcal}$$

For 4 h of drying the total heat requirement = 240 000 × 4 = 960 000 Kcal. For drying 1 t of paddy the heat requirement (960 000/7) = 137 143 Kcal ≃ 137 200 Kcal. Therefore, the total heat requirement for parboiling 1 t of paddy equals the heat required for soaking, steaming, and drying = 86 000 + 25 200 + 137 200 = 248 400 Kcal ≃ 249 000 Kcal.

Fuel Value of the Paddy Husk

The average caloric value of the husk is 3000 Kcal/kg. On the average a paddy variety yields about 20% husk by weight. Therefore, the total husk obtained from 1 t of paddy will be 200 kg and the total heat content of this husk will be 600 000 Kcal. Assuming a 45% efficiency of the husk fired boiler, the heat available from the husk will be 270 000 Kcal. This shows that the total husk content of the paddy is sufficient to provide all the heat required for the parboiling operation. In India, there are some rice mills which are parboiling paddy using only the husk as fuel; however, they utilize the same boiler for generating the steam that is used for heating the drying air in the steam heat exchangers.

Cost Analysis (Bal et al. 1974)

Conventional Parboiling Plant (4 t/h)

The flow diagram of a parboiling plant is shown in Fig. 106. The following assumptions were made in the calculation of the parboiling cost (based on prices during the period 1972–1973):
(1) Cost of equipment and accessories (Table 37) = Rs. 210 000;

(2) Cost of land, buildings, and civil works (Table 37) = Rs. 400 000;

(3) Life of the equipment and accessories = 10 years;

(4) Life of the buildings etc. = 25 years;

(5) Number of working days per year = 250 days;

(6) Number of productive working hours per day = 20 h;

(7) Resale value = 10%;

(8) Interest on capital = 10%;

(9) Electricity = Rs. 0.70/t;

(10) Fuel = husk;

(11) Cost of fuel per tonne of paddy processed = nil.

(12) Staff: (a) one manager = Rs. 600.00; (b) one assistant manager = Rs. 400.00; (c) one cashier = Rs. 300.00; (d) three clerks = Rs. 750.00; (e) one chief mechanic = Rs. 400.00; (f) three watchmen = Rs. 450.00.

Total cost per month = Rs. 2900.00.

The expenditure on staff is equally allocated to parboiling and milling units.

(13) Staff for parboiling and drying units only: (a) one boiler operator = Rs. 300.00; (b) three helpers = Rs. 600.00. Total cost per month = Rs. 900.00;

(14) Labour: (a) loading and soaking tanks = Rs. 0.06/bag; (b) sun drying labour = Rs. 2.00/t; (c) repair and maintenance = Rs. 0.90/t;

(15) Quantity of paddy processed per day (4 × 20) = 80 t/day;

(16) Quantity of paddy processed per year (80 × 250) = 20 000 t/year.

Calculation of Fixed Costs

(1) (a) Depreciation on plant and machinery

TABLE 37. Equipment and cost estimate for a conventional 4 t/h parboiling plant.

Item/equipment	Size	Quantity	Cost (Rs.)
Land	—	1.2 ha	60 000
Masonry soaking tanks (3 m × 5 m × 1.5 m)	160 t	4	40 000
Steaming kettles (1.5 m dia. × 3 m high)	1 t	8	25 000
Water pump	14 t	1	2 000
Drying yard @ Rs. 16/m²	75 000 m²	1	120 000
Godown @ Rs. 150/t, cost equally allocated to milling and parboiling unit	1600 t	1	120 000
Tube well	—	1	10 000
Boiler with accessories	1000 kg/h	1	150 000
Electrification	—	—	2 000
Platform scales	1-t capacity	1	2 000
Compound wall @ Rs. 30 per running metre equally allocated to milling and parboiling	600 m	—	9 000
Office @ Rs. 320/m² equally allocated to milling and parboiling	15 m × 5 m	1	12 000
Boiler house @ Rs. 200/m²	15 m × 8 m	1	24 000
Foundations, civil works, pipe fittings, etc.	—	—	10 000
Trollies with hopper bottom and pneumatic wheels for transporting paddy and paddy handling and stirring equipment, such as, baskets, spades, etc.	—	—	10 000
Miscellaneous	—	—	15 000
Total capital investment			611 000 (610 000)

$= (210\ 000 - 0.1 \times 210\ 000)/10$

$= $ Rs. 18 900/year

(b) Depreciation on land, building, and civil works

$= (400\ 000 - 0.1 \times 400\ 000)/25$

$= $ Rs. 14·400/year

Total depreciation on the plant

$= $ Rs. 33 300/year

(2) Interest on capital invested

$= 0.5\ (610\ 000 + 0.1 \times 610\ 000)$

(0.10)

$= $ Rs. 67 100/year

(3) Annual maintenance

$= $ Rs. 1500/year

Total fixed cost per year

$= (1) + (2) + (3)$

$= $ Rs. 101 900/year

Calculation of Variable Costs

(1) Cost of electricity

$= $ Rs. 0.70/t

(2) Cost of labour

    (a) Loading and soaking tank

      $= $ Rs. 0.81/t

    (b) Cost of labour for steaming

      $= $ Rs. 1.35/t

    (c) Cost of labour for sun drying

      $= $ Rs. 2.00/t

Total cost of labour $= (a) + (b) + (c)$

$= $ Rs. 4.16/t

(3) Cost of office and other staff

$= $ Rs. 0.5 $(600 + 400 + 300 + 750$

$+ 400 + 450) + (300 + 600)$

$= $ Rs. 0.5 $(2900) + (900)$

$= $ Rs. 1450 + 900

$= $ Rs. 2350

Cost per tonne

$= $ Rs. 2350/2400

    (2400 t of paddy is processed per month)

$= $ Rs. 0.98

(4) Cost of fuel

$= $ nil

(5) Repair and maintenance

$= $ Rs. 0.90/t

Total variable cost

$= (1) + (2) + (3) + (4) + (5)$

$= 0.70 + 4.16 + 0.98 + 0 + 0.90$

$= $ Rs. 6.74/t

Therefore the total cost of parboiling and drying per tonne of paddy

$= $ fixed costs + variable costs

$= $ Rs. 101 900 $\times (1/20\ 000) + 6.74$

$= $ Rs. 5.10 + 6.74

$= $ Rs 11.84

Modern Parboiling Plant (4 t/h)

The flow diagram for the parboiling and drying plant is shown in Fig. 110. The following assumptions were made in calculating the cost of parboiling.

(1) Cost of equipment and accessories (Table 38) $= $ Rs. 550 000

(2) Cost of building and civil work (Table 38) $= $ Rs. 190 000

(3) Life of equipment $= $ 10 years

(4) Life of building $= $ 25 years

(5) Number of working days per year $= $ 250 days

(6) Resale value $= $ 10%

(7) Interest on capital $= $ 10%

(8) Electricity $= $ Rs. 0.70/t

(9) Fuel $= $ husk

(10) Cost of husk per tonne of paddy processed $= $ nil

(11) Labour: (a) contract labour for loading tanks Rs. 0.04/bag of about 75 kg; and (b) five trained operators to operate parboiling plant and driers per shift Rs. 4.80 each.

(12) Staff: (a) one manager $= $ Rs. 750; (b) one assistant manager $= $ Rs. 500; (c) one head mechanic $= $ 500; (d) four clerks $= $ Rs.1000. Total $= $ Rs. 2750/month. The permanent staff is equally allocated to the parboiling and drying plant and the rice mill.

Calculation of Fixed Costs

If the parboiling plant works 20 h/day then the total quantity of paddy processed per year

$= 4 \times 20 \times 250$

$= $ 20 000 t/year

(1) Depreciation on plant and machinery

$= (550\ 000 - 0.1 \times 550\ 000)/10$

$= $ Rs. 49 500/year

Depreciation on building and civil works

$= (190\ 000 - 0.05 \times 190\ 000)/25$

$= $ Rs. 7220/year

TABLE 38. Equipment and cost estimate for a modern 4 t/h parboiling plant.

Item/equipment	Size	Quantity	Cost (Rs.)
Scalper precleaner	6 t/h	1	
Holding bin, hopper bottom	32 t	1	
Parboiling tanks (1.8 m dia. × 2.7 m high) with perforated steam pipes	6 t each	6	
Steam pipes			
Hot water tank	—	1	
Bucket elevator	32 t/h	1	
Belt conveyor	32 t/h	1	200 000
Hot water pump	28 l/s	1	
Foundation and civil works	—	—	
Pipe works for steam and water	—	—	
Electrical works	—	—	
Steel structure with platform and roof for the plant	—	—	
Mechanical driers	10 t each	2	
Bucket elevators for the driers	20 t/h	2	200 000
Tempering bins	20 t each	2	
Boiler (husk fired) with accessories	1000 kg steam/h	1	150 000
Godown @ Rs. 150/t, cost is equally allocated to milling and parboiling unit	1600 t		120 000
Tube well	—	1	10 000
Office @ Rs. 300/m², cost is equally allocated to milling and parboiling unit	12.5 m × 8 m	1	15 000
Boiler house @ Rs. 200/m²	15 m × 8 m	1	24 000
Miscellaneous			20 000
Total capital investment			739 000 (740 000)

Total depreciation on the plant
    = Rs. 56 720/year
(2) Interest on capital invested
    = 550 000 + 0.1 × 550 000 +
        190 000 + 0.05 × 190 000) (0.10)
    = Rs. 80 450/year
(3) Annual maintenance
    = Rs. 2000 per year
Total fixed cost per year
    = (1) + (2) + (3)
    = Rs. 139 170/year
Cost per tonne
    = Rs. 139 170/20 000
    = Rs. 6.96/t

Calculation of Variable Costs

(1) Cost of electrical energy = Rs. 0.70/t

(2) Cost of labour for:
    (a) loading parboiling tank = Rs. 0.54 t
    (b) operating parboiling and drying plants
    = (Rs. 4.80/operator) ×
        (5 operator/shift)
        × (3 shifts/day) ÷ (30 t paddy/ day)
    = Rs. 0.90/t

Total labour cost

      = Rs. 0.54 + 0.90

      = Rs. 1.44/t

(3) Cost of permanent staff

      = Rs. 2750/month

Cost per tonne

      = Rs. 2750/month ÷ 2400 t/month

      = 1.15/t

(4) Cost of fuel = nil

(5) Repair and maintenance = Rs. 1.50/t

Total operating cost

      = (1) + (2) + (3) + (4) + (5)

      = 0.70 + 1.44 + 1.15 + 0 + 1.50

      = Rs. 4.79/t

Therefore, the total cost of parboiling and drying one tonne of paddy

      = fixed cost + variable cost

      = Rs. 6.96 + 4.79

      = Rs. 11.75/t

These cost estimates and calculations are projected costs taking basic input data from the operation of paddy processing complexes. However, due to the very large quantity of paddy to be processed per day it is not possible to operate a conventional unit at the capacity of 80 t/day or 20 000 t/year. The cost estimates of two types of parboiled and drying systems have been made at the same capacity to compare the economics of the two systems.

The unit cost of parboiling and drying 1 t of paddy by the modern method is Rs. 11.75/t; whereas, the unit cost of parboiling and drying 1 t of paddy by the conventional method is Rs. 11.84/t.

An additional recovery of 1–2% of the rice has been reported by most of the rice millers using modern parboiling and drying methods. An increase of 1% in the rice outturn is nearly equivalent to a 1.5% increase in paddy. Assuming a paddy price of Rs. 700/t, the saving due to reduced losses by modern parboiling and drying system amounts to Rs. 10.50/t. Therefore, the net cost of parboiling and drying by a modern method is only Rs. 1.25/t (11.75 − 10.50). Therefore, although the modern parboiling and drying method may appear to be more expensive due to very high initial capital investments and higher operation cost, the extra rice outturn not only justifies the economics of the modern method but also provides 0.4–0.8 million tonnes of rice per year, based on a total production of 40 million tonnes per year. — NAWAB ALI AND T. P. OJHA. *Agricultural Engineering Department, Indian Institute of Technology, Kharagpur– 721302 W.B., India.*
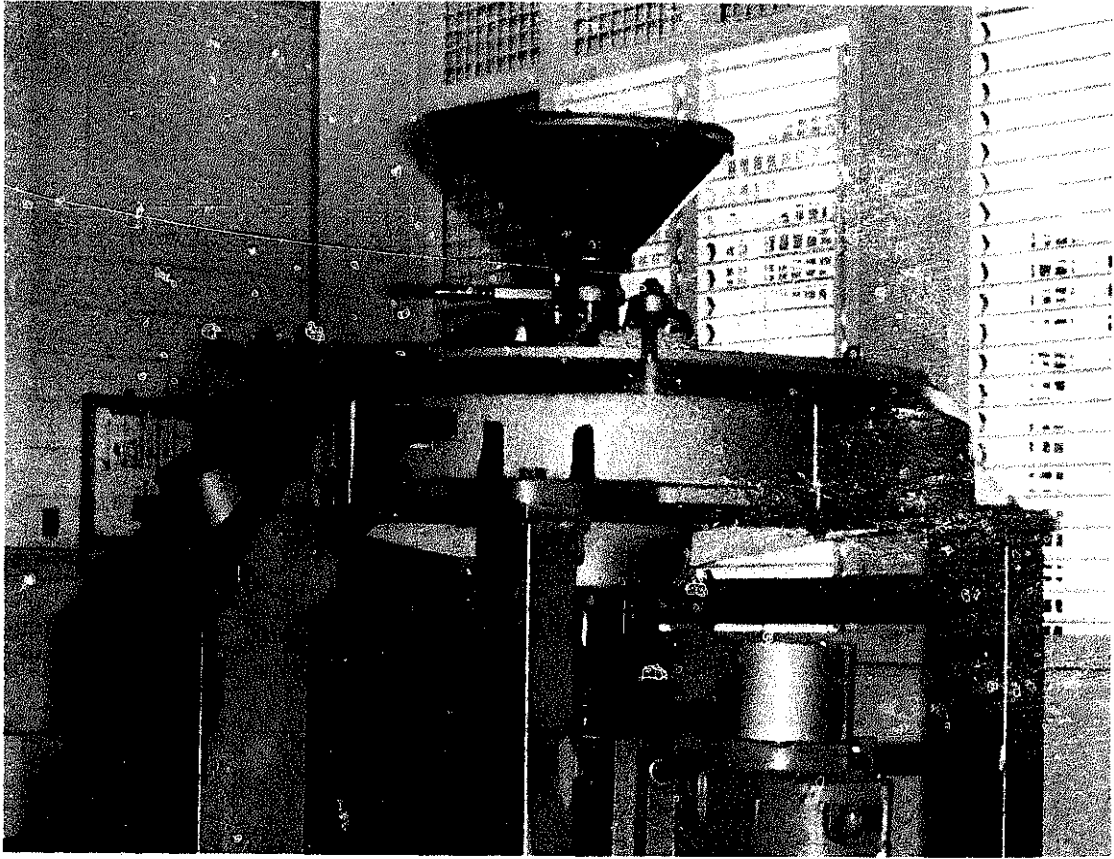
MILLING

Precleaning

Prior to the actual milling operation, the paddy received from the farmer is cleaned in precleaning machines. Foreign matter or impurities are removed to protect the processing equipment and improve the final product. The impurities can be divided into large impurities, small impurities, and impurities of about the same size as the paddy grain. Large impurities normally consist of rice straw, panicles, bag string, soil, stones, and sometimes iron parts. Small impurities consist of dust, sand, soil particles, weed seeds, insects, and small stones. Impurities of about the same size as the paddy grains can be empty grains, stones, and iron particles.

In the precleaning process use is made of differences in the size, weight, and sometimes length of the impurities compared to the paddy grain. Impurities lighter in weight than paddy can be removed by aspiration or by sieving. Large and small impurities heavier than paddy are removed by sieving; whereas, particles the same size but heavier can be removed by gravity separation. Foreign material about the same weight and size as the paddy grain is difficult to remove, and it is presumed to disintegrate during the actual milling process.

Weed seeds are generally small impurities normally separated through sieves. If they are not separated during the precleaning process, the seeds will not be processed during the milling operation and will finally be mixed with the end product, consequently downgrading the white rice. In those rice mills that produce mainly white rice for high-quality markets, trieurs (rotating grading cylinders) are used to remove the seeds based on differences in their length as compared to paddy grains.

Iron parts or particles are removed by sieving, by gravity separation, or by permanent or electro-magnets.

Open Double-Sieve Precleaner (Fig. 127)

In most of the rice mills in the Philippines, simple precleaning is performed through open double-layer oscillating sieves. The precleaners are driven directly by an eccentric drive from the main transmission shaft. The frequency of oscillation is equal to the speed of rotation of this transmission shaft and varies between 300 and 400 double strokes per minute.

The paddy is fed into the top of the machine (A), and passes to the first sieve (1) that has large perforations and retains only large impurities, which are conveyed to the overflow (B). The second sieve (2) with small perforations holds the paddy and allows small impurities to fall to the bottom pan where they are discharged (D). The precleaned paddy, held by the second sieve, is then removed (C).

This type of sieve has many disadvantages: (1) Since it is an open sieve, dust formation is considerable, and in fact this machine is mainly responsible for the very dusty appearance of the cone-type rice mills in the Philippines; (2) None of these precleaners has been equipped with self-cleaning sieves and consequently, most of the bottom sieves with small perforations are clogged, and separation efficiency is reduced considerably. Consequently, many weed seeds are not removed and white rice produced in the cone-type mills of the Philippines holds many weed seeds; (3) Impurities of about the same size as the paddy grains are not separated.

The precleaning efficiency of this type of machine, therefore, is insufficient.

Self-Cleaning Sieves (Fig. 128)

The introduction of self-cleaning sieves will improve the operation of the open double-sieve precleaner. Self-cleaning sieves are not only used in precleaning machines but also in other machines where sieves with round or slot perforations and wire screens are used in the rice milling process.

A self-cleaning sieve consists of a wooden frame dividing the sieve surface into square compartments of about 20 × 20 cm or larger. The top of this frame is covered with the
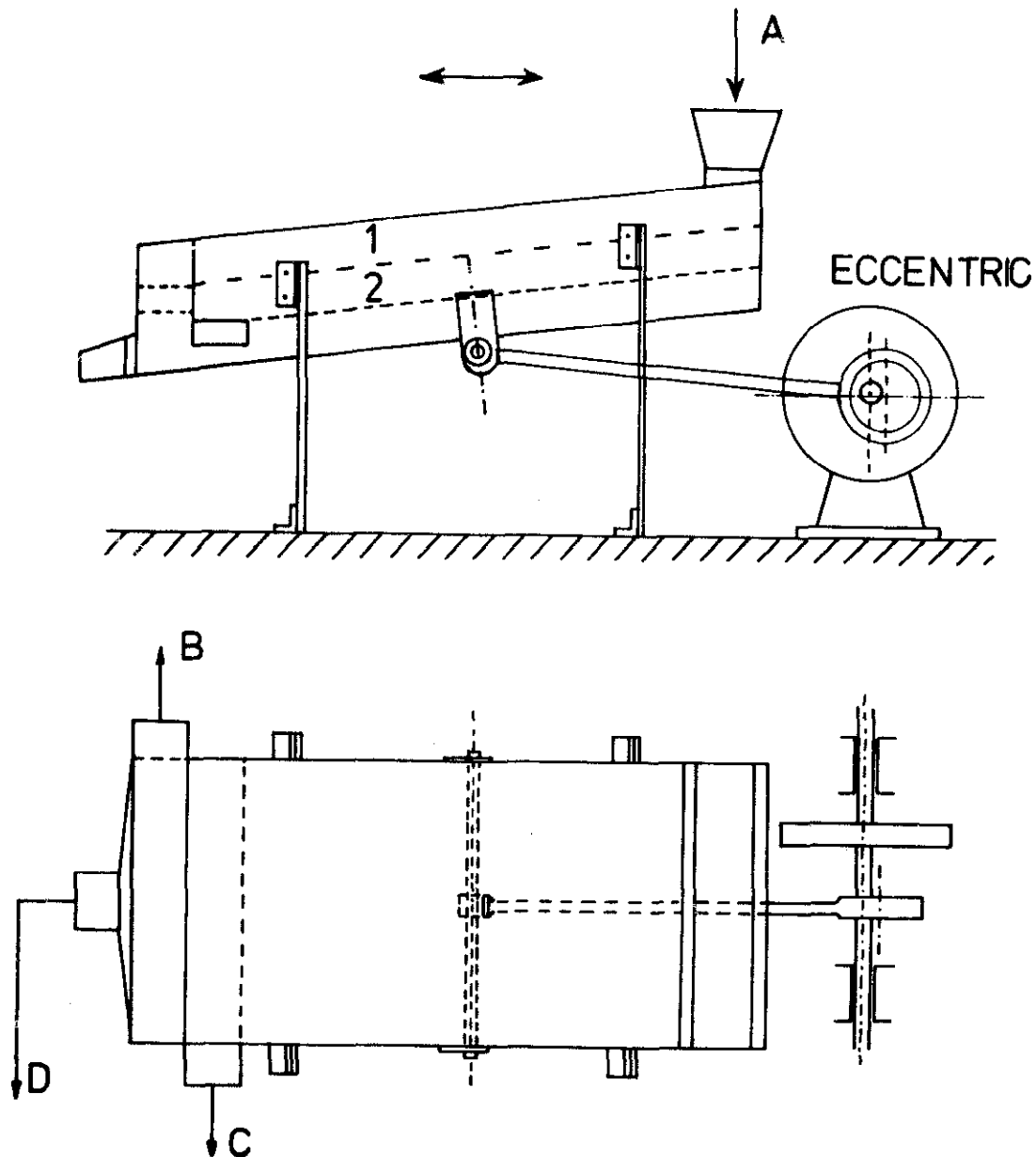
FIG. 127. Open double-sieve precleaner.

selected perforated sheet or wire screen, and the bottom is covered with a wire screen of large mesh for free discharge of the separated products (A). In the compartments are one or two rubber balls (B) varying between 1.9 and 3.2 cm (0.8 and 1.3 inches) in diameter depending on the size of the machine. During the operation of the machine these balls continuously hammer the top sieve and knock the particles, which normally clog the sieve, out of the perforations (C). Nevertheless, these self-cleaning sieves must be cleaned manually at least once a day.

Single-Action Aspirator-Precleaner (Fig. 129, 130, and 131)

To avoid the formation of dust by the pre-
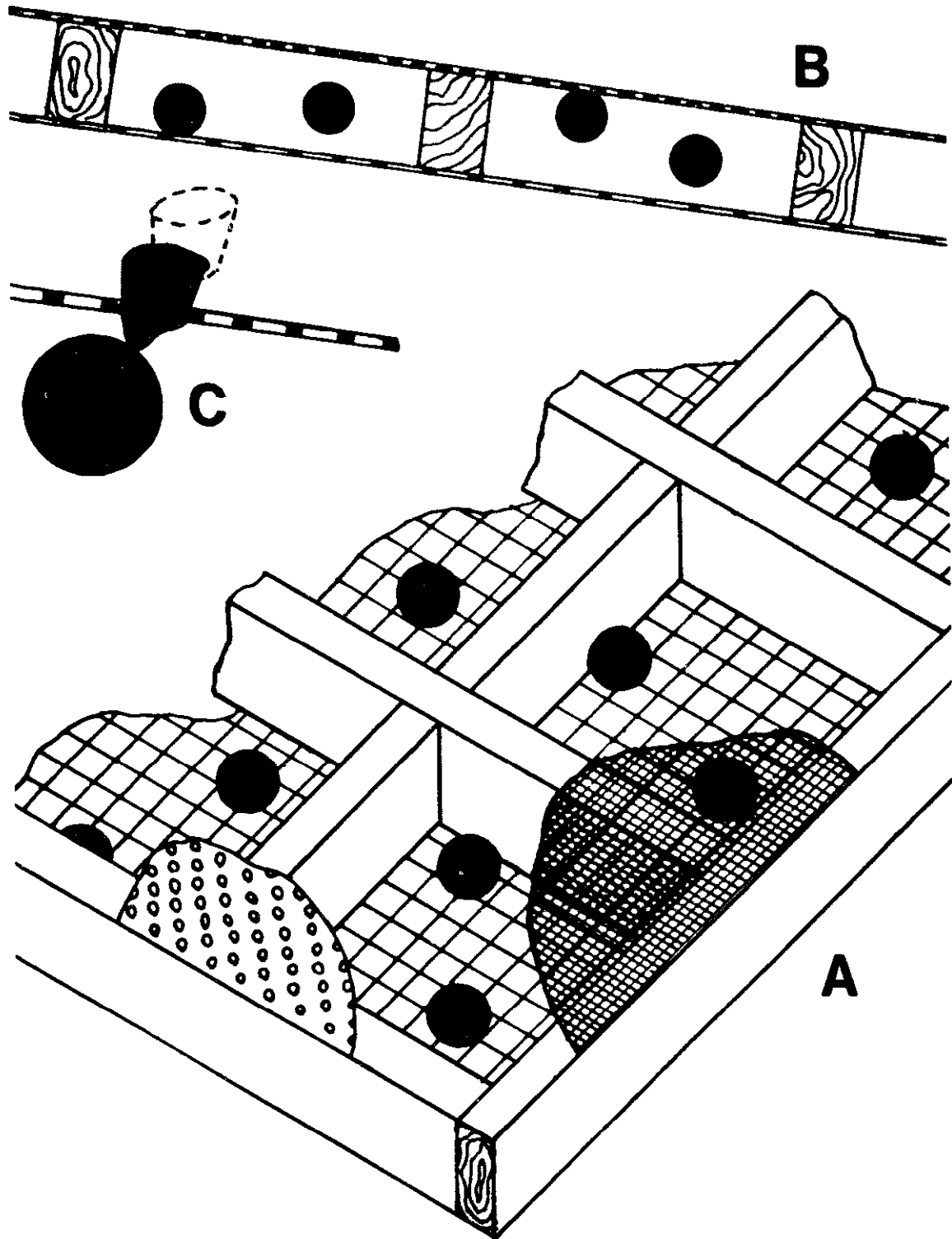
FIG. 128. Self-cleaning sieve. (A) Sieve frame showing square compartments and different mesh sizes. (B) One or two rubber balls are used in each compartment. (C) Balls strike particles in top mesh and knock them free.

cleaner, the machines can be combined with an aspirator (Fig. 129, I) and are known as closed-type aspirator-precleaners. These units consist of a stationary section and an oscillating section (Fig. 129, II). The stationary section is fixed in a wooden or iron frame and houses a suction fan. The oscillating section hangs in this frame and is driven by an eccentric from a transmission shaft (Fig. 130). The paddy is fed into this machine through an opening in the top (Fig. 129, A). The suction fan draws air through the film of grain and separates all dust and light impurities (Fig. 129, I). The flow of the grain and the capacity of the suction air can be controlled (Fig. 129, 2).

The light impurities drop to the cone-shaped bottom of the aspiration housing for automatic discharge (Fig. 129, F) through double air valves (Fig. 131). The grain falls to a sieve with large perforations, for discharge of large heavy impurities (Fig. 129, B), and is unloaded on the long top sieve of the oscillating section, where more large impurities are removed (Fig. 129, C). (Quite often magnets are installed under the guide plate of the short top sieve (Fig. 129, 3).) The paddy and remaining impurities fall to the bottom sieve, which allows the small impurities to pass through (Fig. 129, D). The overflow of this sieve is the precleaned paddy (Fig. 129, E). The fan in the top section
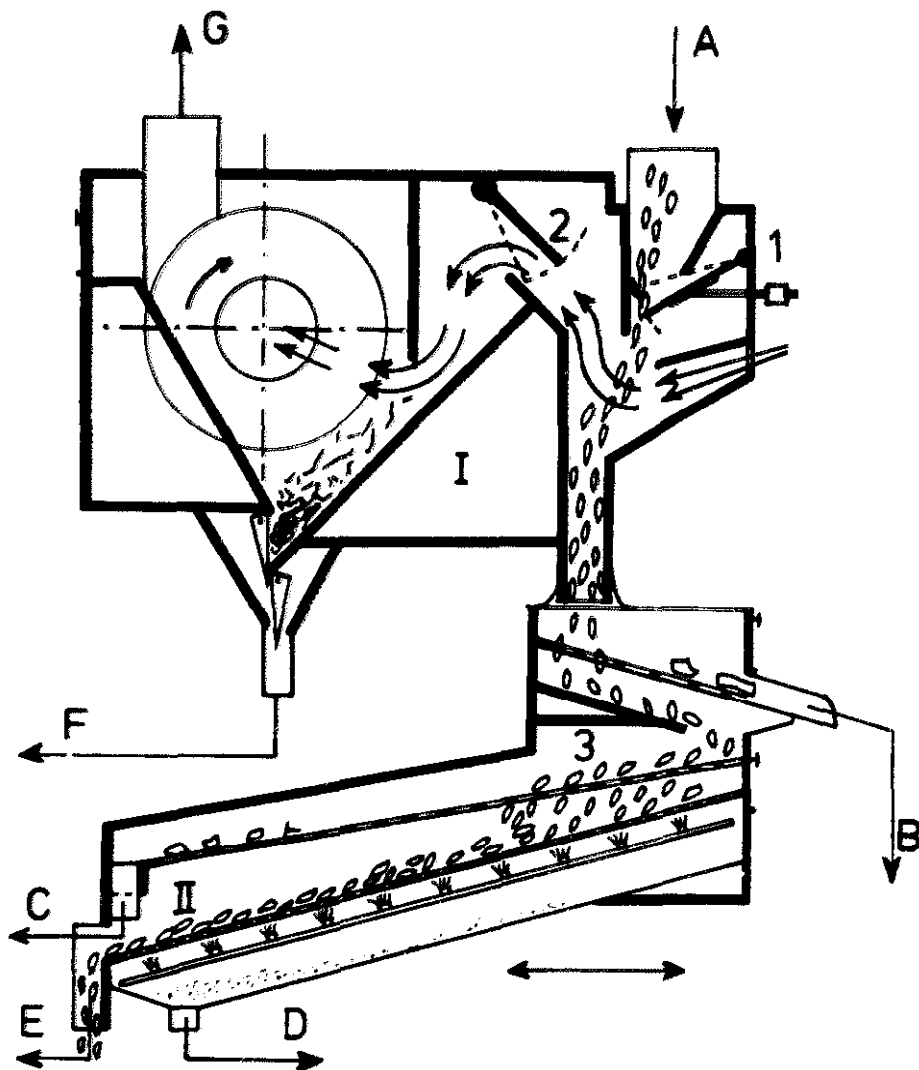
FIG. 129. Closed-type single-action aspirator-precleaner.
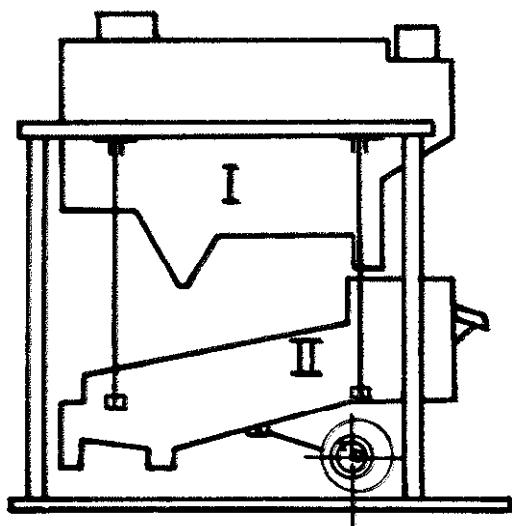
Fig. 130. Unmoving (I) and oscillating (II) section
of aspirator-precleaner.
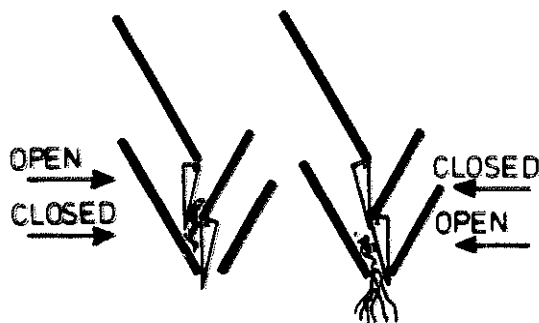
Fig. 131. Double air valves used for automatic
discharge.

of this machine blows air and dust in a cyclone for dust separation, making the entire precleaning operation practically dust-free.

Double-Action Aspirator-Precleaner (Fig. 132)

This machine is basically the same as the single-action aspirator-precleaner. The only difference is that the precleaned paddy passes a second airstream for final removal of dust. The back part of the unmoving section of the machine (I), housing the suction fan, is equipped with an air compartment through which a controlled airstream is sucked by the blower (4). The air passes first through the precleaned paddy (E), absorbing all remaining

light impurities, which will then drop into a cone-shaped section at the bottom of the aspirator housing for automatic discharge through double air valves. Being a double-action suction unit, the aspirator housing of this machine is equipped with two sets of double air valves for impurity discharge (F).

Double-Drum Type Precleaner (Fig. 133)

A number of drum-type paddy precleaners have been designed, one of which is a double-drum aspirator-precleaning unit, produced in West Germany. This machine basically consists of two horizontal perforated rotating cylinders and a suction fan.

The first cylinder has small perforations through which small heavy impurities are removed (B). At the same time an airstream is sucked through this cylinder, removing most of the light impurities. These impurities drop into the cone-shaped bottom of the fan-housing section for automatic discharge through a rotating air valve (F). The paddy and its large impurities then reach the second horizontal cylinder, this time equipped with a perforated sheeting of larger perforations for the separation of the large impurities (C). The precleaned paddy passes through this cylinder for direct discharge into the rice mill hulling section (E). The fan blows the air and dust into a cyclone for dust separation (D).

The flow of paddy into this machine (1) and the airstream can be controlled by adjustable valves (2, 3).

Single-Drum Precleaner (Fig. 134)

The Japanese have developed single-drum type precleaners, sometimes with gravity separation of stones. One of the single-drum type precleaners is made in combination with an oscillating sieve.

The horizontal rotating cylinder is covered with a wire screen of large mesh for the separation of the large impurities (B). Some of the large impurities, however, are separated by a vibrating inclined sieve prior to the drum cleaning process (1). The paddy and the smaller
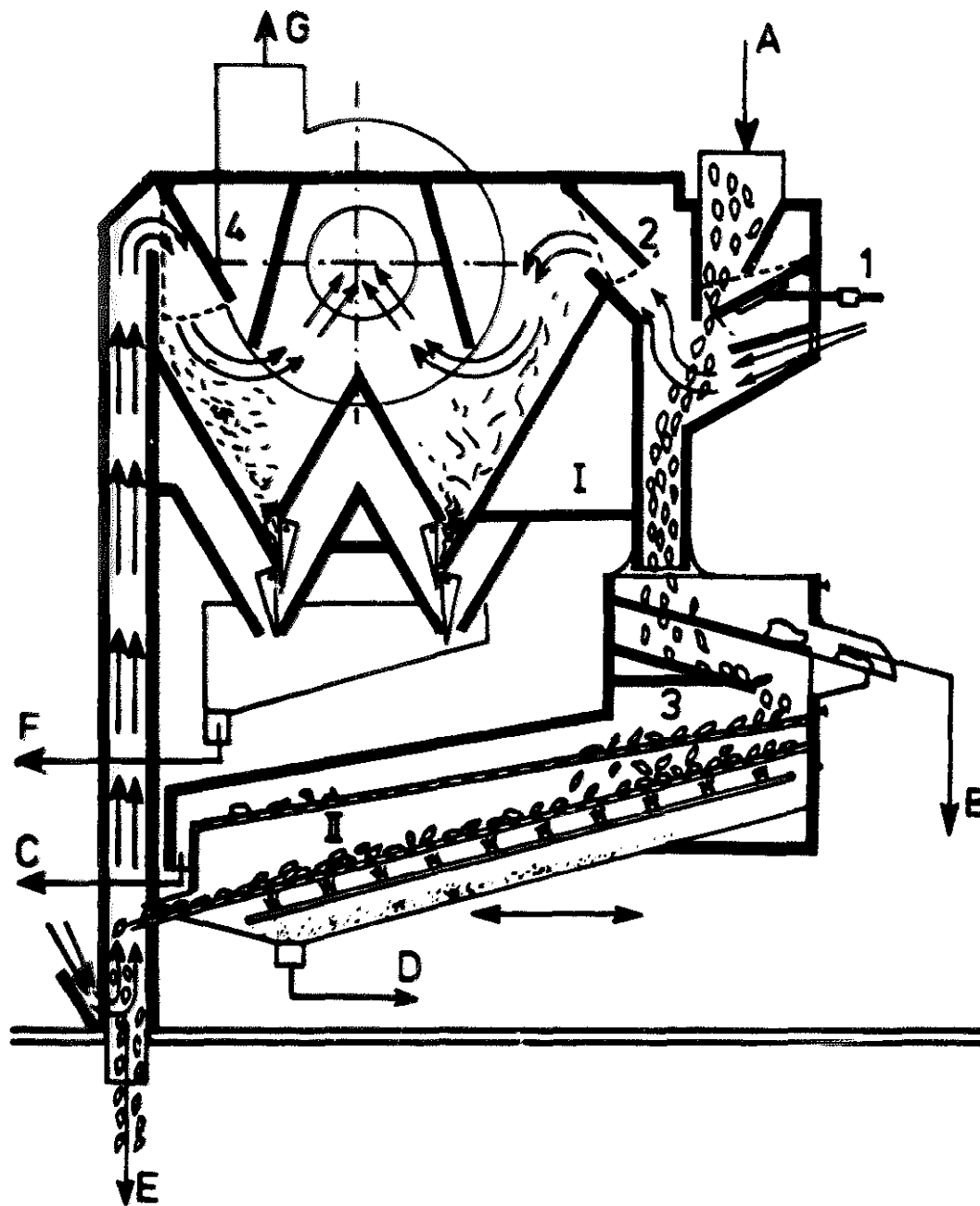
FIG. 132. Closed-type double-action aspirator-precleaner.

impurities drop through the wire screen of the drum and reach the oscillating sieve as a film of grain. On the way down, an airstream is sucked through the film of grain, removing light impurities and dust for discharge by the suction fan (C). This fan blows the air and dust into a cyclone for the separation of the impurities.

The oscillating sieve is a double-layer type. The top sieve has large perforations for the separation of the larger impurities (D) and the bottom sieve has small perforations for the removal of small impurities (E). The overflow of the bottom sieve represents the precleaned paddy (F).

Paddy input is controlled by an adjustable
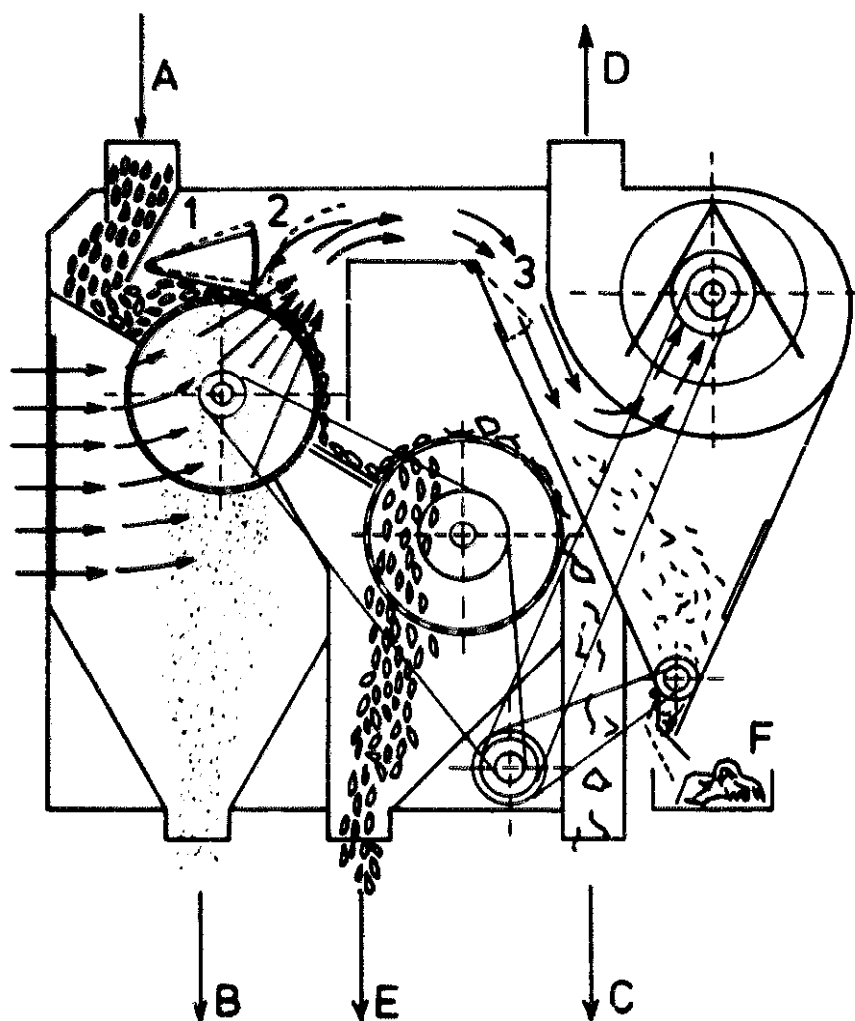
FIG. 133. Double-drum type of precleaner (West Germany).

valve (2), and equal distribution of the paddy over the full width of the vibrating top sieve and rotating cylinder is secured by a rotating paddle and adjustable flap (3, 4). The wide screen of the cylinder is continuously cleaned by a rotating drum cleaner (5) and a special scraping device on top of the oscillating sieve removes the separated impurities.

Stoner (Fig. 135 and 136)

Stones of about the same size as the paddy grains are separated by gravity separation methods. The basic principle is that the lighter paddy grains are carried away by the airstream, leaving the stones behind. Different types of machines have been designed in Germany, the USA, and Japan.

One of the stoners now introduced in the Philippines is made in Japan. It consists of a perforated screen in an inclined position (Fig. 135). Through a parallel mechanism driven by an eccentric, this sieve makes an upward movement (Fig. 136).

A relatively large amount of air is blown from underneath through the sieve (Fig. 135, A), lifting the paddy grains from the sieve and slowly carrying them down to the discharge spout (Fig. 135, C). As a result of the upward movement of the sieve, little stones are transported to the top of the sieve. Any paddy grains transported upwards with the stones
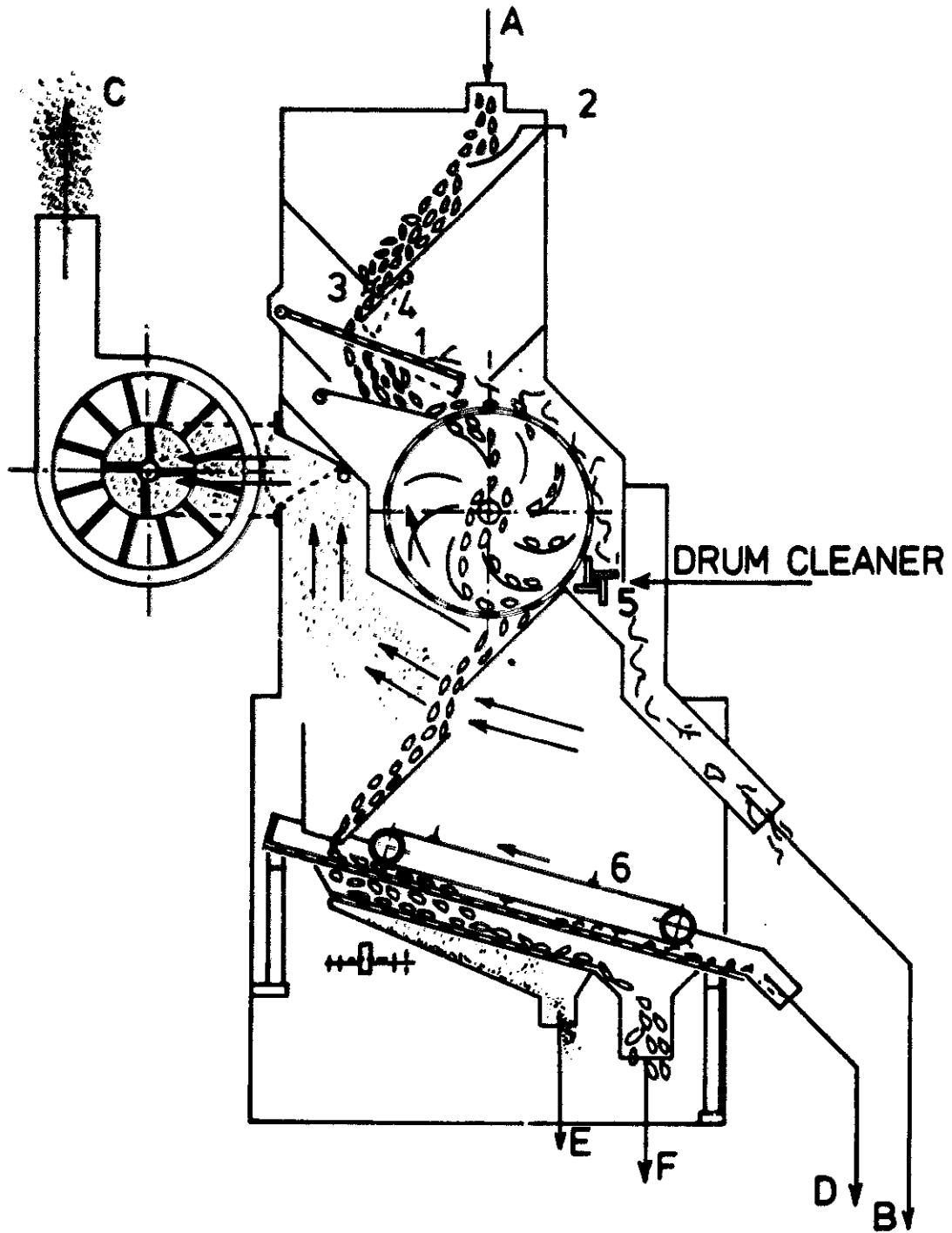
FIG. 134. Single-drum type of precleaner (Japan).
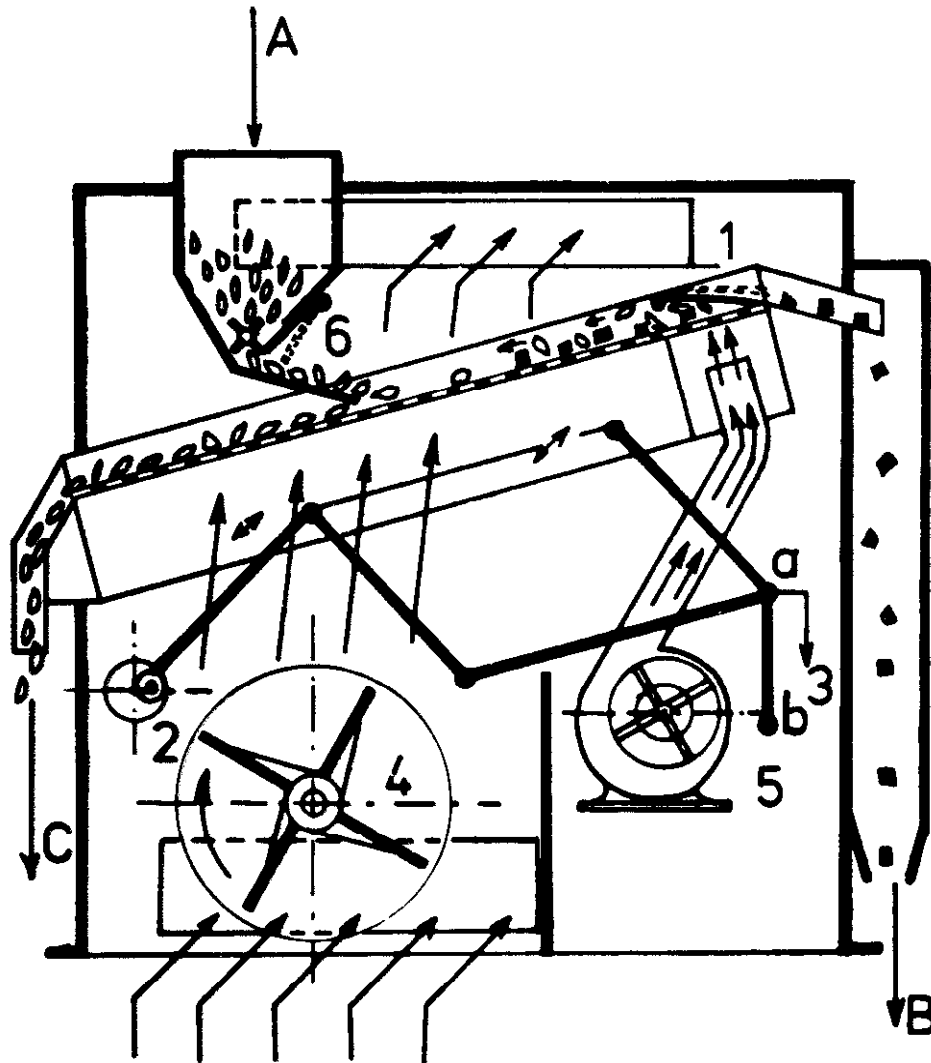
Fig. 135. Stoner (Japan).

are blown free by a smaller second blower mounted under the sieve (Fig. 135, 5). The stones are collected under a flap (Fig. 135, 1) and are unloaded into the discharge spout by manually lifting this flap (Fig. 135,B).

Because different varieties of paddy are to be processed, the inclination of the sieve has been made adjustable. This is done by manually changing the length of bar a–b, which changes the position of the parallel mechanism carrying the sieve, allowing the sieve inclination to be increased or decreased (Fig. 136).

The paddy is fed into the top of the machine and its flow and equal distribution are secured by a rotating paddle and adjustable valve (Fig.

135, A). Stoners are always used after the main precleaning process, so that only precleaned paddy is actually fed into these machines.

Magnetic Separator (Fig. 137)

The bulk of the iron particles mixed with the paddy is removed during the normal precleaning operation as large or small impurities. If no special stoner is installed, iron particles of about the same size as the grains can only be removed by magnetic separators. Nevertheless, we have to take into account that bolts
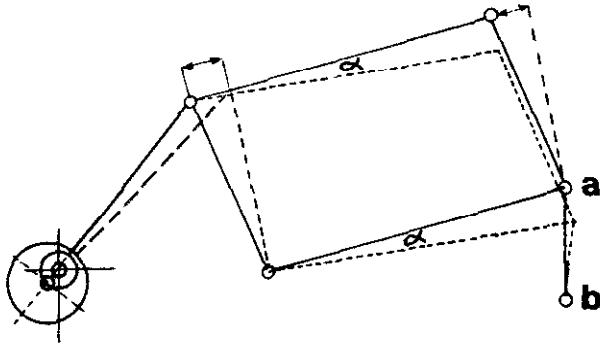
FIG. 136. Change in length of bar a–b changes inclination of sieve (α).

and nuts from the paddy processing machines may get loose any time and if not removed can seriously damage the processing equipment. Therefore, magnetic separators are installed not only in precleaning equipment but also in husk separators and the discharge spouts of elevators.

There are simple permanent magnets for machines and/or discharge spouts (Fig. 137A,B). Another type of permanent magnetic separator is a rotating brass cylinder passing over a half-round permanent magnet (Fig. 137C). The grain film is transported by the rotating cylinder that unloads the grain in the discharge spout (1), but holds the iron particles attracted on its surface because of the magnet. When the cylinder is not moving over the magnet, the iron is automatically released and is discharged separately (2). In some of the larger rice mills special high-capacity magnetic separators are installed for mechanical and continuous discharge of the iron. Most of the magnetic separators are of the permanent type; however, electromagnets may also be used. — HARRY VAN RUITEN. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*
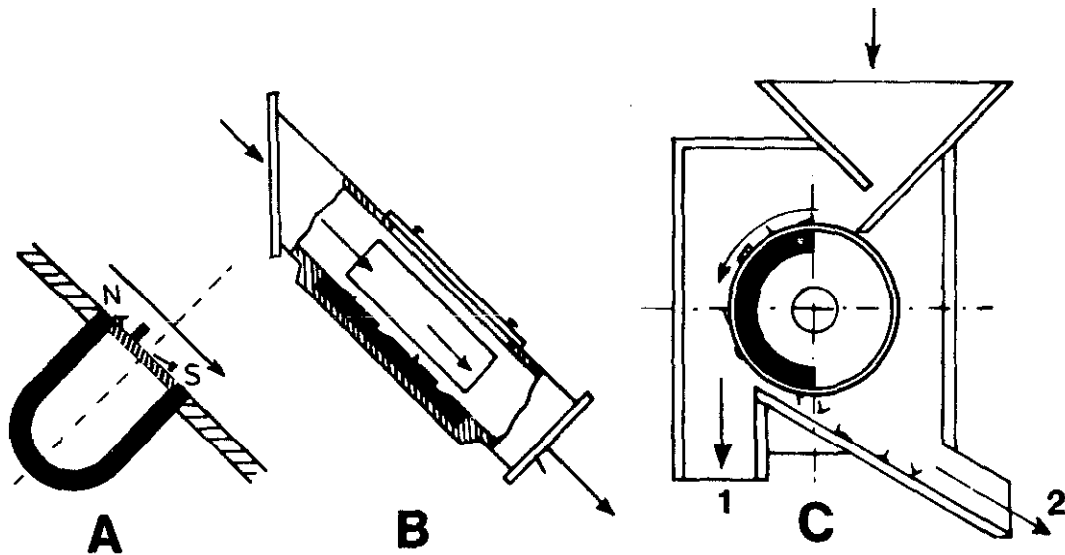
FIG. 137. Different types of magnetic separators: A, B simple permanent magnets; C rotating brass cylinder and permanent magnet.

The huller efficiency is the percentage of grain actually hulled with a minimum of breakage.

Hulling

The Under-Runner Disc Huller, or Disc Huller (Fig. 138)

The objective of a hulling machine is to remove the husk from the paddy grain with a minimum of damage to the bran layer and, if possible, without breaking the brown rice grain.

Because the structure of the paddy grain makes it necessary to apply friction to the grain surface to remove the husk, a certain percentage of brokens cannot be avoided; however, much can be done to reduce this breakage. In this respect the construction of the machine, its precision, its maintenance, its adjustment, and the way it is operated can secure optimum performance in huller efficiency and head rice production. However, if the grain is damaged in the field as a result of moisture cracking (suncracking), breakage during the milling process cannot be avoided.

Because the adjustment of the huller depends on the variety of paddy to be processed, uniformity of the grain is essential for optimum performance. However, under most circumstances, pure varieties are not available and a mixture of varieties can be responsible for a less efficient hulling process. The negative effect on hulling of mixed varieties can be avoided by the grading of paddy prior to hulling or can be reduced by the rearrangement of the grain flow in a rice mill.

The most common machines used in hulling paddy are the under-runner disc huller, which is the most commonly used machine, and the rubber roll huller, which was introduced after World War II and is slowly gaining popularity. A rubber band huller developed in Europe in 1947–48 disappeared from the market shortly afterwards and the small centrifugal hullers are still in the experimental stage.

Hulling machines are known by different names, such as shellers, hullers, dehuskers, huskers, and hulling mills. Most commonly these machines are called "hullers." A huller has an efficiency that does not refer to its capacity but to its performance as a huller.

The under-runner disc huller consists mainly of two horizontal cast-iron discs, partly coated with an abrasive layer. The top disc is fixed in the frame housing; the bottom disc rotates. The rotating disc is vertically adjustable (2) so the clearance between the abrasive coating of the disc can be adjusted (3). This adjustment depends on the variety of paddy, the condition of the grain, and the wear of the coating.

The paddy is fed into the centre of the machine through a small hopper. A vertically adjustable cylindrical sleeve (1) regulates the capacity and equal distribution of the paddy over the entire surface of the rotating disc. By centrifugal force the paddy is forced between the two discs and under pressure and friction most of the grain is dehusked.

The adjustment of the clearance between the discs is rather critical and requires continuous rechecking to avoid excessive breakage or insufficient huller efficiency. Quite often, the effective width of the abrasive coating is made too large, causing unnecessary breakage of the grain. Empirically, it has been proven that this width should not be more than 1/6 to 1/7 of the stone diameter. The peripheral speed of the disc should be about 14 m/s, making the speed a function of the diameter of the stone. The larger the diameter, the lower the revolutions per minute of the shaft (Fig. 139).

Example

D = stone   diameter = 700 mm   (0.7 m); and V = peripheral speed = 14 m/s.

$$V = \frac{\pi \times D \times n}{60} \quad (m/s)$$

$$n = \frac{60 \times V}{\pi \times D}$$

$$= \frac{60 \times 14}{3.14 \times 0.7}$$

$$= 380 \text{ rpm}$$
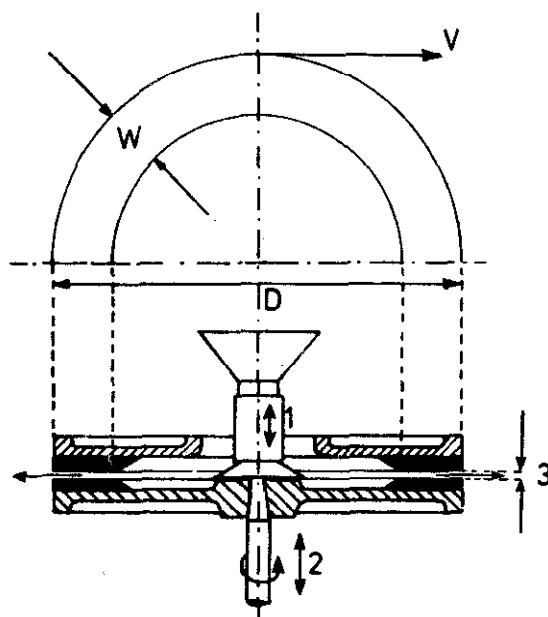
FIG. 138. Particulars of the under-runner disc huller: V = peripheral speed (recommended 14 m/s); W = width of coating; D = stone diameter; and W/D = 1/6 or 1/7.

FIG. 139. Under-runner disc huller peripheral speed-curve for V = 14 m/s.

The wear of the abrasive coating of the disc is not equal over the full surface of the coating. Hulling is concentrated in the centre part of the coated surface and, consequently, wear in that section of the coating is greater than at the outer or inner rings. Slowly a small ridge is made at the outer ring of the coating (Fig. 140B), which is responsible for an excessive buildup of pressure on the grain between the stones. Consequently, the rice is broken not only because of this excessive pressure but also because of the presence of the ridge, which the hulled rice has to pass when leaving the machine. When these ridges are produced, the surface of the stones must be redressed (corrected), and the life of the coating is unnecessarily reduced (Fig. 140C). It is more effective with respect to the efficiency and the life of the coating to redress the stone surfaces more often so ridges will not be formed.

Vertical adjustment of the rotating disc is accomplished by moving the entire shaft-disc assembly. The housing of the shaft-end bearing is moved by a steel beam controlled by a handwheel adjustment (Fig. 141). The bar

may be moved by two handwheels, or the supporting bar can be hinged on the base of the huller frame and controlled by a single wheel.

Vibration in the machine components is to be avoided because this breaks the rice. In this respect proper bearing of the shaft and maintenance of these bearings are very important. The shaft-end bearing absorbs radial and axial forces; therefore, a double bearing assembly is recommended. For this purpose a combination of a single or double ball bearing and a taper roller bearing can be used (Fig. 141). These bearings must be maintained and greased properly. If the roller bearing is not greased the ball grooves will be damaged, resulting in excessive tolerance and vibration, which can only be corrected by replacing the bearing. In a locally made huller (and also in a whitening cone), very often only a roller bear-
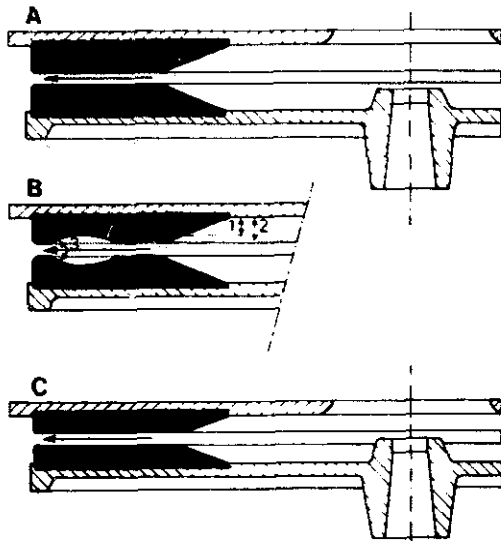
FIG. 140. Under-runner disc huller maintenance: (A) original condition of stone coating; (B) uneven wear developed at centre of coating; and (C) redressed surface of abrasive coating.

FIG. 141. Under-runner disc huller bearings and adjustment details.

ing is used for radial forces and a simple steel ball absorbs the axial forces (Fig. 142). In this case the end of the shaft is rounded. With this construction the actual contact area between shaft and ball is very small and, when not sufficiently greased, there is immediate damage to the shaft and the ball causing vibrations.

The upper part of the shaft is normally guided by a bronze bush bearing, lubricated by grease (Fig. 143). The grease is pressed between the bush and shaft; however, quite often only the lower portion of the bearing is lubricated. Friction between the upper portion of the bush bearing and the shaft then becomes excessive, causing heat and wear, and leads to vibrations in the upper portion of the shaft assembly (Fig. 143, wrong). This problem can be overcome by drilling an extra lubrication hole in the bronze bush bearing, allowing grease to be distributed over the full working surface of the bearing (Fig. 143, right). The housing for this bearing is normally bolted to the huller frame with bolts and nuts. When no spring washers are used the nuts may loosen and the upper part of the shaft will vibrate. Both surfaces of the discs should be fully level and remain level,

FIG. 142. An end-bearing assembly of the under-runner disc huller containing a roller bearing and steel ball (Philippines).

otherwise the huller will be transformed into a perfect rice breaker. Consequently, continuous maintenance remains essential.

The huller shaft is normally driven by a flat-belt or a V-belt transmission. When lifting the
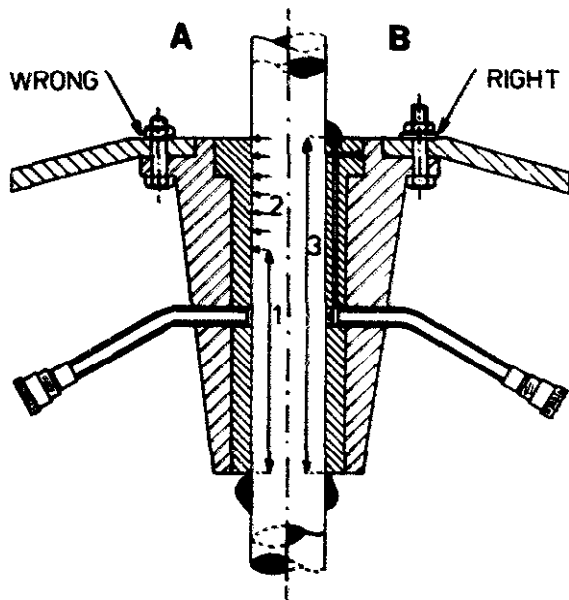
FIG. 143. Details of the bronze bush bearing used in under-runner disc huller: (A) poor lubrication; and (B) additional hole drilled providing proper lubrication.

shaft assembly for disc adjustment, the driven pulley on this shaft will also be lifted. For a flat-belt pulley-drive the transmission will remain unaffected by this adjustment since the extra width of the flat-belt pulley will allow free movement of the belt over the pulley (Fig. 144A). For a full V-belt transmission (two V-belt pulleys with V-belts), this belt correction is not possible and, consequently, the belt will be out of line when an adjustment is made (Fig. 144B). This causes extra friction on the belt, resulting in heat and excessive wear. Nevertheless, this method is used quite often in the Philippine-made rice mills. The problem can be overcome if the large V-belt on the huller shaft is replaced by a flat-belt pulley (Fig. 144C). However, this reduces the grip of the belts on the driven pulley and more belts are required.

The position of the driving pulley may be changed after adjustment of the huller shaft (Fig. 144D). This is done in electric motor-driven machines by lifting the entire motor support assembly.

A mistake often made, when driving a huller by flat-belt transmission, is not making the pulling part of the belt perpendicular to the
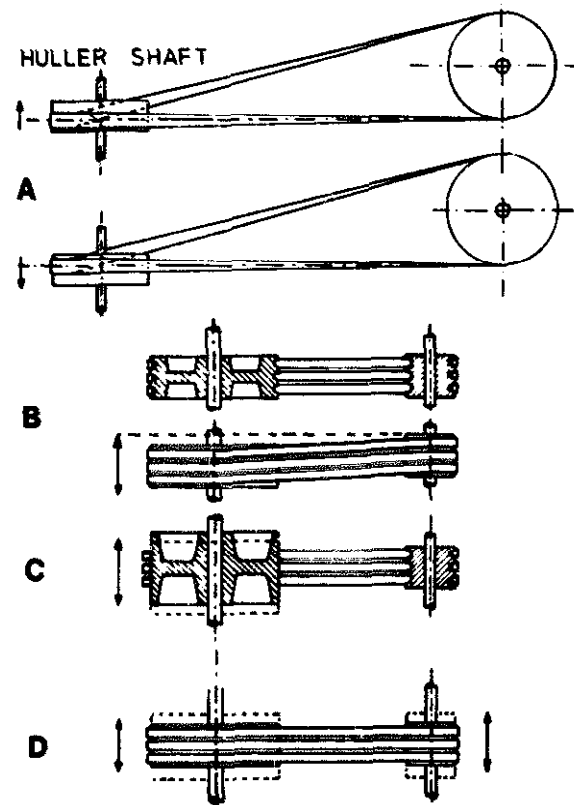
FIG. 144. Methods for transmission-drive: (A) flat belt pulley-drive; (B) full V-belt transmission; (C) V-belt on transmission shaft replaced by flat pulley, and (D) position of driving pulley changed.

main transmission shaft. This is essential for an optimum transmission of force from transmission shaft to machine (Fig. 145).

In many rice mills, the abrasive coating is applied to the stone in a rather primitive way making it practically impossible to secure a uniform, fully level, working surface. Fortunately, very simple and cheap tools can be made that provide a perfectly level surface of both the fixed and rotating discs, and any corrections on the surface of the abrasive coating can be done by simple redressing tools (Fig. 146).

The use of these tools is indispensable for smooth and efficient operation of the huller. In general, in the Philippines, a pure emery
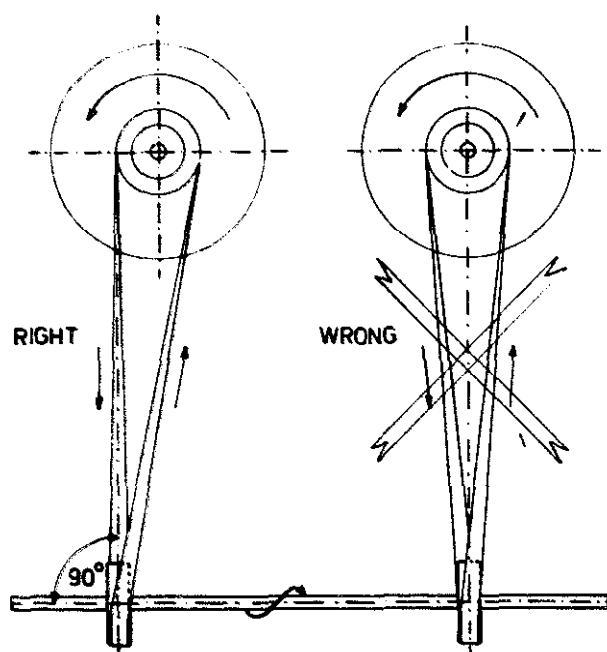
Fig. 145. Position of the drive-pulley in under-runner disc huller.

composition for the coating for the discs is used. Normally this composition consists of 100 weight units of emery grit 14, 20 weight units of magnesite, and magnesium chloride brine (30° Baumé). This composition became outdated many years ago and with the newly recommended composition much better huller capacity and huller efficiency, and longer life of the stone are obtained. The secret of the new composition is a new component silicium carbide (carborundum), whose hardness is about two and one-half times higher than that of emery. The recommended composition of the new coating is grit (50% by weight emery grit 14, 16⅔% by weight emery grit 16, and 33⅓% by weight silicium carbide grit 16), 20% by weight magnesite, and 20% by weight chloride brine (29° Baumé).

In the Philippines, the under-runner disc hullers are normally mounted on elevated concrete foundations so that the actual hulling section will be at working level on the first floor (Fig. 147A). The disc adjustment must be done on the ground floor level under less attractive working conditions. In some rice mills abroad, this adjustment is made from the working level on the first floor by simplifica-

tion of the construction of the huller frame and by extension of the handwheel controlled adjustment device (Fig. 147B). In practically all horizontally projected rice mills in other countries, the huller is mounted on the ground floor level (Fig. 147C).

Because in the Philippines the paddy supplied to rice mills in general does not represent a pure variety and as paddy grading has not been implemented, quite often, because of the mixture of varieties, huller efficiency cannot be kept at a high level without breaking the brown rice. This is caused mainly by the varying thickness of the paddy grains. The mill operator wants to dehusk as many grains as possible and, therefore, reduces the clearance between the discs. By doing so he is actually cracking the thicker grains while dehusking the thinner ones. When he sees this, he readjusts the huller and consequently reduces the huller efficiency.

The paddy not hulled during the first pass through the huller is then separated by the paddy separator and, in most of the rice mills in the Philippines, returned to the paddy bin feeding the huller. However, when samples of the initial paddy and the paddy rejected by the paddy separator are analyzed carefully, it is seen that for the same volume, the weight of the initial paddy is more than 10% higher; whereas, the number of grains of the rejected paddy is about 10% higher. Consequently, the average size of the rejected paddy grain is smaller than the average size of the initial paddy grain. This was the main reason why these grains were not hulled and, therefore, it is not logical to return these grains to the same huller.

It is recommended that the rejected paddy be returned to a separate bin for independent hulling in a smaller huller that can be adjusted to the smaller size of the rejected paddy (Fig. 148). This allows the main huller to be adjusted to avoid excessive breakage of brown rice, and the total dehusking capacity of the huller section is increased by at least 20%.

The recommended rearrangement of the grain flow in the huller section is advantageous in rice mills with disc hullers as well as those with rubber roll hullers. However, urgent implementation is more important for disc hullers
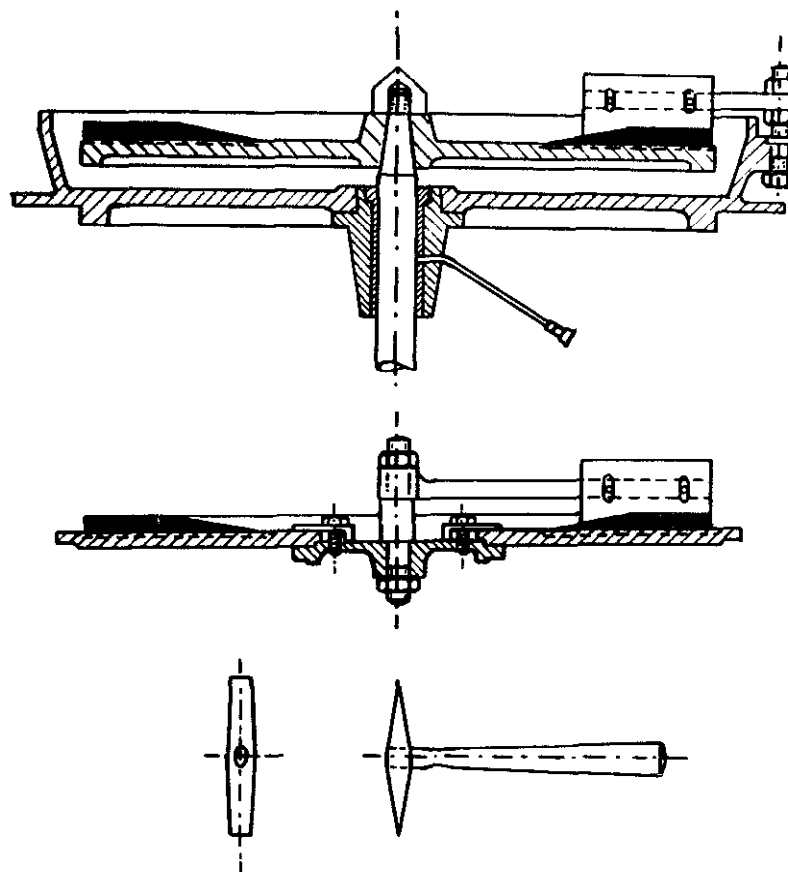
Fig. 146. Special tools used for resurfacing the abrasive surface.

than for rubber roll hullers because of the more flexible surface of the rubber rollers.

Rubber Roll Huller

In principle the rubber roll huller consists of two rubber rolls. One has a fixed position, the other is adjustable to obtain the desired clearance between the two rolls. The rolls are driven mechanically and rotate in opposite directions, the adjustable roll normally running about 25% slower than the fixed one. Both rolls have the same diameter, varying between 150 and 250 mm depending on the planned capacity, and the same width, about 60 to 250 mm.

When the rolls are new, their peripheral speed is about 14 m/s so that the smaller roll runs faster than the larger one (see table below).

Roll diam.		Roll width		High speed	Low speed
(mm)	(inches)	(mm)	(inches)	(rpm)	(rpm)
150	6	64	2.5	1320	900
220	8.5	76	3	1200	900
250	10	250	10	1000	740

The clearance between the two rolls is smaller than the thickness of the paddy grains, and because the rolls run at different speeds, their peripheral speeds differ. When the paddy is fed between the two rolls, the grains are caught under pressure by the rubber and, because of the difference in speed, the husk is stripped off (Fig. 149A). Wear on the rubber is considerable and, with reduction of the roll diameter, capacity is also reduced. The main reason for this capacity reduction is the decrease in the relative speed of the two rolls, and it is this relative speed that actually strips the husk from the paddy grain.
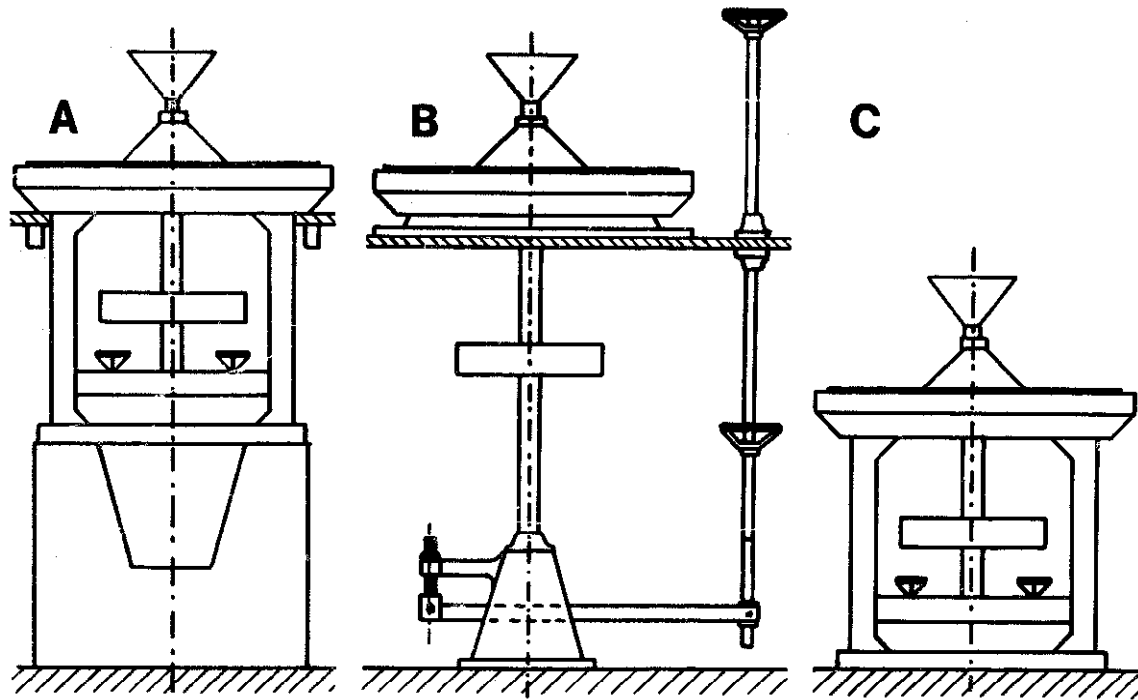
Fig. 147. Different setups for the under-runner disc huller: (A) mounted on elevated concrete foundation; (B) modified huller frame construction; and (C) mounted on ground floor.

Example (Fig. 150)

When the roll diameter is reduced from 254 to 216 mm (less 15%), the peripheral speed also drops by 15%. Because the speed of rotation of both rolls does not change, their relative speed, which is the difference in the peripheral speeds of both rolls, will also drop by 15%. At that point the hulling capacity of the machine has been reduced by about 15%.

In general the faster running unadjustable rubber roll wears out quicker than the adjustable roll. Because the rolls have been made interchangeable, it is recommended they be transferred from time to time to ensure even wear of the set of rolls. To obtain optimum hulling performance, the grain should be evenly distributed over the full width of the rolls. However, quite often the grain distribution device does not function correctly, and the roll surface wears out unevenly, which badly disturbs efficiency and capacity (Fig. 151). The roll surfaces are corrected by removing part of the rubber; therefore, the life of this set of expensive rolls is reduced considerably.

The efficiency of rubber rolls in tropical countries is still unfavourable and is slowing down their introduction. There are many reasons for this: higher temperature, higher humidity of the air, the structure of the husk, and especially the fact that in Japan short grain varieties are hulled; whereas, in tropical countries mainly long grain or medium grain varieties are hulled.

When hulling long grain varieties, the contact area of the grain with the rubber, the moment it is stripped off its husk, is much larger compared with short grain varieties. Consequently, the wear is higher and the life of the rubber is considerably shorter. Whereas 200 t of paddy can be hulled in Japan, the same quality of rubber will only hull about 100 t in tropical countries (Fig. 152). Better quality substitutes for the rubber exist; however, the increased durability in terms of tonnes of paddy hulled does not cover the much higher price of these substitutes.

The dehusking performance of this type of huller is superior to the conventional disc huller, because production of unbroken brown rice and huller efficiency are higher. However,
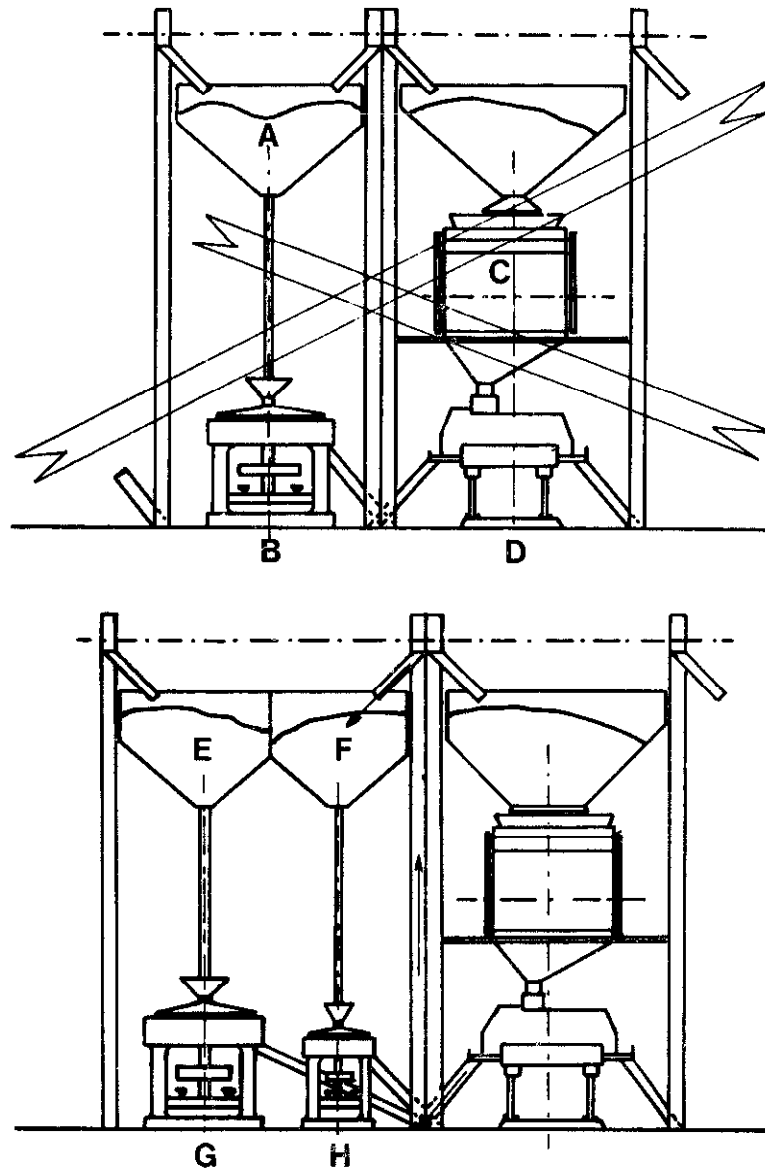
FIG. 148. Methods of return of rejected paddy:(top) grain flow without separate return hulling, not recommended; and (bottom) grain flow with separate return hulling, recommended. A = precleaned and returned paddy, B = huller, C = huskaspirator, D = separator, E = precleaned paddy, F = returned paddy, G = first huller, and H = return huller.

this does not mean the head rice yield of the mill is higher. Because the silver skin of the paddy is undamaged by the rubber roll huller, cracked grains appear as unbroken brown rice, but during the first pass of the whitening process these grains will break.

Rubber rolls can only be stored for a limited period because their durability slowly deteriorates (Fig. 153). Therefore, a continuous supply of rolls should be guaranteed in order to utilize them at optimum efficiency in the interest of total mill efficiency.

The fact that in a rubber roll huller one roll runs in a fixed position and the second roll is adjustable; that one roll runs clockwise while one roll runs counter-clockwise; and that both rolls are driven, requires special provisions in the drive mechanism. There are three
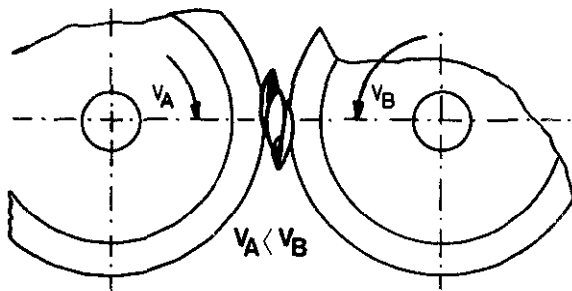
FIG. 149. Dehusking principle of rubber roll huller.
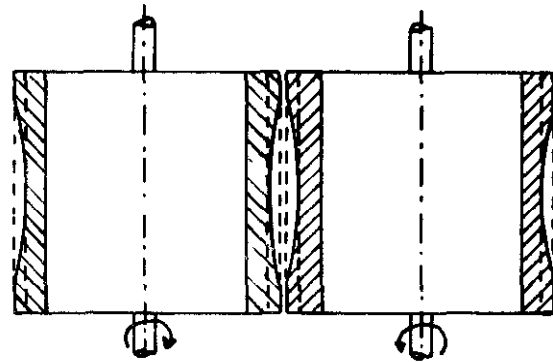
FIG. 151. Unevenly worn and damaged surface of rubber rolls as a result of unequal distribution of the paddy.
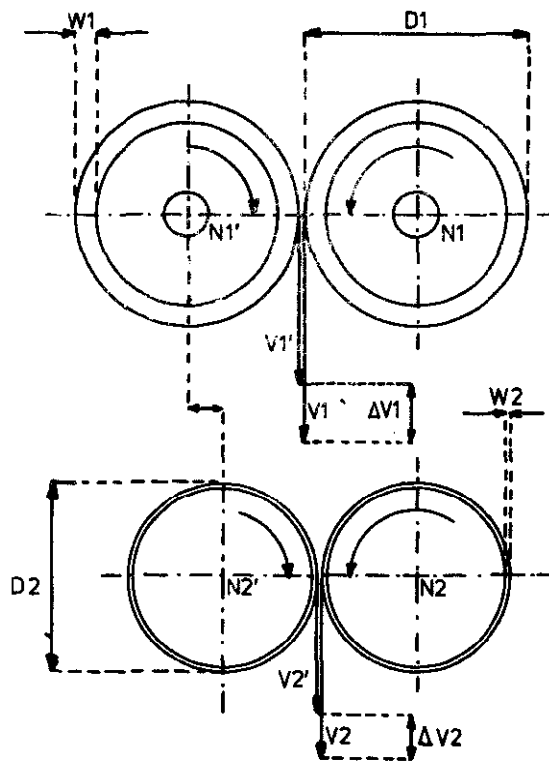
FIG. 150. Relation between diameter of rolls and capacity of huller: W1 − W2 = 19 mm; D1 = 254 mm; W1 = 25.4 mm; N1 = 1000 rpm; N1′ = 740 rpm; V1 = 13.30 m/s; V1 = 3.46 m/s; D2 = 216 mm; W2 = 6.4 mm; N2 − N1 = 1000 rpm; N2′ − N1′ = 740 rpm; V2 = 11.30 m/s; and V1 − V2 = 0.52 m/s = −15%.
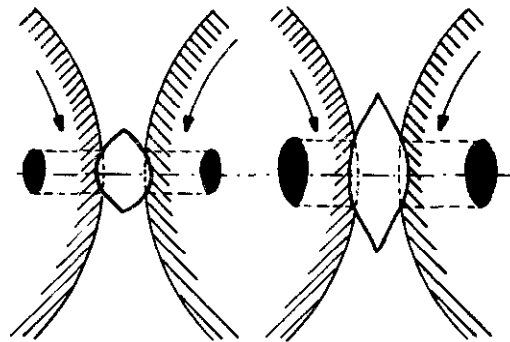
FIG. 152. The relation between paddy variety and hulling capacity.
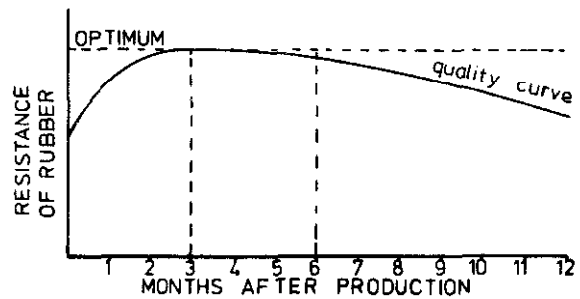
FIG. 153. Relation between durability of rubber rolls and age. The recommended period for utilization of rubber rolls for optimum efficiency is between 3 and 6 months after production.

Chain Transmission

kinds of drive transmission: (1) chain transmission; (2) V-belt transmission; and (3) gear-wheel transmission.

If both rolls always ran in a fixed position a simple endless chain over chain-wheels could drive the rolls. However, one roll must be

adjusted continually; therefore, chain tension must also be corrected immediately. A British-made design solved this problem by mounting the chain-wheel of the adjustable roll and two extra chain wheels for chain tensioning on one sturdy bevel plate that is tiltable over a fixed point (Fig. 154). To adjust the rubber roll clearance, the sturdy bevel plate is tilted by a handwheel adjustment, controlling both the rubber roll and the two extra chain wheels. The adjustment of these three gear wheels is not the same because their distance from the tilting point of the bevel plate differs.

The chain tension, however, is not fully corrected by this method and, therefore, one of the two extra gear wheels swings around the initial turning point of the gear wheel. This proved to be sufficient for continuous adjustment purposes. The advantage of this rather complicated system is the clearance of the rubber rolls can be adjusted when the machine is running even under full load. A simpler method for chain adjustment is a manually adjustable gear wheel for chain tensioning after adjustment of the roll clearance. However, in this case the roll clearance can only be adjusted when the huller is unloaded and not running, which is a great disadvantage.

V-Belt Transmission

This type of transmission is most commonly used for the rubber roll hullers. Figure 155 demonstrates the mechanical adjustment necessary to obtain the appropriate clearance between the rubber rolls. Assume the original positions of the linkages were A, B, C, and D for the V-belt pulleys driving the rubber rollers mounted at A and B. The belt tension is changed by moving the idler pulley at C, which is controlled by a screw adjustment. In this transmission system drive D is fixed, the rubber roller at A is fixed, and at B there is a spring loaded bearing mounted on a sliding plate, which allows the roller at B to move for appropriate clearance. For example, to reduce the clearance between the rollers, the handwheel screws out V-belt pulley C to position C' and the corresponding position of B' is obtained. Pulley C must be mounted like pulley B so that sliding is possible.

Gear Transmission

Figure 156 illustrates the third common method adopted for clearance adjustment of the rubber rollers. In this arrangement, assume A, B, C, and D are the positions of the gears prior to adjustment. A and C are fixed assuring the desired contact; whereas, B and D are adjustable. However, BD is rigid and maintains the required contact between gears B and D. By adjusting the position of gear B with the screw at the right, the clearance is determined, and the link BD starts to push D out of mesh with gear C; however, this is corrected by the spring loaded rigid bar shown below the adjustment lever. — HARRY VAN RUITEN. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*
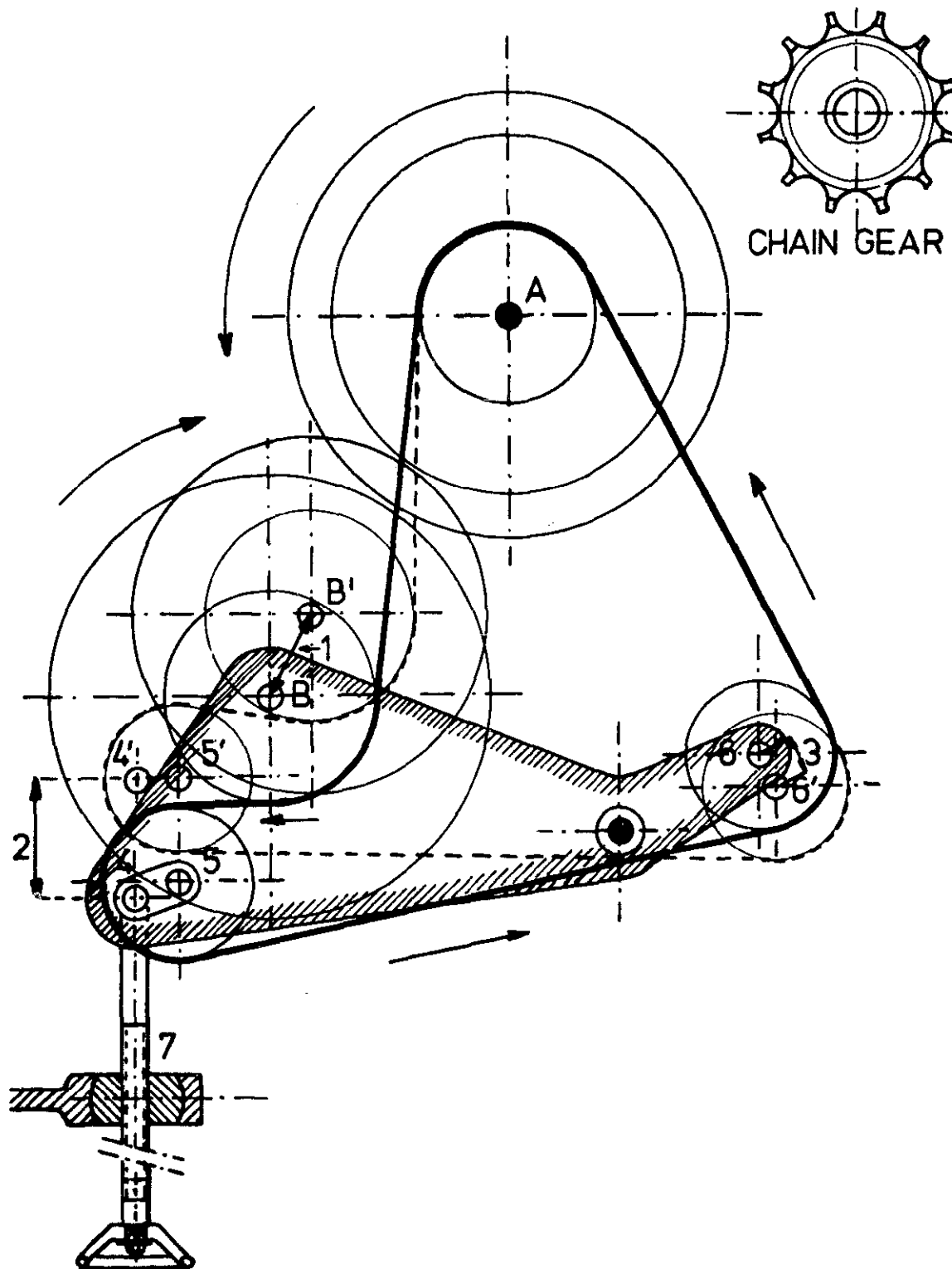
FIG. 154. Method of adjusting clearance of rubber rolls and tension of chain for a chain-drive transmission.
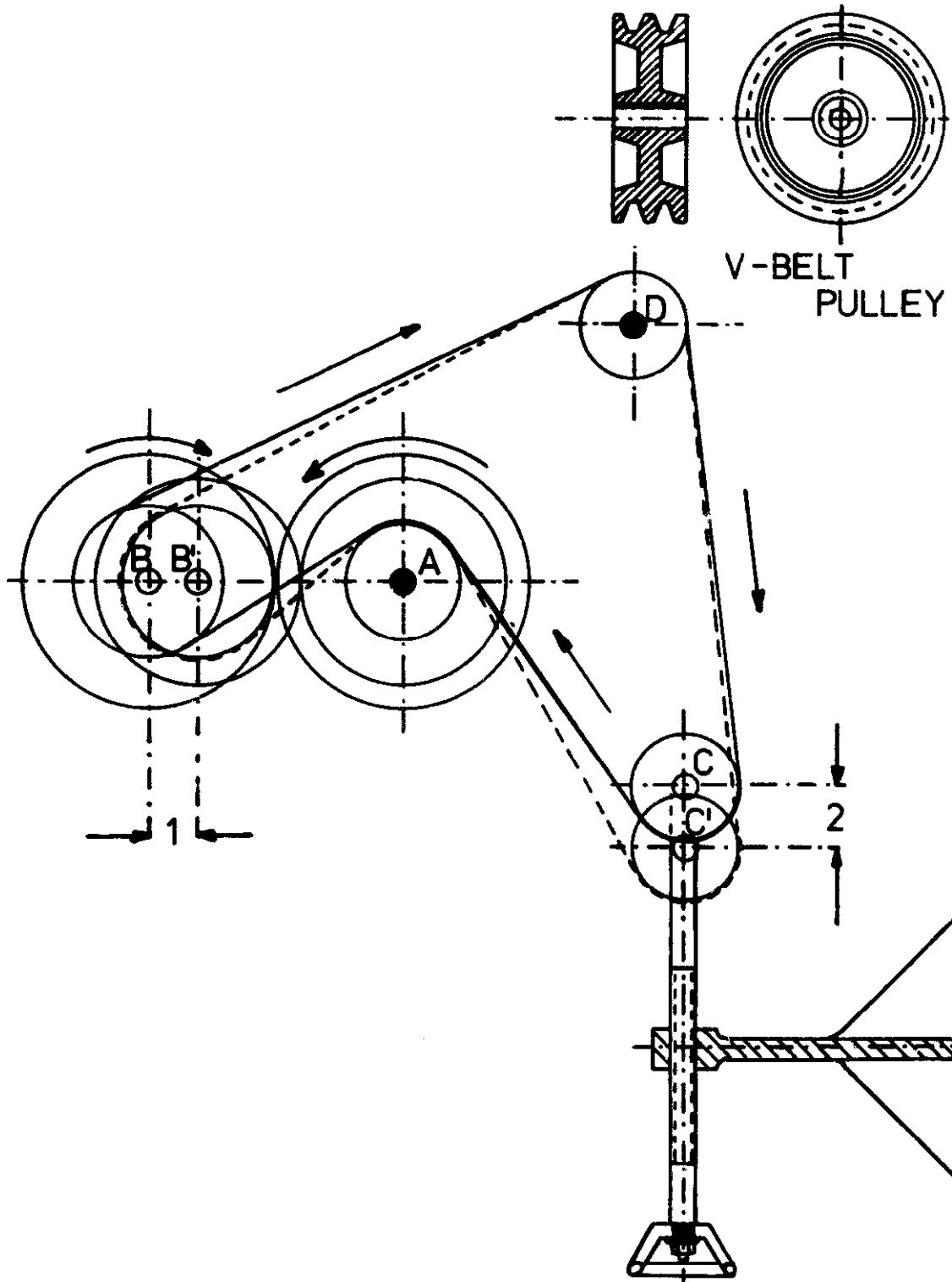
FIG. 155. V-belt transmission for the adjustment of the clearance between the rubber rolls.
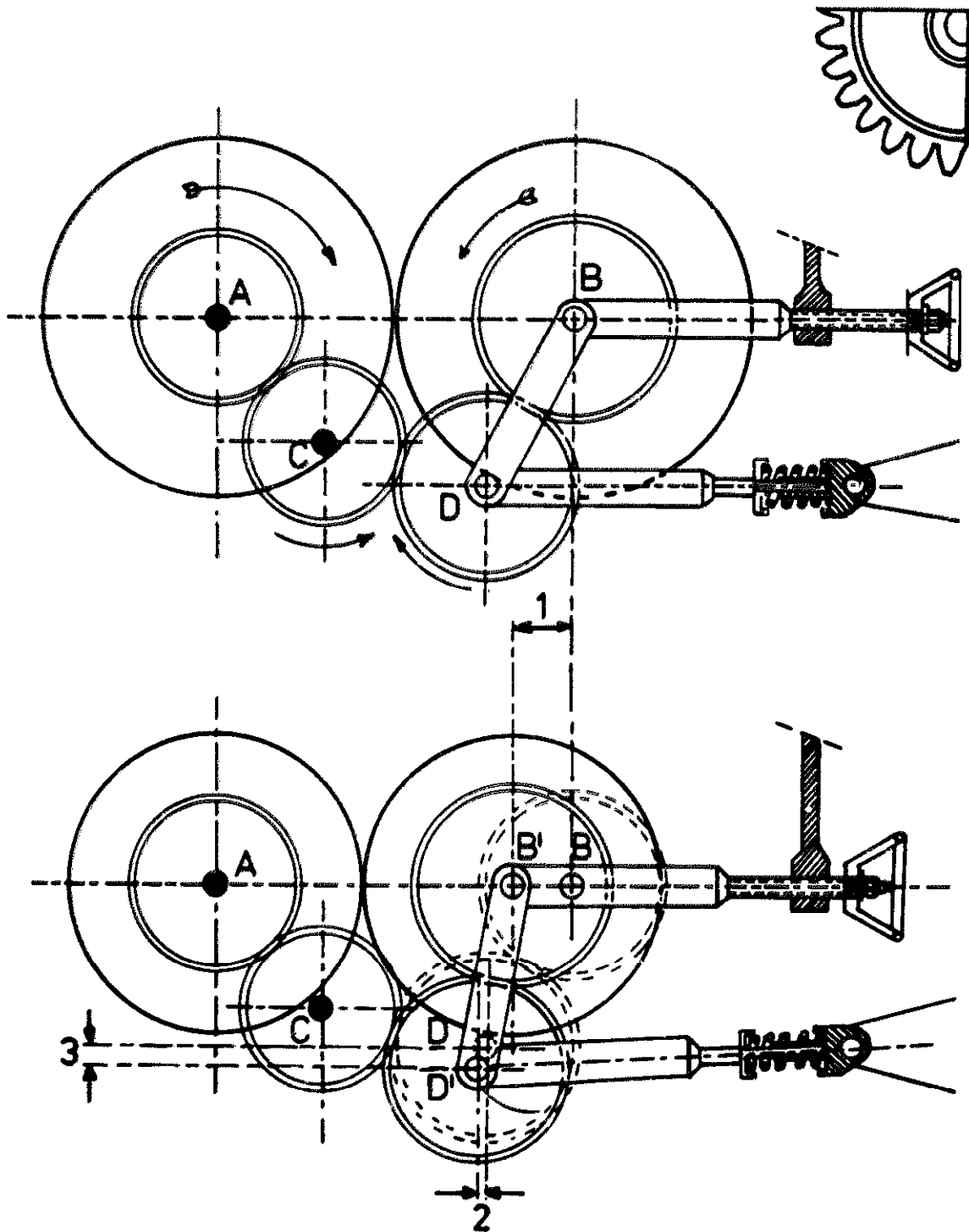
FIG. 156. Gear transmission for clearance adjustment of rubber roll huller.

Husk

Separation

The discharge of a rice huller is a mixture of brown rice, paddy, husks, bran, dust, brokens, and immature paddy grains. The paddy separators normally only receive the brown rice, the paddy, and sometimes the immature paddy grains. Between these two rice mill machines the husks, bran, dust, brokens, and immature paddy grains must be removed.

Normally, the bran and dust are separated through an oscillating sieve with fine perforations and discharged as a waste product; however, they may be mixed with the bran and removed by the bran aspiration cyclone system. The separation of brokens and immature grain before husk aspiration is essential because both of these commercial by-products would be lost as waste through the husk aspiration system. Their recovery increases the efficiency of the mill in terms of production of commercial products and money. Losses of up to 2% of the paddy intake capacity of the rice mill have been recorded due to improper separation.

The brokens are normally separated through self-cleaning sieves and discharged directly to the whitening section. The separation of the immature grains is a more difficult problem and, when done prior to paddy separation, a system is normally incorporated into the actual husk aspirator. Quite often, however, the immature grains are separated from the brown rice after the paddy separator, and consequently, it is possible for the immature paddy grains to be blown out with the husks because this method only works on dehusked immature grains.

For these reasons, the husk separators are sometimes designed to separate more than just husks. A large number of machines have been developed for this purpose. However, no one machine combines all necessary functions, and quite often additional machines are necessary to achieve optimum performance. Because these extra investments are not made in most rice mills, a certain percentage of loss through husk separation cannot be avoided. However, much can be done to reduce this loss.

Out of the large range of husk separators the following are discussed in this paper: (1) husk aspirator with air traps and suction blowers, Philippines; (2) husk aspirator with suction blower, West Germany; (3) husk aspirator combined with plansifter, West Germany; (4) husk aspirator combined with a rubber roll huller, Japan; (5) closed circuit husk separator, West Germany; (6) double action husk aspirator, Philippines; and (7) high capacity husk aspirator, West Germany.

Husk Aspiration with Air Traps
(Philippines)

In this system the husks are removed through air traps connected to suction blowers. Aspiration is introduced in two places between the huller and the paddy separator: (1) an air trap on top of the oscillating sieve that receives the discharge of the huller and removes through fine perforations the bran and dust (Fig. 157, no. 4); and (2) air traps between the holding bin for the huller discharge and the paddy separator (Fig. 157, no. 6).

For this double husk aspiration system two suction blowers (Fig. 157, no. 1 and 2) with a central pulley drive (Fig. 157, no. 3) are normally used. Usually there is one air trap on top of the oscillating sieve, and two to five traps between the holding bin and the paddy separator depending on the size of the separator. When more than three air traps are used between the bin and paddy separators, some of the air traps are connected with the suction blower, which is normally connected with the air trap on top of the sieve. When properly adjusted and controlled, this system gives efficient husk aspiration. However, many factors make control very difficult and in practice the mill operators do not know how to set a proper air and grain distribution.

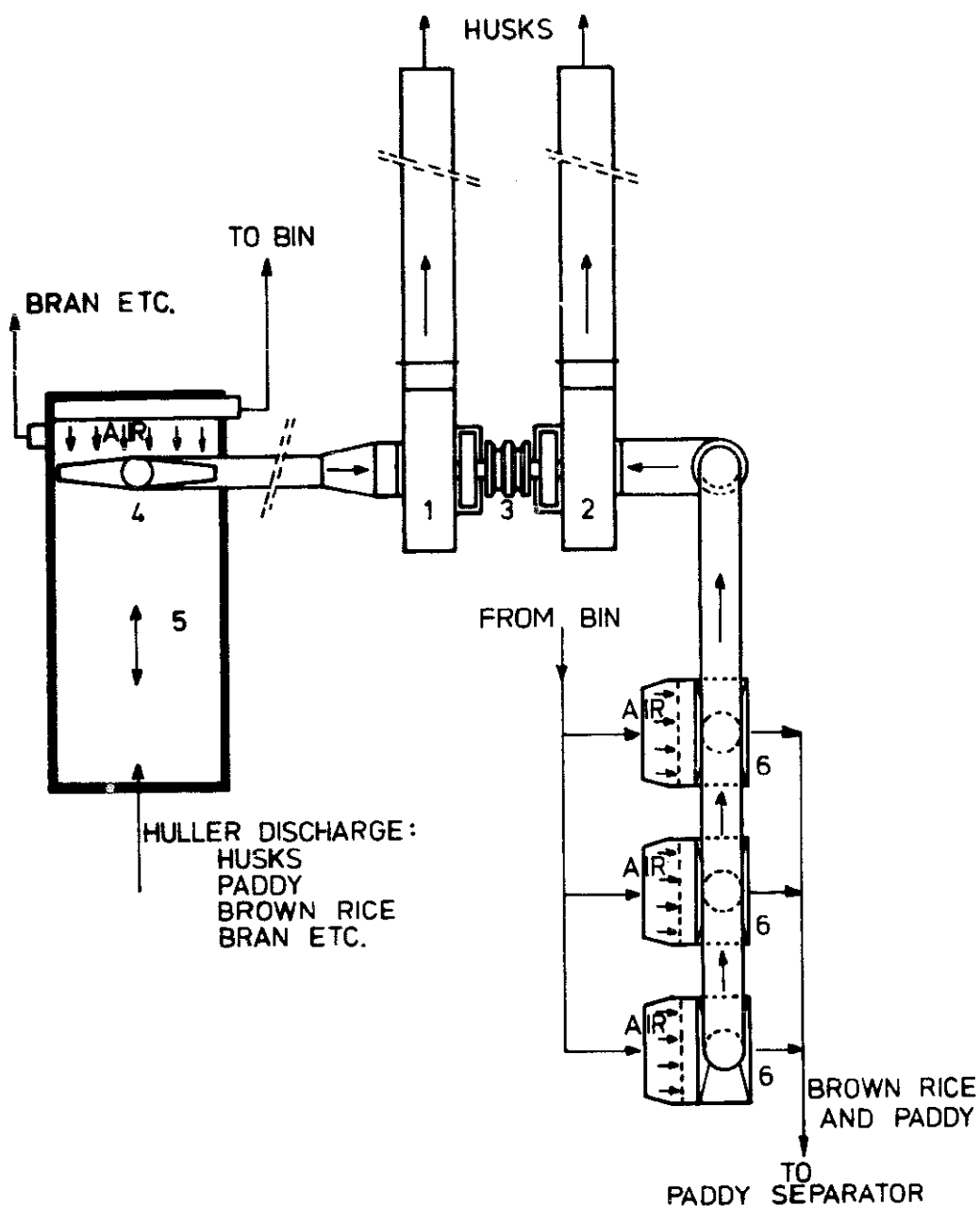What makes this setting so difficult? (1) Effi-

Fig. 157. Husk aspirator with air traps and suction blowers in cone-type rice mills (Philippines).

cient husk aspiration on top of the sieve can only be achieved when the huller discharge is equally distributed over the full width of the sieve. (2) The thickness of the grain-husk layer should be constant because this determines the clearance between the top of the grain layer and the bottom of the air trap. Through this clearance the air is sucked into the air trap, lifting the husks floating on top of the grain layer. (3) The airstream should be constant and not too strong; otherwise, grains will be lifted and discharged with the husks. (4) The distribution of the grain over the three, four, or five air traps on top of the separator should be equal. (6) The airstream in these air traps should not be too strong to prevent the loss of

grains with the husk discharge. (7) The efficiency of the air trap system strongly depends on the moisture content of the grain and the throughput capacity of the mill. The adjustment is different at low capacity than at full capacity.

The equal distribution of air and grain over the traps on top of the paddy separators seems to be especially difficult. The grain, feeding the traps, comes out of one holding bin (Fig. 158, A) and leaves the traps at the bottom (Fig. 158, B). The air is sucked through special openings in the air traps (Fig. 158, C), passes through the grain, and lifts the husks when entering the air tubes (Fig. 158, D). These separate air tubes with adjustable air sleeves are connected through a central air tube with the suction blower (Fig. 158, E). To obtain equal air distribution the air tubes must be separated from each other (Fig. 158). Although the principle of the system is sound, its implementation is responsible for considerable grain losses through husk discharge because the mill operators generally fail to adjust the air and grain flow properly.

Husk Aspiration with Suction Blower (West Germany)

These compact units are commonly used in German-made mills and are normally placed on a steel frame over the paddy separator. The machine has a double function because it removes the husks (Fig. 159, B) and separates the immature grains (Fig. 159, C). The grain (paddy, brown rice, and husks) is fed into the machine over its full width (Fig. 159, A). An adjustable sleeve and a belt-driven rotating paddle (Fig. 159, no. 4) release a thin film of grain. Air sucked through the grain lifts the husks that are discharged through the built-in suction blower. The airstream is strong enough to lift the immature grains as well. However, these grains drop into a V-shaped compartment for automatic discharge through double air valves (Fig. 159, no. 5 and 6).

The brown rice and the paddy leave the machine at the bottom for direct discharge into the paddy separator (Fig. 159, D). The airstream can be controlled by two adjustable

air valves; one on top of the machine (Fig. 159, no. 2) controlling the husk aspiration efficiency; and the second valve inside the machine controlling the efficiency in the separation of the immature grains (Fig. 159, no. 1). A glass window allows visual inspection of the grain distribution inside the machine (Fig. 159, no. 7).

Quite often this machine is produced in combination with an oscillating self-cleaning sieve for the separation of the bran, dust, and brokens. The sieve is then fixed on top of the husk aspirator and they are sold as one compact unit.

Husk Aspirator Combined with Plansifter (West Germany)

In large rice mills the husk aspirator with suction blower is often combined with a plansifter, which is fixed in a solid steel frame above the husk aspirator (Fig. 160). The husk aspirator and the plansifter together are considered as one compact husk-aspirator unit. The plansifter is equipped with two self-cleaning sieves. The first sieve (Fig. 160, no. 1) has fine perforations for the separation of bran and dust, the second (Fig. 160, no. 2) has larger perforations for the discharge of brokens. Therefore, the sieve overflow is a mixture of husks, paddy, and brown rice.

Husk Aspirator Combined with Rubber Roll Huller (Japan)

The compact lightweight construction of the rubber roll huller makes it possible to combine the huller and the husk aspirator. Because the rubber roll huller does not damage the bran layer of the brown rice, the huller discharge does not contain any bran. Therefore, any dust produced by the huller can be discharged with the husks.

The operation of the machine is quite simple. The paddy fed into the huller is dehusked and fed immediately into the husk aspirator. The grain is distributed as a film over the full width of the aspirator, and an airstream is sucked through this film, carrying
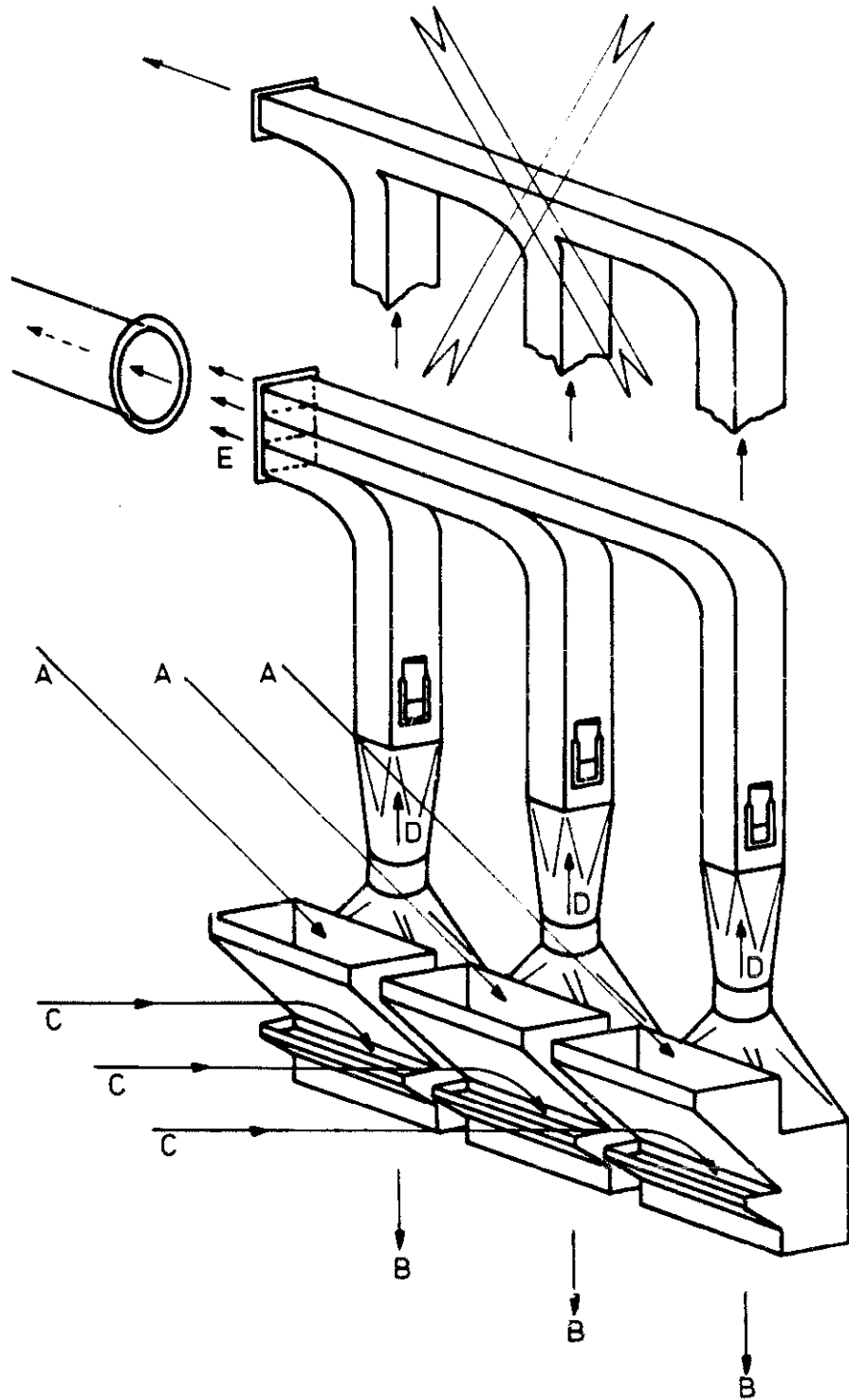
FIG. 158. System used to distribute air equally over the air traps for husk separation (Philippines).

● HUSKS

● IMMATURE GRAINS
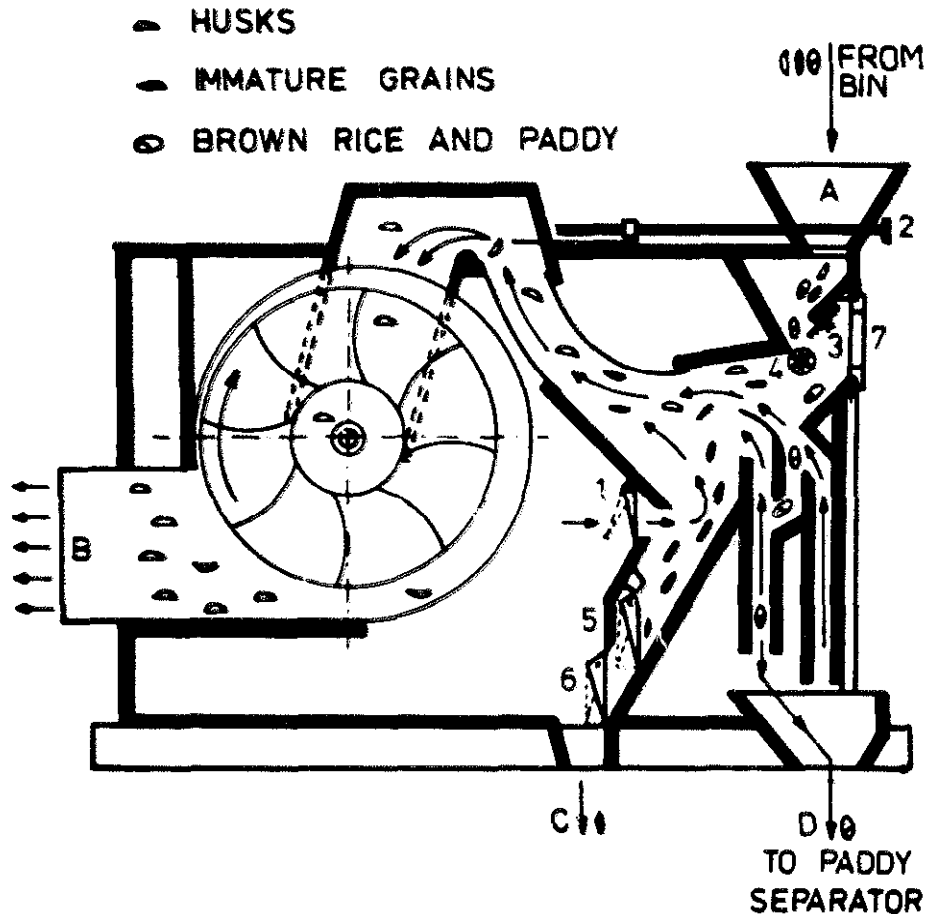
○ BROWN RICE AND PADDY

Fig. 159. Husk aspirator with suction blower (West Germany).

away the husks and lifting the immature grains. The immature grains drop into a separate hopper for discharge by a screw conveyor; the paddy and the brown rice leave the machine through a spout; and the husks are blown out by the strong suction blower.

A large air sleeve on top of the air duct controls the quantity of air drawn through the grain and the performance of the airstream with respect to the separation of the husks and immature grains is controlled by three valves (Fig. 161, no. 1, 2, 3). It requires experience to correctly adjust these valves. There are no provisions for the separation of small brokens. The separation of immature grains, in general, is not sufficient, and it is difficult to check whether or not immature grains and brokens are blown out with the husks. However, the husk aspiration efficiency is generally very high.

Closed Circuit Husk Separator (West Germany)

The closed circuit husk separator separates the husks and immature grains from the paddy and brown rice. The machine is called a "closed circuit" separator because it does not blow the husks out with the air; the air used for the separation of the husks is continuously recirculated (Fig. 162).

The mixture of paddy, brown rice, immature grains, and husks is loaded into a hopper on top of the machine. This mixture passes through inclined plates and falls as a grain film. A strong airstream built up by the pressure or discharge side of a built-in suction blower passes this film of grain and separates the husks from the mixture. Because of the special shape of the separator housing, the husks follow the housing pattern as in a
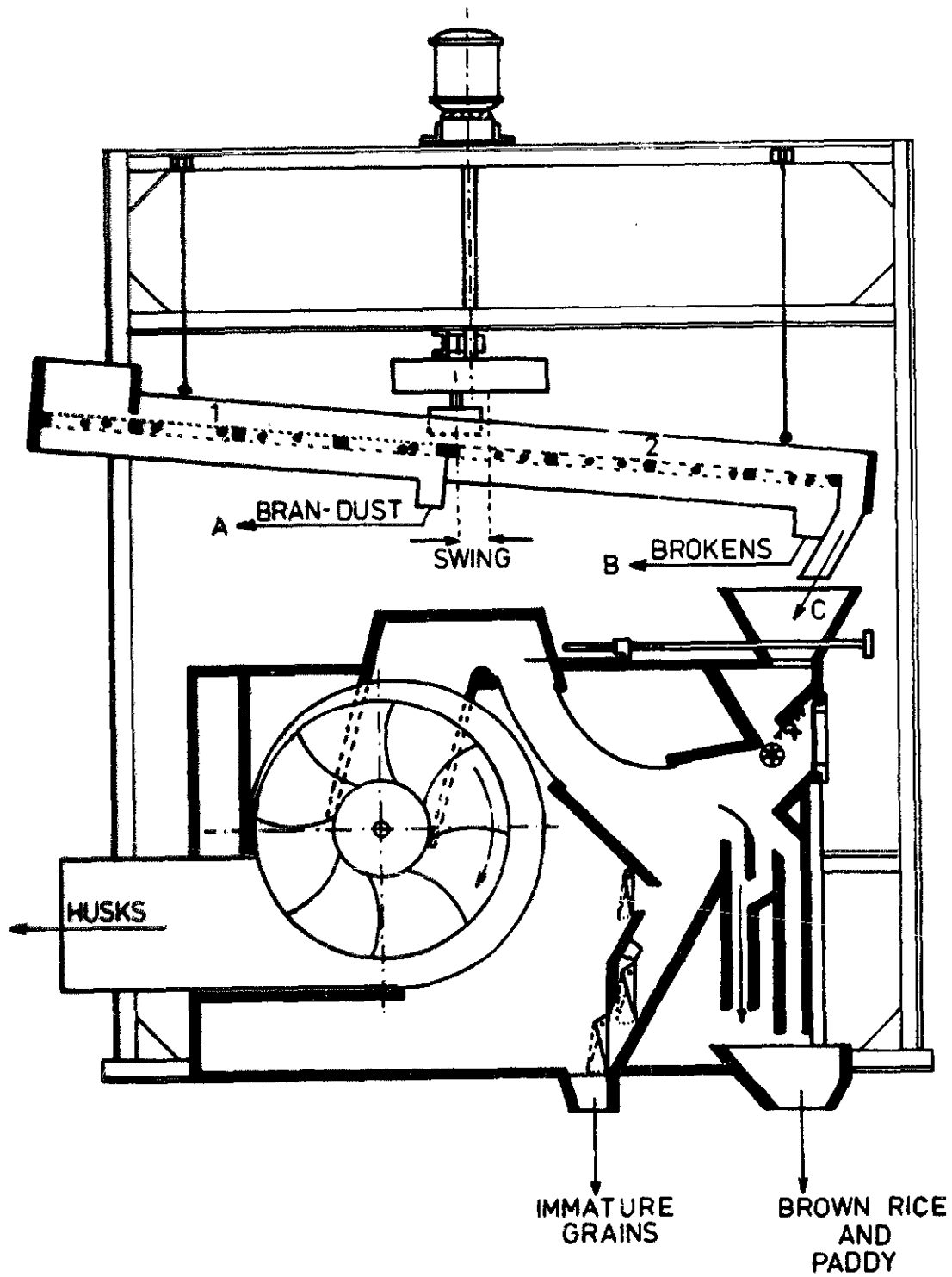
FIG. 160. Husk aspirator combined with plansifter (West Germany).

A   PADDY

B   BROWN RICE – HUSKS –

    PADDY–IMMATURE GRAINS

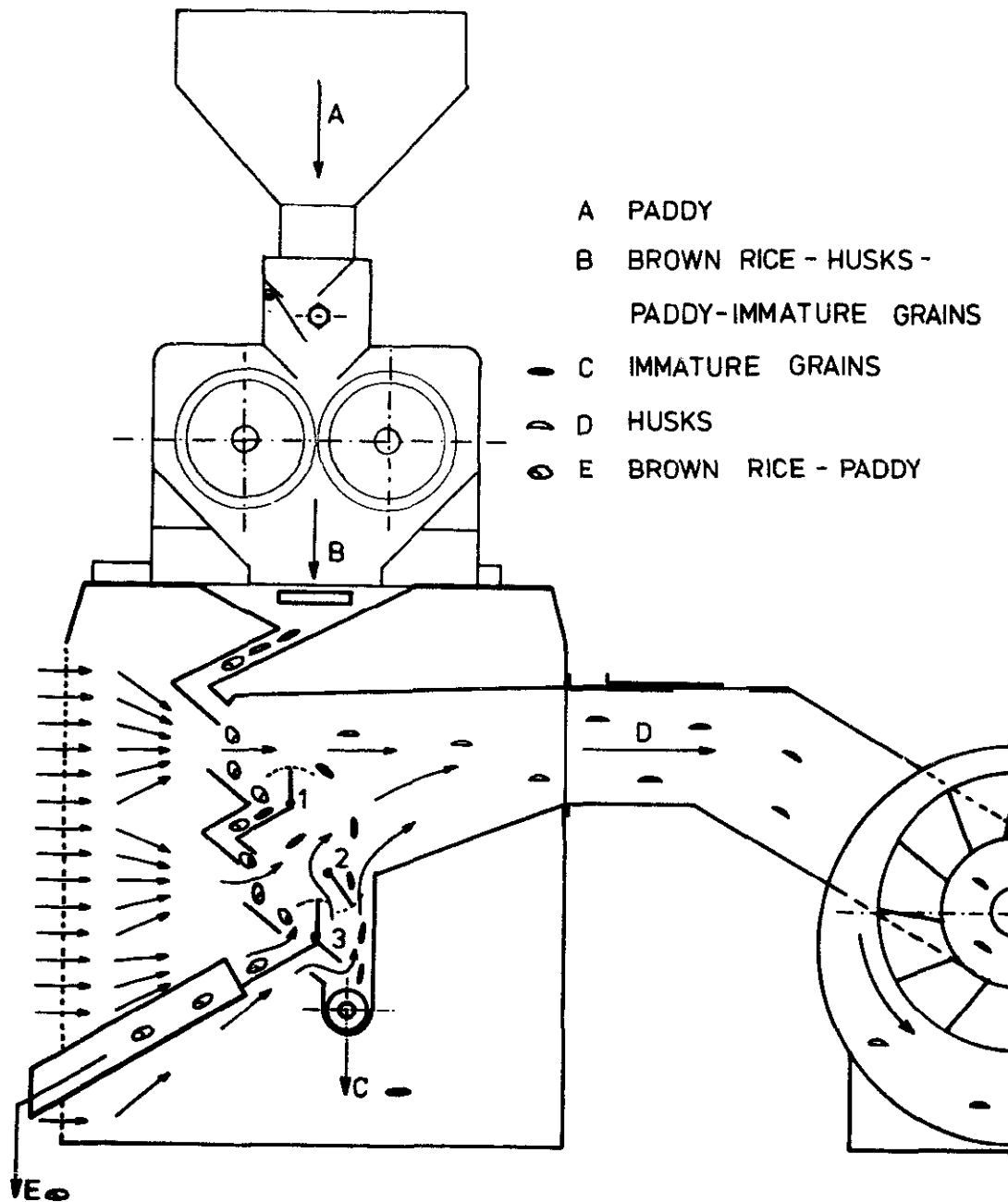C   IMMATURE GRAINS

D   HUSKS

E   BROWN RICE – PADDY

FIG. 161. Husk aspirator combined with rubber roll huller (Japan).

cyclone. As a result of the speed of the air and the impact of the separating centrifugal force, the husks are freed from the recirculating airstream and drop into the bottom of the V-shaped housing (Fig. 162, no. 1) for side discharge through a screw conveyor (Fig. 162, B).

The air, now free from husks, is recirculated by the blower and is used to lift the immature grains from the grain film. The immature grains and a mixture of brown rice and paddy fall into separate compartments and are discharged by screw conveyors (Fig. 162, no. 2, 3).

The quantity of air recirculated is controlled by a bypass valve (Fig. 162, no. 4) and the separation performance by an adjustable
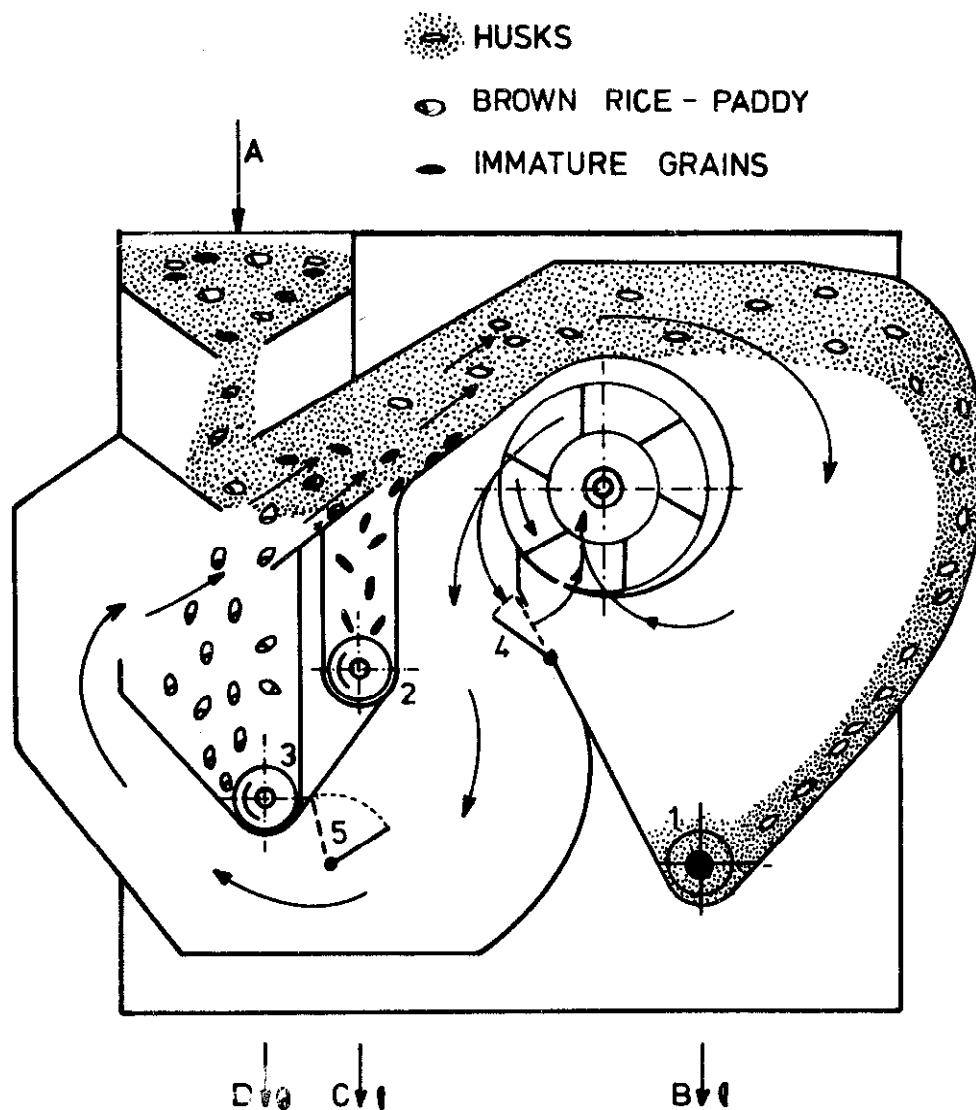
FIG. 162. Closed circuit husk separator (West Germany).

throttle valve (Fig. 162, no. 5). This machine does not separate bran, dust, and brokens from the huller discharge, so that prior to husk separation a plansifter or oscillating sieve must be installed.

Double Action Husk Aspirator (Philippines)

The double action husk aspirator as designed and made in the Philippines separates the husks from the brown rice and paddy and separates the brokens for later cleaning.

The mixture of husks, brown rice, paddy, brokens, bran, immature grains, and dust is discharged onto an oscillating sieve (Fig. 163, no. 1). Through the sieve perforations pass the bran, dust, and small brokens. The overflow, being a mixture of husks, paddy, and brown rice is unloaded into the actual husk aspirator and the grain falls as a film (Fig. 163, top). The airstream, caused by the built-in suction blower, is sucked through the front opening of the machine and separates the husks from the falling grains. These husks, carried away by the air, pass the suction blower and are discharged. The mixture of paddy

HUSKS

IMMATURE GRAINS

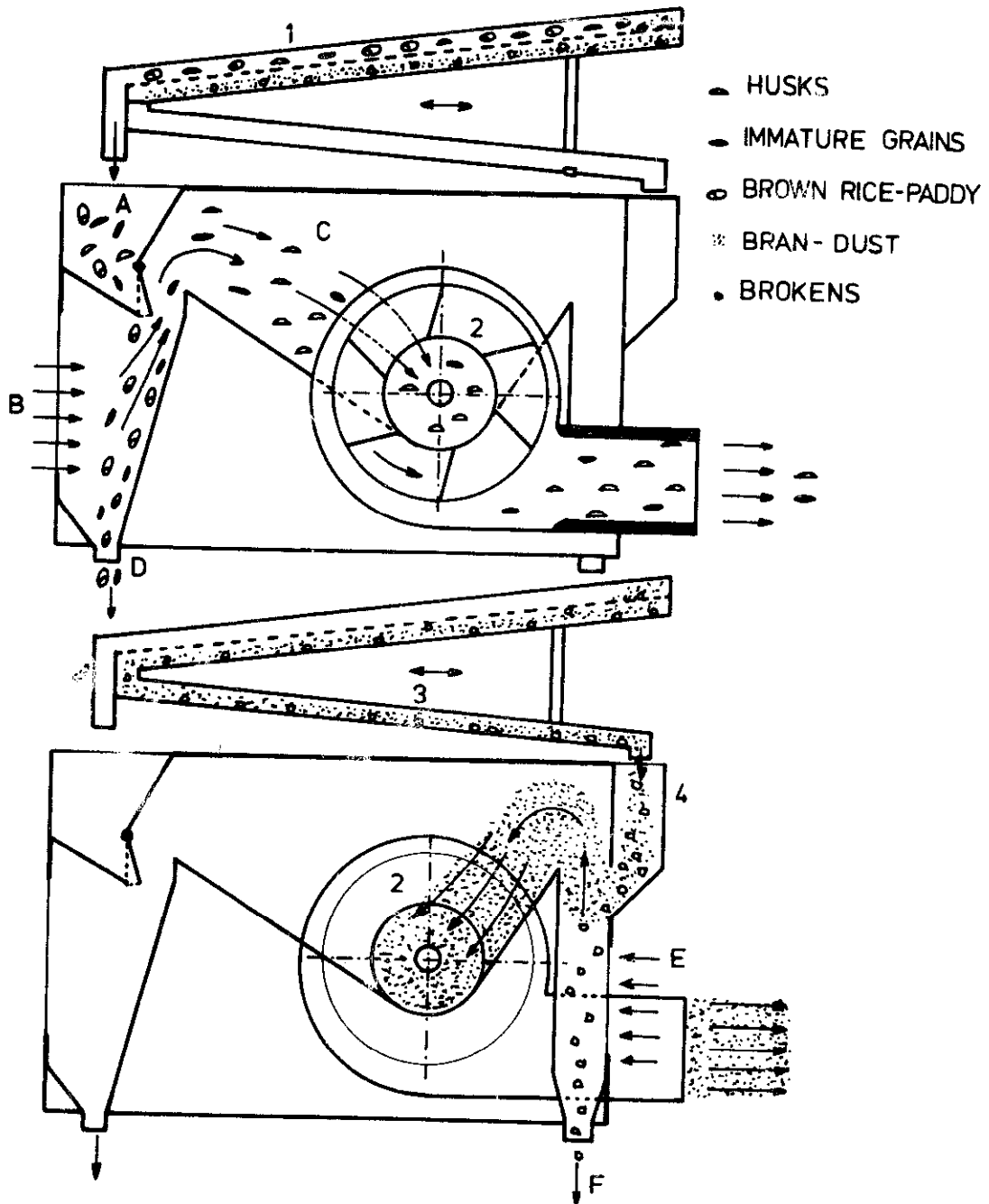BROWN RICE-PADDY

BRAN- DUST

BROKENS

Fig. 163. Double action husk aspirator (Philippines).

and brown rice then leaves the machine through a bottom opening for direct discharge into the paddy separator. The bran, dust, and brokens, separated by the oscillating sieve, are discharged into two openings (left and right) at the back of the actual aspirator body (Fig. 163, bottom). An airstream passes through this falling product and separates the bran and dust from the brokens. These brokens are discharged through a bottom opening of the machine for further processing in the whitening section of the rice mill. If no separate fine-perforation sieve is installed between the huller and this husk aspirator, the bran will be lost because it will be blown out with the husks as mill waste.

No provisions for the separation of immature grains are included, and consequently some of these immature grains are separated with the husks, representing a loss. It should be possible to incorporate a recovery system for immature grains into this type of machine.

The sieve on top of the husk aspirator is never self-cleaning; therefore, brokens are not separated efficiently from the husks and are blown out of the machine. This loss could be avoided by using self-cleaning sieves. Wear of the husk discharge spout is enormous; however, this wear has been limited by coating the spout with the emery composition used for the under-runner disc huller.

High Capacity Husk Aspirator (West Germany)

In large, mainly vertical, rice mills, a strong central aspiration system with cyclones and filters is installed, which makes it possible to use aspiration air without installing separate suction blowers in the individual machines (Fig. 164). This makes the machines more compact and cheaper. In such installations, precleaners and husk aspirators with vertical aspiration are installed.

The mixture of paddy, brown rice, husks, brokens, bran, and dust is unloaded into the machine and spread over the full width of the self-cleaning sieve (B). This sieve is a high frequency vibrator driven by an electric motor through a V-belt transmission (S). The brokens, bran, and dust pass through the sieve perforations and are discharged through an outlet spout at the bottom of the machine (D). The bran and dust are removed from the brokens later in the process. The sieve overflow, consisting of husks, paddy, and broken rice, is discharged into the vertical aspiration tube through a specially shaped plate (F) that increases the spread of the grain to about two and one-half times that of the sieve. A strong airstream, moving upwards, enters the machine through a large opening in the front of the aspirator and through two side openings (G). On its way up the aspiration tubes (H), the air carries the husks and any paddy and brown rice grains that are in a horizontal position. However, as soon as the grain position is vertical, the grain falls and is discharged with the rest of the paddy and the brown rice through the main discharge spout (R), which often incorporates a permanent magnet. The quantity of air used for the vertical aspiration is controlled by an adjustable valve.

The operation of the machine, especially the effect of the airstream on those grains lifted by the air, can be observed through a transparent panel (L) which can be illuminated for more careful observation at night (N). This allows immediate adjustment of the aspirator in case grain is being discharged with the husks.

The transparent front of the machine shows the battery of vertical aspiration tubes that secures an optimum spread of the grains over the full width of the machine, a perfect distribution of the air, and, consequently, perfect husk aspiration performance. — HARRY VAN RUITEN. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*
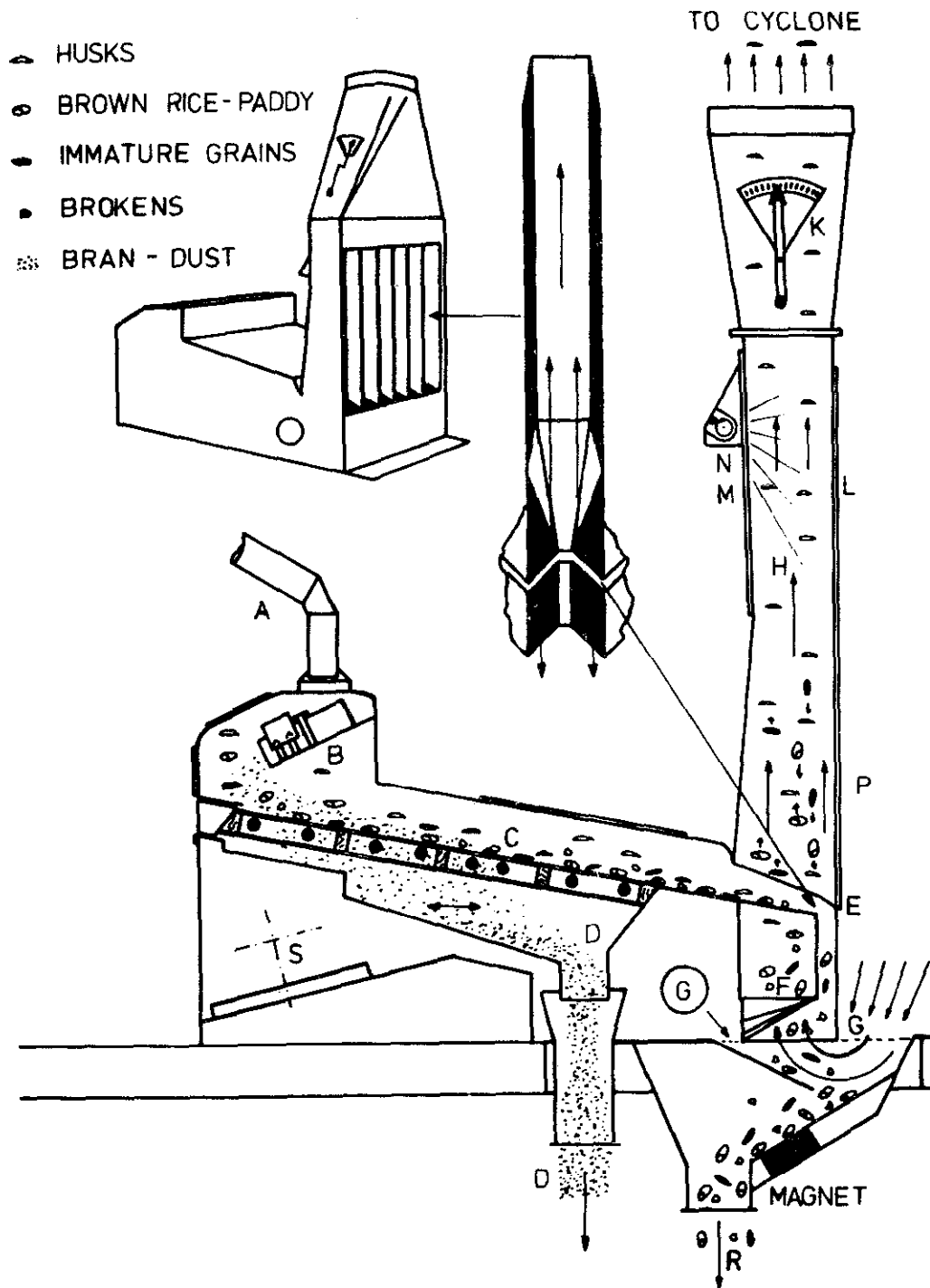
FIG. 164. High capacity husk aspirator (West Germany).

Paddy Separation

In the paddy hullers of a rice mill not all the paddy grains are hulled at once. The huller efficiency, namely the percentage of paddy actually hulled with a minimum of breakage, varies between 80 and 95% and depends on: (1) the uniformity of the paddy; (2) the variety of paddy hulled; (3) the condition of the paddy; (4) the type of huller; (5) the condition of the huller; and (6) the operator of the machine. The huller, therefore, produces a mixture of brown rice, husks, and paddy. After separation of the husks, dust, bran, and small brokens, a mixture of brown rice and paddy is obtained.

The amount of paddy that must be removed to produce brown rice free of paddy is indicated in the following example. If the huller efficiency is 80%, then 80% of the paddy will be hulled and 20% will be unaffected. The output will be 64% brown rice, 16% husks, and 20% paddy. The total of brown rice plus paddy is 84%; therefore, in this mixture there is 24% paddy ($20/84 \times 100$). When the huller efficiency is increased to 90% the output will be 72% brown rice, 18% husks, and 10% paddy. The total of brown rice plus paddy is 82%, meaning there is 12% paddy in this mixture. Therefore, when the huller efficiency is increased from 80 to 90% the amount of paddy is reduced from 24 to 12%. Consequently, a maximum of about 25% paddy must be removed from this mixture to produce a brown rice free of paddy.

This paddy is separated in a padd rator. In the separation of paddy use is of the different characteristics of paddy brown rice. These differences are: (1) the average weight of paddy by constant volume is lighter than that of brown rice; this is sometimes expressed as "the specific gravity of paddy is lower than that of brown rice"; (2) the paddy grains are more buoyant than the brown rice kernels; (3) the paddy grains are longer than the brown rice; and (4) the paddy grains are wider and thicker than the brown rice kernels. Basically there are three types of paddy separators: the compartment-type, the tray-type, and the screen-type.

The compartment-type paddy separator uses differences in specific gravity and buoyancy of the paddy grain and brown rice; the tray-type separator uses differences in specific gravity and length; and the screen-type paddy separator uses differences in width and thickness. This last type of separator, however, is practically outdated and is very seldom used. Most of the paddy separators are compartment-type. It was only recently that the Japanese introduced the tray-type separators.

Compartment-Type Paddy Separators

The main part of this paddy separator is the oscillating compartment-assembly where the actual separation of paddy and brown rice takes place. This assembly is normally made of wood; however, full steel machines are also produced. The compartment-assembly consists of a number of compartments in one, two, three, or sometimes four decks. The number of compartments depends on the capacity of the rice mill, and varies from 5 to 80. For up to 10 compartments a simple deck will do; from 12 to 20 compartments two decks are normally used; up to 51 compartments, there are three decks; and up to 80 compartments, four decks are used.

For instance: 20 compartments, two decks each with 10 compartments; 48 compartments, three decks each with 16 compartments; and 80 compartments, four decks each with 20 compartments.

The capacity of a compartment is about 40 kg of brown rice per hour. This figure is normally used to determine the number of compartments required for a rice mill. Thus, a rice mill with a capacity of 2000 kg of paddy per hour (about 525 cavans per 12 h), and an efficiency of 80% would produce about 1600 kg of brown rice per hour. Therefore, the number of compartments required would be 1600/40

= 40. In this case a compartment separator of 48 compartments in three decks, each holding 16 compartments, would be sufficient.

It requires experience to balance the performance of the paddy separator at optimum capacity. A well-adjusted paddy separator discharges brown rice absolutely free of any paddy grains and paddy with no, or only a few, brown rice kernels. At the same time the machine must produce enough rice to meet the mill separation requirements. The capacity and feeding of the compartments are controlled by (Fig. 165): (1) a valve for the control of the main feeding; (2) an independent adjustment of the feeding of each compartment by an adjustable valve; and (3) a handwheel-controlled multisleeve valve controlling simultaneously the feeding of all compartments from zero to maximum. The separation performance is controlled by (Fig. 165): (4) the adjustable inclination of the separator assembly, also called separator table; (5) the adjustable overflow strips for paddy at each end of the compartments (paddy discharge side); and (6) the adjustable frequency of the oscillation.
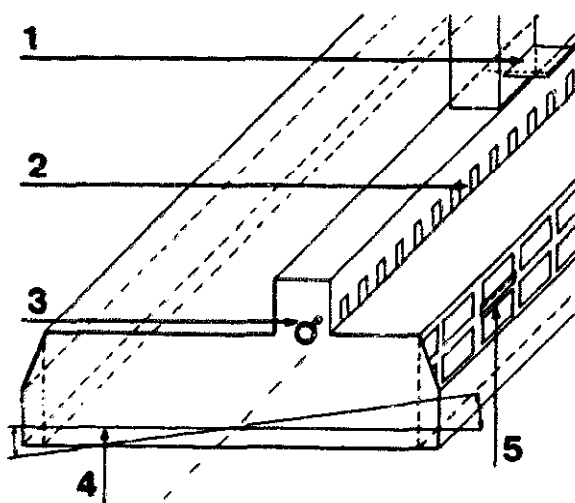

Fig. 165. Adjustability of paddy separators: (1) valve for control of feeding; (2) independent control of compartment feeding; (3) adjustable sleeve for all compartments; (4) adjustable inclination; and (5) adjustable paddy overflow strip. The frequency is also adjustable.

It is essential that a perfect distribution of the grain over the full length and width of the central feeding box on top of the separator is continuously maintained to feed all compartments. For this reason two grain-feeding spouts with control valves are sometimes installed. The feeding of each compartment can be adjusted from zero to maximum by a simple sleeve that can be lifted or lowered and whose position can be locked with a screw. This system makes it possible to reduce the number of operating compartments in case the actual feeding capacity is too small for the separator.

A multisleeve valve is not always installed in the conventional-type paddy separator; however, its presence is essential for a smooth and well-controlled equal distribution of the grain over the compartments. It mainly consists of a long steel strip with rectangular perforations overlapping the feeding box outlets to the compartments. By handwheel adjustment this strip can partly or even fully close simultaneously all outlets feeding the many compartments.

To obtain a perfect separation of paddy and brown rice the separator table should be slightly inclined, with the lifted position for that side of the table where the paddy will be discharged. This inclination depends on the percentage of paddy mixed with the brown rice, the variety of the paddy, the condition of the paddy, and the feeding capacity. Because all these factors are continuously changing, it is necessary to regularly check the performance of the separator and adjust the inclination when necessary. When the brown rice overflow contains paddy grains, the inclination must be reduced. This separation efficiency is not always adjustable through the table inclination and quite often the frequency of the oscillation must be increased or decreased as well. This is done by belt transmission adjustment when cone-shaped flat-belt pulleys are used, or by adjustment of a totally enclosed variable gear box transmission.

Each compartment has an adjustable strip fixed at the end of the compartment to control the overflow of paddy. This strip controls the presence of brown rice since the heavier brown rice kernels will remain in the compartment; whereas, the lighter paddy grain will float over

the brown rice and strip (about 5–8 mm) for immediate discharge.

Normally the stroke is not adjustable. However, a West German manufacturer patented a special design with adjustable stroke, which will be discussed later. The frequency of the separator table varies from 90 to 120 double strokes per minute. Generally this frequency is set between 95 and 105 per minute. When not adjustable, the length of the stroke normally is about 200 mm.

How to Operate the Paddy Separator

The bottom of the compartment is a highly polished steel sheet offering minimum resistance to the grains moving over its surface. The sides are Z-shaped steel flanks that have an impact angle of about 30° (Fig. 166). The grain, a mixture of paddy and brown rice, is fed into the centre of the compartment, which is slightly inclined, and moves over its width back and forth with a frequency between 95 and 105 movements per minute and a stroke of about 200 mm.

The impact of the Z-shaped flanks causes the paddy grains to slide upwards along the bottom of the compartment. The brown rice kernels, on the other hand, move downwards and leave at the lower end of the inclined compartment. When the inclination is too low, brown rice kernels move upwards with the paddy grains, and the paddy overflow becomes badly mixed with brown rice. This must be avoided because this brown rice will be returned to the huller, overloading the huller section and damaging the brown rice during its unwanted pass through the huller. When the inclination is too high, paddy grains move downwards with the brown rice kernels and are fed into the whitening section of the rice mill, which must be avoided. Consequently, the setting of the inclination should be controlled continuously.

When the paddy separator is built in two, three, or four decks, the lower decks are fed by small spouts. These spouts should pass through the idle triangles of the Z-shaped flanks and never through the working area of a compartment (Fig. 167). The triangles quite often become filled with grain and dust and
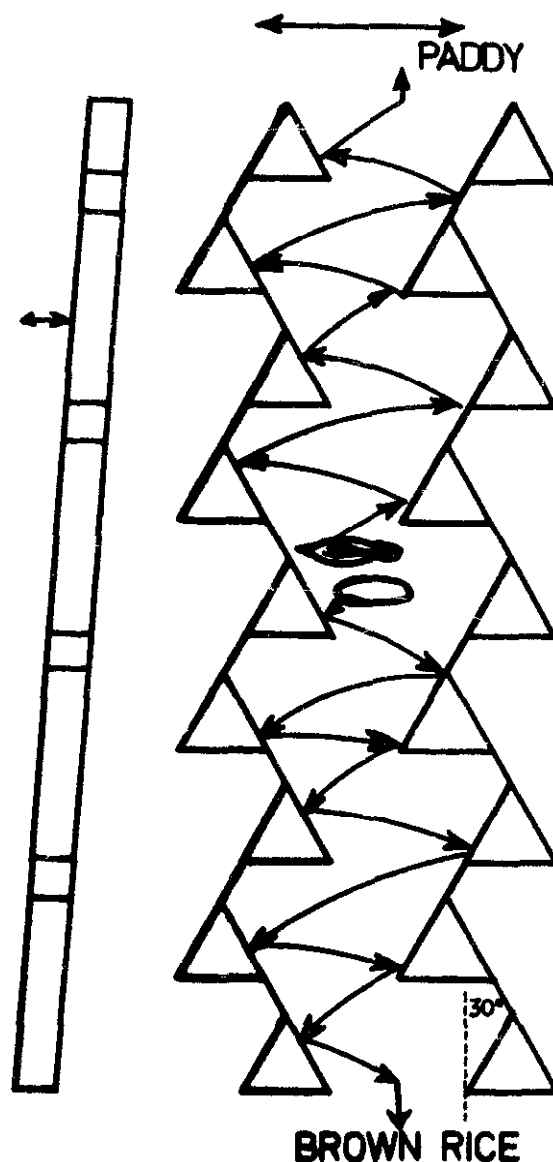

FIG. 166. Internal construction of one compartment of the paddy separator.

are a permanent source of insect infestation. Therefore, the triangles in the top deck of the separator should be sealed with a steel sheet cap or wooden plug.

Although the pattern of the Z-shaped flanks is basically the same, there are differences in the size and detail of the available designs. The German pattern is about the same as the one used in Italy, but the size of the Z-pattern of the German design is larger. The Indian pattern, also used in the Philippines, has rounded corners for a smoother flow of the

FIG. 168. Inclination of separator table is adjusted by turning a handwheel attached to a threaded shaft that moves the supporting swingable levers.
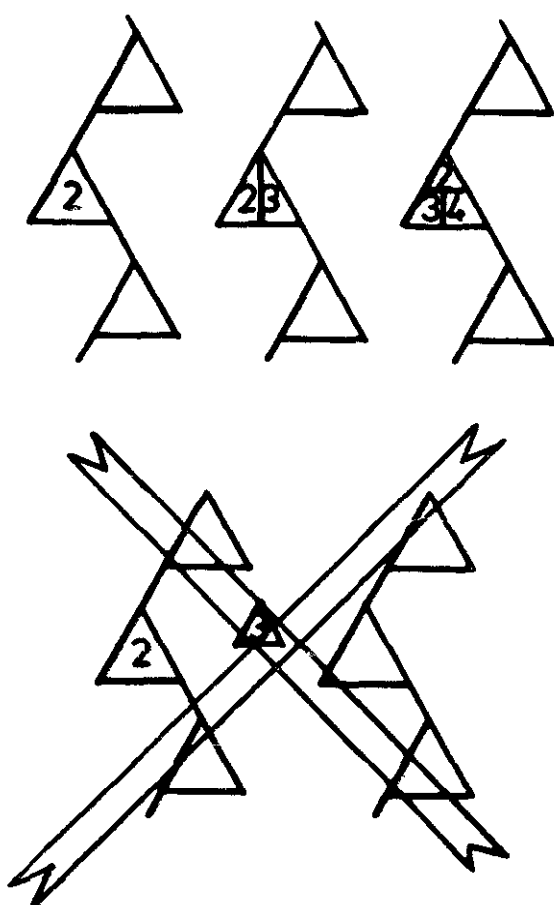

FIG. 167. Spouts to feed lower decks of separator pass through idle triangles of flanks not through the working area of the separator.

grain. For all patterns, however, an identical performance is recorded so no specific pattern can be recommended.

The inclination of the separator table can only be changed when the machine is stopped. It is adjusted by a handwheel fixed to a long threaded shaft under the table (Fig. 168). When this shaft is turned, two nuts supporting swingable levers are moved back and forth, lifting or lowering the separator table, which tilts on a central shaft. The inclined position of the table is locked by two handwheel screws (Fig. 169).

The separator table must move horizontally and remain perfectly aligned. The supports for this table, either four or six, are specially constructed to secure this pure horizontal
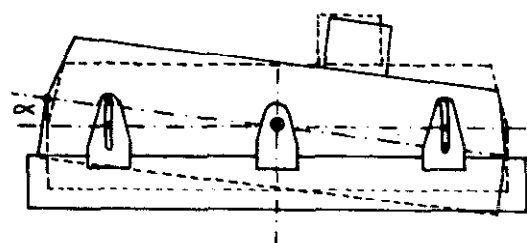
movement and to make sure that this rather bulky machine will not move off its supporting frame. A British design (Fig. 170, A) uses swinging supports with teeth, rolling back and forth over a toothed steel bar bolted to the underframe. The pressure on the tooth transmission is reduced by a spring-loaded weight absorber. In German constructions (Fig. 170, B) the swinging supports have a side plate for guidance, and a smooth polished bottom surface that rolls back and forth over a smooth hard-steel bar. The position of the support is fixed by a spring-loaded assembly between the support and the underframe. In the Philippines, the supports are fixed on the underframe and roll- or ball-bearings are mounted on the top of the support (Fig. 170, C). The separator table moves over these bearings and its position is kept in line by steel guidebars mounted under the table. The movement is very smooth; however, the bearings are used under conditions violating all basic principles related to bearing techniques.

The separator table should always be horizontally levelled. However, since most of the paddy separators are made of wood and work under tropical conditions, they often bend, which badly disturbs separation performance. The bending of the table can be corrected if each side of the table is equipped with a straightening device (Fig. 171). This should be standard on all new machines; however, this device can still be installed on existing units.

The so-called "rocking" of a paddy separator happens very often and has a very disturbing effect on separation performance. The separator table should move horizontally and
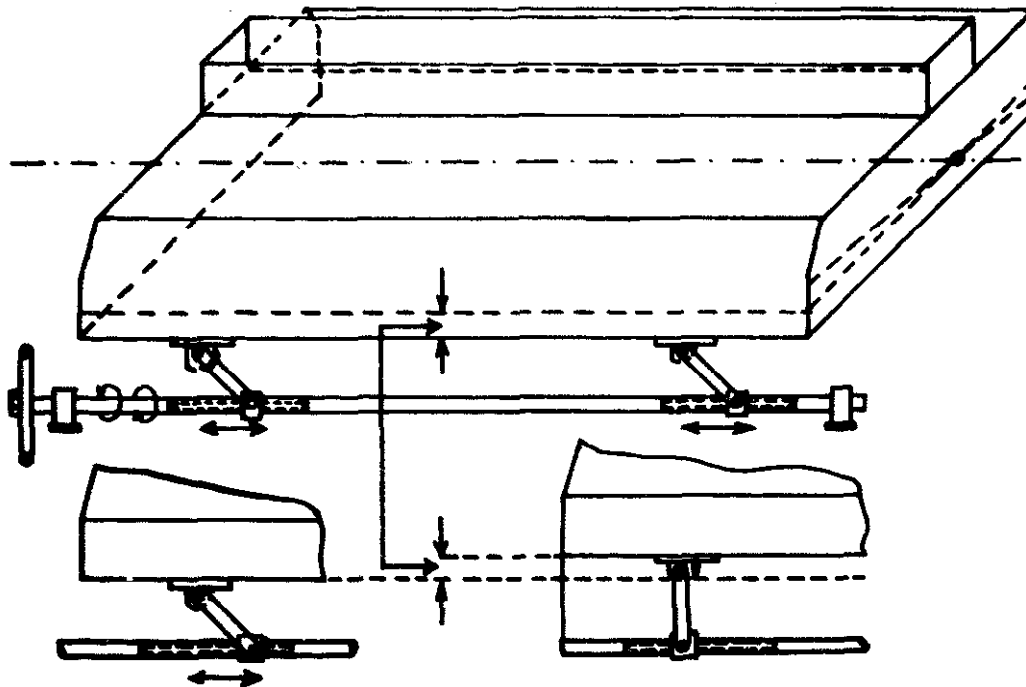
Fig. 169. The separator table tilts on a central shaft

in a straight line (Fig. 172, A). When the swinging supports have not been aligned correctly with respect to the separator table and the driving shaft, the table will not move in a straight line, but, when moving horizontally, will follow a curved line (Fig. 172, B). This results from movement in two directions. As a result the program of action of the grain, paddy as well as brown rice, in the compartments is disturbed and separation efficiency is reduced.

The separator is driven by a flat-belt transmission or by an electric motor through a variable speed gear and V-belt transmission. Conical pulleys are used to change the transmission ratio, which adjusts the frequency of the stroke between fixed limits (90–120 per minute). The conical pulleys are fixed on the main transmission shaft and an intermediate transmission shaft (Fig. 173, A), or can be mounted on an intermediate transmission shaft and the machine shaft driving the eccentric rod (Fig. 173, B). Very often a motor-driven variable gear box with V-belt drive over the flywheel of the separator is used to drive the paddy separator and to adjust, within specified limits, the frequency of the stroke (Fig. 173, C). Several methods are used to obtain this

variable drive. One is a variable ratio setting controlled by an adjustable V-belt transmission with conical discs. This system may be used because the actual horsepower requirements are rather low for this bulky type of machine (about 0.6 hp for every 10 compartments). A heavy flywheel secures a smooth balanced operation of the machine.

The paddy separator may be placed in a variety of positions in the rice mill because, by design, the discharge spouts can be built in various positions (Fig. 174). The paddy discharge can be at the left or the right side, and even when two separators are used simultaneously, both separators can discharge the paddy at the right or left side. As an alternative, both separators can unload the paddy in the centre, or the brown rice in the centre. When two separators are installed in line, again the paddy can be discharged at the left or the right side. The separator compartments discharge the grain into a collector that can discharge in front of the machine, halfway to the separator table, or at the end of the machine. Therefore, when ordering a paddy separator both its position in the mill and the placement of the discharge spouts must be clearly stated.
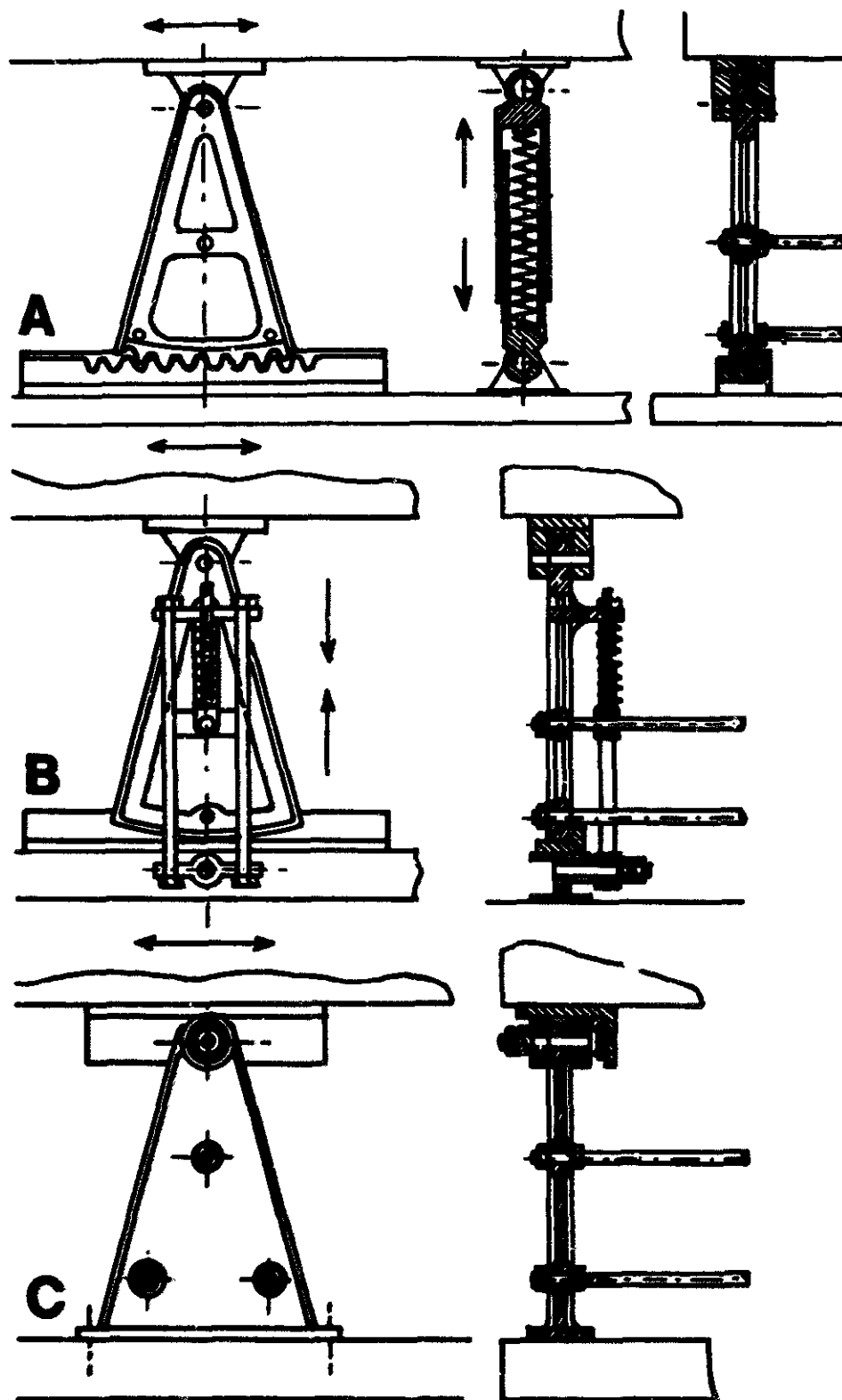
Fig. 170. Three different designs of supports for paddy separators: (A) British; (B) German; and (C) Philippine. See text for details.
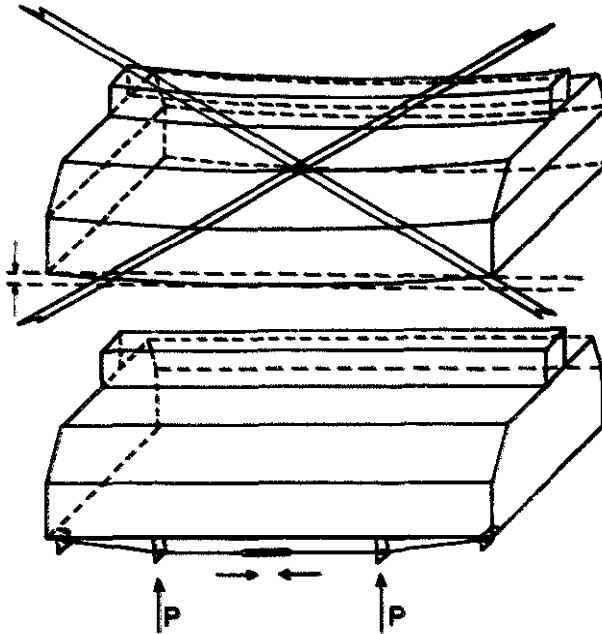
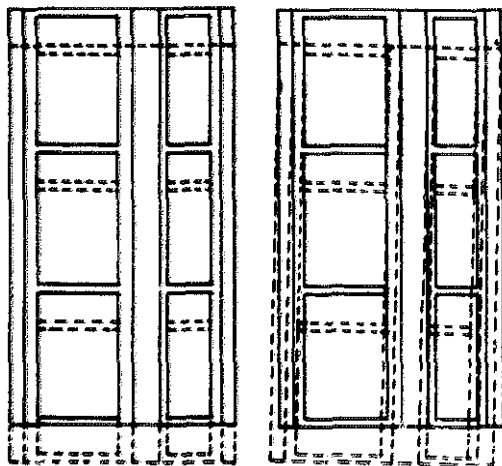FIG. 171. Straightening device for paddy separators

A

B

FIG. 172. Movement of the paddy separator. (A) normal straight-line movement. (B) rocking of separator caused by motion in two directions. Results in reduced separation efficiency.

Stroke Adjustment

Normally the stroke of a paddy separator cannot be adjusted; however, a German manufacturer has patented a system that allows stroke adjustment (Schule separator). This is a great advantage because the separation
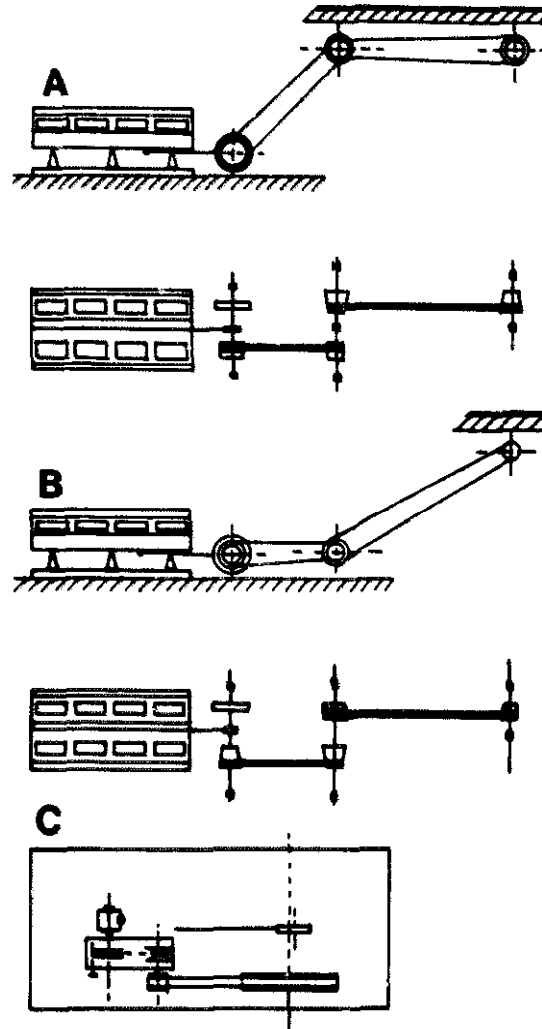

A

B

C

FIG. 173. Frequency adjustment of the paddy separator. (A) Conical pulley on main and intermediate transmission shafts. (B) Conical pulley on intermediate and machine shafts. (C and D) Motor driven variable gear box, with ratios controlled by adjustable V-belt transmission with conical discs (D).

capacity of each compartment is increased by at least 50%. This allows smaller separators to be installed, meaning that if 60 compartments were required normally, now only 40 compartments are needed. The selection of capacities is very limited and only separators with 24, 35, or 45 compartments, all in three decks, can be supplied. Their capacities are about 1500, 2200, and 3000 kg of intake per hour, respectively. Because this type of machine has
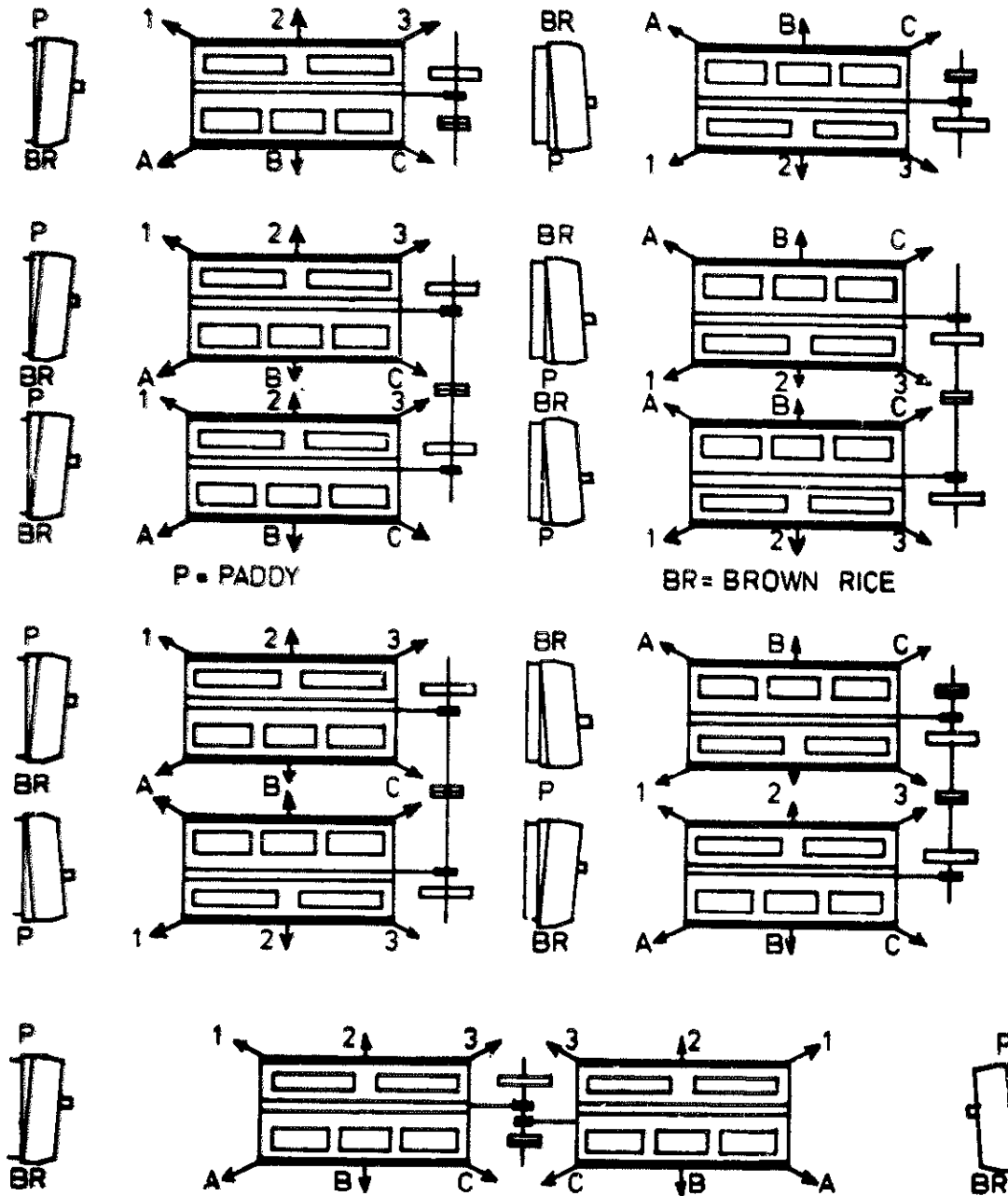
P ▪ PADDY

BR= BROWN RICE

FIG. 174. Different positions the paddy separator can occupy in a rice mill because of its flexible design.

been introduced in the Philippines and already installed in two large rice mills, the principle of its operation will be explained. Our main concern is the way the length of the stroke can be adjusted.

Under normal circumstances the eccentricity is a fixed value (M-E)(Fig. 175, A ', and consequently the stroke is fixed too namely, double the eccentricity (e.g. crankshaft and piston stroke) (Fig. 175, B). If, however, the eccentricity M-E is obtained by two rods M-S and S-E locked in a fixed position by a locking device at S, the stroke can be made adjustable by increasing or decreasing the angle between rods M-S and S-E (Fig. 176). When that angle is reduced to 0°, rods M-S and S-E are in one line, overlapping each other. and the eccentricity M-E is at its minimum value (Fig. 177,
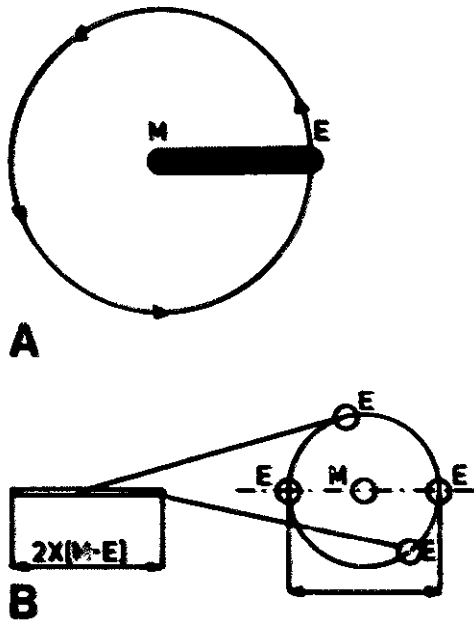
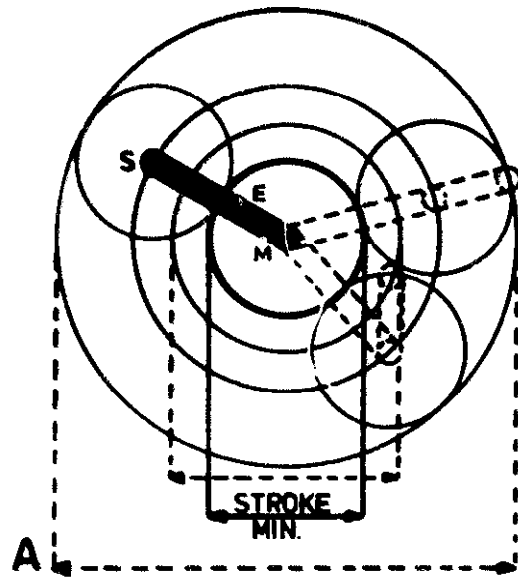Fig. 175. Normal characteristics of separator movement: (A) stroke fixed at M-E; and (B eccentricity equal to 2 (M-E).

Fig. 176. Schule paddy separator with adjustable stroke obtained by changing angle between rods M-S and S-E.

Fig. 177. (A) Angle between rods M-S and S-E is 0° and stroke is at minimum value. (B) Angle between the two rods is 180° and stroke is maximized.
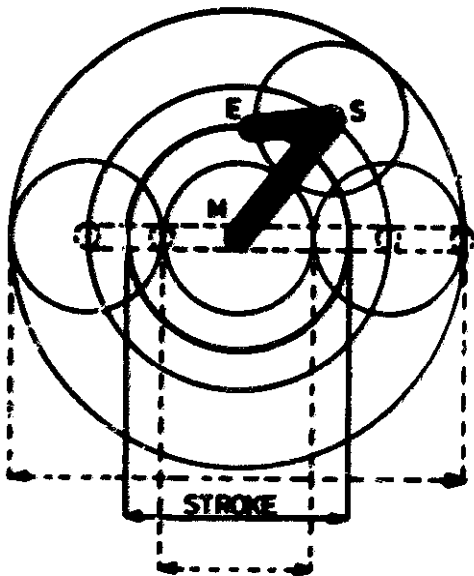
A). Consequently, the stroke made by this eccentricity is of minimum length. However, when the angle is increased to 180°, rod M-S is in line with rod S-E, and both the eccentricity M-E and the stroke are at their maxi-

mum values (Fig. 177, B). Any angle of rods M-S and S-E between 0 and 180° will fix an eccentricity and stroke between the fixed minimum and maximum values.

This principle is implemented in the separator with adjustable stroke. Rod S-E is extended and equipped with a swing rod that

allows the whole device to be fixed with a screw into a circular groove on the horizontal flywheel. The centre of rotation of this flywheel is M and the pin causing the eccentricity is E. By moving the end of the V-shaped rod along this groove the length of the stroke is changed (Fig. 178). When the end of the rod is fixed in position 1 the angle between rods M-S and S-E is 0° and the stroke is minimized. At position 4 the angle is 180° and the stroke is maximized. Positions between locations 1 and 4 are selected to give any desired stroke length (e.g. position 3 in Fig. 178).

The flywheel is driven by an electric motor through a V-belt transmission. There are markings on the side of the flywheel that indicate the positions in the flywheel groove where the adjustment device should be locked for given stroke lengths (Fig. 179, A). The locking screw has a special safety design. The separator table is moved back and forth over the full length of the selected stroke because the eccentricity pin E moves between two guide plates of special design mounted under the separator table (Fig. 179, B). The entire mechanism of drive, flywheel, and stroke adjustment device is built under the separator table and is very compact (Fig. 179, C). The stroke, however, can only be adjusted when the machine is not operating. The table inclination is adjusted by

a handwheel at the side of the machine that lifts or lowers the entire frame supporting the table (Fig. 180). The table rolls very smoothly over large wheels with rubber bands and is kept in line by guide-rolls. Heavy springs at both sides of the frame, supporting the table, partly neutralize the shock effect of the shaking table and reduce the wear on moving parts.

Although it is their main product, compartment separators are not exclusively designed for paddy. They are also used for separation of bird seeds, oats, peas, wheat, rye, barley, and millet.

Tray Separator

The tray separator was designed in Japan as a paddy separator and has now been intensively introduced in most of the Far East countries (Satake separator).

The machine is entirely made of steel and basically consists of from three to seven identical indented trays having a double inclined position. The trays are mounted one on top of the other with a spacing of about 5 cm (2 inches). The front inclination is fixed and very slight. The side inclination is adjustable (Fig. 181). The tray assembly as a whole moves up and forward, making a jumping, slightly bent
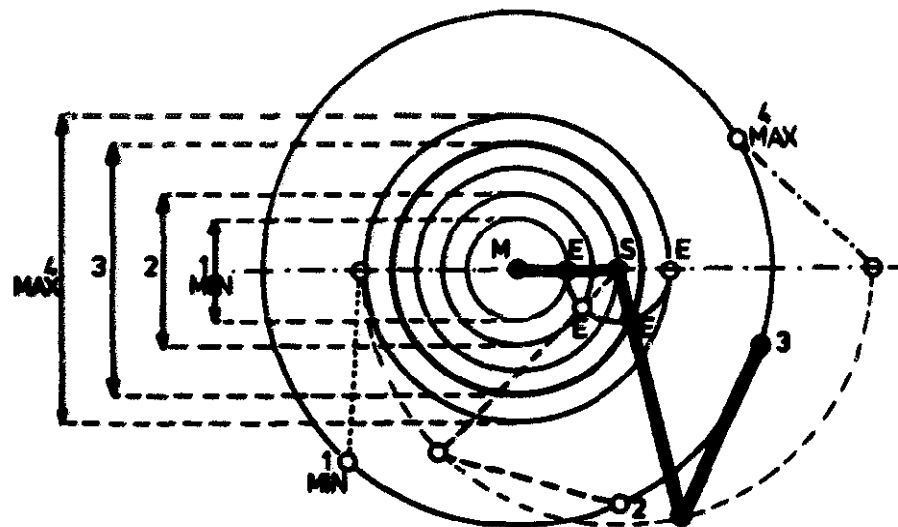

FIG. 178. V-shaped extension added to rod S-E is fixed in a circular groove on the flywheel. By sliding the rod along this groove the angle between rods M-S and S-E is changed and the length of the stroke is adjusted.
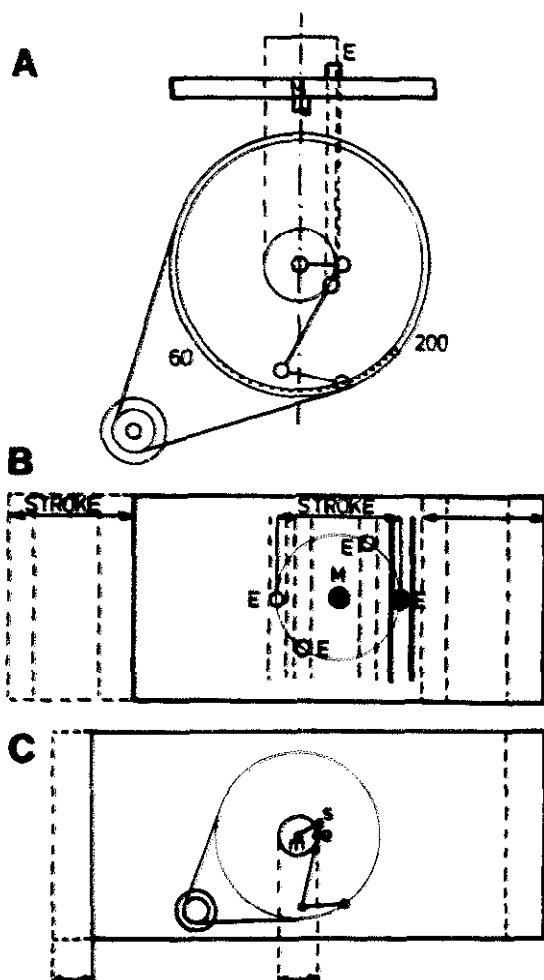
FIG. 179. Stroke adjustment of Schule separator. (A) Markings on flywheel indicate settings for specific stroke lengths. (B) The eccentricity pin. E. moves in special guide plates allowing separator table to move along full length of stroke. (C) The entire mechanism fits compactly under the separator table.

movement. The amount of grain fed into the left top side of the machine is adjustable, with each tray receiving an equal quantity of grain. Because of the double inclination and the jumping movement of the tray assembly, the paddy and brown rice slowly move to the right, separating brown rice on the top of the tray, paddy on the bottom of the tray, and leaving a mixture of paddy and brown rice in the centre part. The tray overflow, therefore, has three products (Fig. 181): (1) brown rice, fed to the whitening machine; (2) paddy, returned

to the hullers; and (3) a mixture of paddy and brown rice recirculated immediately to the same separator. Consequently, the intake capacity of the tray is the sum of newly loaded grain plus the recirculated mixture.

In its separation process this type of machine makes use of differences in the specific gravity and length of the paddy grains and the brown rice kernels. Because of the upward jumping movement of the trays the grains will be lifted off the tray. The brown rice kernel jumps higher than the paddy (Fig. 182). Consequently, the brown rice kernel will reach the tray at a more remote point from its initial lifting point than the paddy grain. Its downward movement is partly neutralized by indents in the tray that are wide enough to have a grip on the brown rice kernels, but not to have a sufficient grip on the paddy (Fig. 182). The downward movement of the brown rice kernel over the tray, therefore, is less than the movement of the paddy. Slowly the brown rice creeps to the upper part of the tray and the paddy slowly moves down to the lower part of the tray. This separation is not completed when the grain reaches the overflow end of the tray, so three products are discharged: brown rice, paddy, and a mixture of brown rice and paddy.

The actual separation process starts the moment the paddy is loaded onto the tray. However, the production of pure paddy and brown rice can only be observed when the grain is about halfway down the tray. Different varieties of paddy produce different patterns of movement; therefore, it is necessary to adjust the inclination of the separator and the position of the flaps separating the three overflow chambers (Fig. 183).

The table inclination is adjusted by turning a handwheel that turns a shaft through a gear transmission. The principle of adjustment is the same as the compartment separator; however, with this machine the table inclination can be set when the machine is in full operation.

Difficulties with the performance of the machine are encountered when the shape of the indents do not correspond with the length characteristics of the paddy and brown rice or when wet or dirty grains are processed. In
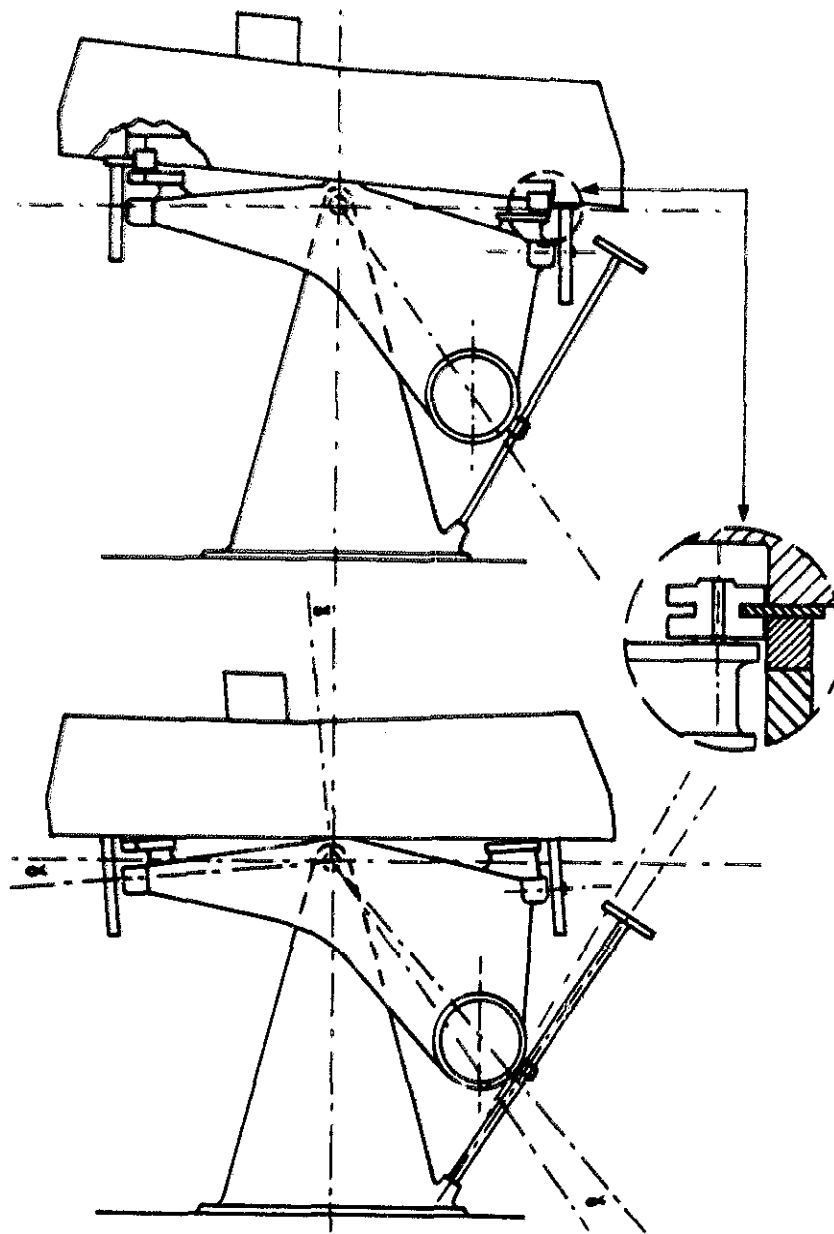
FIG. 180. Table inclination is adjusted by lifting or lowering the entire supporting frame. This adjustment is possible only when the machine is stopped.

the latter case the indents become filled with dirt making separation very inefficient.

Screen Separators

A screen-type paddy separator is very simply constructed. It is a multilayer oscillating sieve with from 6 to 15 screens. Each tray is covered with a wire screen that lets the brown rice pass through but not the paddy grains. Its operation, therefore, makes use of the differences in width and thickness of the paddy grain and brown rice kernel. The overflow of the trays is paddy, and the screen discharge is supposed to be the pure brown rice. Its separation efficiency, however, is insufficient and along with the brown rice man, undersized paddy grains are discharged. Apart from its low efficiency, this type of separator has an additional disad-
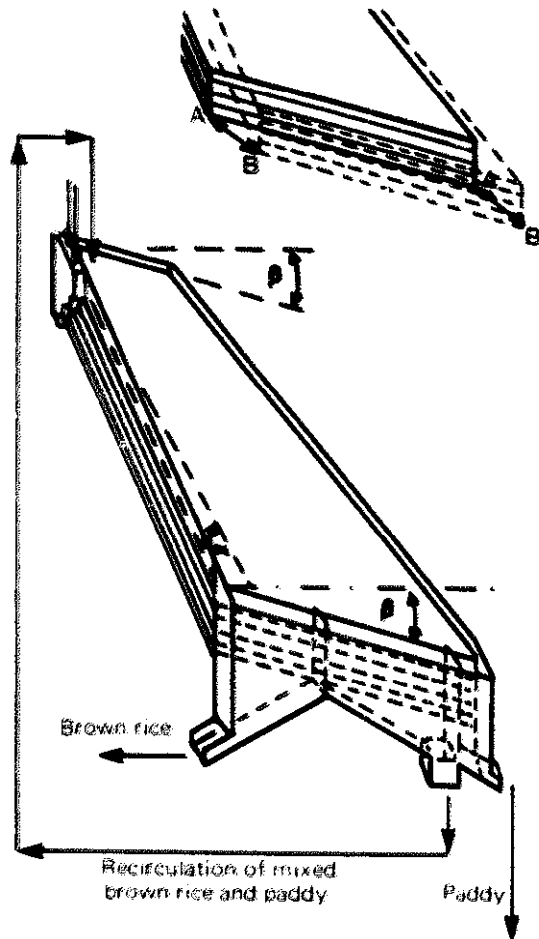
FIG. 181. Satake paddy separator. The separation products are: (1) brown rice; (2) paddy; and (3) a mixture of paddy and brown rice.
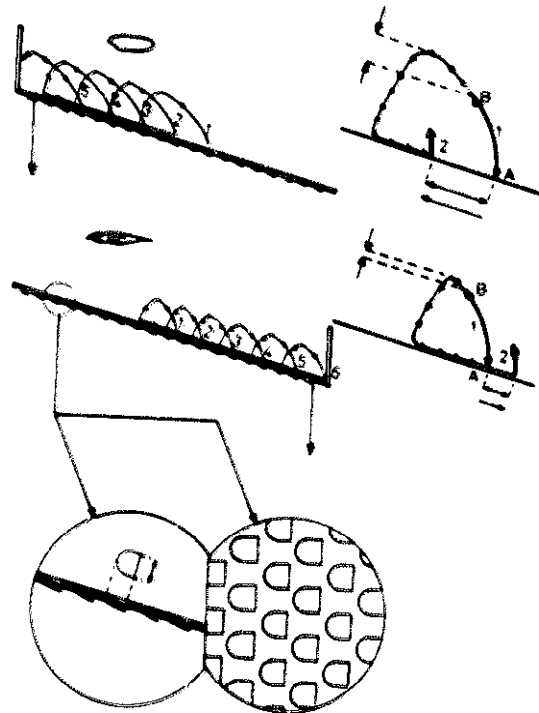
FIG. 182. Operation of Satake paddy separator. (A) Brown rice is lifted higher than the paddy and moves up the separator tray. (B) Indents in the tray grip the surface of the brown rice, but do not hold paddy very well and, therefore, the brown rice suffers less downward movement.
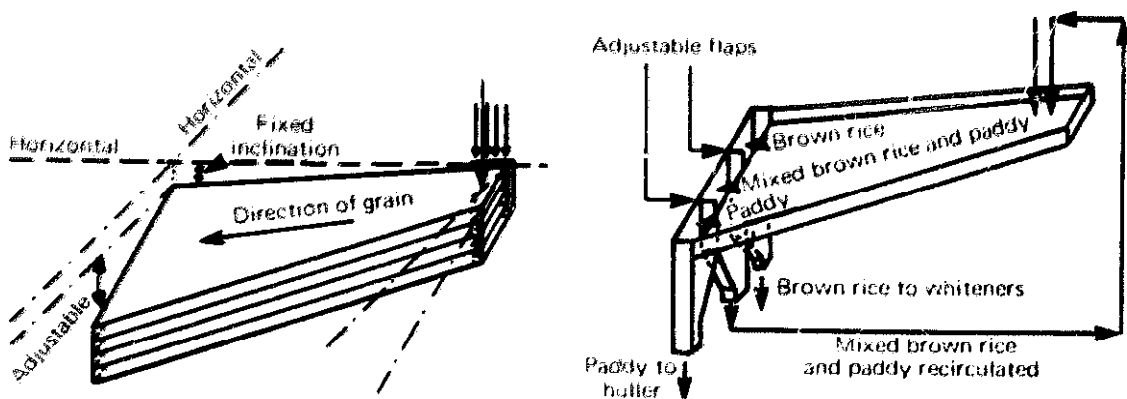
FIG. 183. The inclination of the separator and the flaps controlling the three overflow chambers are adjustable to accommodate the different patterns of movement of different paddy varieties.

vantage. For each different variety to be processed, a different screen mesh is required, making it necessary to change all the trays and to keep a selection of wire screens in stock.

In the rice mill industry this type of machine was abandoned many years ago. However, a Japanese manufacturer is still implementing this principle, and recently a small rice mill designed in the Philippines made use of the screen-type separator. — HARRY VAN RUITEN. *Department of Agricultural Engineering. College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Whitening

and

Polishing

In the process of whitening, the silver skin and the bran layer of the brown rice are removed. In the process of polishing the whitened rice, the bran particles still sticking to the surface of the rice are removed, and the surface of the rice is slightly polished to give it a shinier appearance. Polishing, therefore, always takes place after completion of the whitening process.

Some confusion exists about the words used for these processes. Whitening is sometimes called "polishing" or "milling." Polishing is sometimes called "refining" or "grinding."

Three kinds of whitening machines are widely used in the rice processing industry: (1) the vertical abrasive whitening cone; (2) the horizontal abrasive whitening machine; and (3) the horizontal jet pearler.

The vertical whitening machine in its present form is based on an initial European design. It is made by many manufacturers all over the world and is still widely used for the production of undermilled rice as well as for

first-class rice milled for quality-oriented export markets.

The horizontal whitening machine developed in Japan after World War II is well suited to the short-grain Japanese varieties of rice; however, its introduction in other countries of the Far East and Asia has been delayed because sensitive adjustments are necessary to accommodate medium and long paddy varieties. When this machine is fully adjustable to all paddy lengths its introduction as a substitute for the vertical cone-type whitener will have bright prospects.

The horizontal jet pearler is basically a different design than the horizontal abrasive whitening machine. Actually the machine is partly a whitening machine and partly a polishing machine, with the whitening performance emphasized. It is called a jet pearler because it blows an airstream through the rice being processed in the machine. It was introduced about 10 years ago and is slowly gaining popularity.

Two types of polishing machines are used in the rice mill industry: (1) the vertical cone-type polisher; and (2) the horizontal polisher.

The vertical cone-type polisher looks similar to the vertical abrasive whitening cone; however, the abrasive coating is replaced by leather strips and no rubber brakes are installed.

The horizontal polisher, which is slowly gaining popularity, was developed in Japan about 10 years ago and is actually based on the same principle as the vertical cone-shaped machine.

The Vertical Whitening Cone

This machine basically consists of a cone-shaped cast iron cylinder with an abrasive coating. The cone is fixed on a vertical shaft that rotates either clockwise or counterclockwise. A wire screen that has a mesh size depending on the variety of paddy to be hulled is fixed around the entire cone. The average distance between the cone coating and the screen is about 10 mm. At regular intervals the wire screen is divided into segments by adjustable rubber brakes. These brakes are 30–50 mm wide depending on the size of the ma-

chine. The number of rubber brakes depends on the diameter of the cone and the preference of the manufacturer.

In Germany, the number of brakes is determined by the following formula: $n = (D/100) - 2$ where D = the cone diameter in millimetres. For example if $D = 800$ mm then $n = (800/100) - 2 = 6$. Therefore, the number of brakes is six. In Italy a different formula is used: $n = D/100$. For example if $D = 800$ mm the number of brakes is $800/100 = 8$.

The rotating whitening cone (Fig. 184) is vertically adjustable so the clearance between the abrasive coating of the cone and the wire screen can be adjusted. This adjustment depends on the variety of rice, the condition of the grain, the process method, and the wear of the coating. The rubber brakes (Fig. 184, no. 4) in the wire-screen frame are adjustable through a simple handwheel adjustment, and their clearance with the cone surface is only about 2–3 mm.

The brown rice is fed into the centre of the machine through a small hopper. A vertically adjustable cylindrical sleeve (Fig. 184, no. 1) regulates the capacity and equal distribution of the brown rice over the entire surface of the rotating cone. By centrifugal force the rice is fed between the cone and the wire screen. If no rubber brakes were installed, the rice would very quickly pass through the free space between the cone and wire screen and nothing would happen. However, the presence of the rubber brakes prevents the immediate discharge of the rice. The resistance built up by these brakes brings the grain under pressure and presses it against the abrasive coating of the cone and against the wire screen. This friction removes part of the bran layer. The bran passes through the wire screen and drops into the cone housing. The partly or fully whitened rice leaves the cone, falls into a self-unloading discharge spout (Fig. 184, no. 5), and is fed to a bin for further processing. The bran is scraped from the bottom of the cone housing by a rotating scraper (Fig. 184, no. 6) and is unloaded into a spout for bran discharge (Fig. 184, no. 7).

The rotating scraper is driven by a gear wheel (Fig. 184, no. 8) fixed on a vertical shaft that is driven by a flat-belt transmission from the vertical cone shaft (Fig. 184, no. 9). Air is sucked through this machine to cool the grain and at the same time to remove part of the bran (Fig. 184, no. 10). This makes it necessary to blow the air to a cyclone for bran separation.

Vertical adjustment of the rotating cone is done manually. The entire shaft-cone assembly is moved by moving the housing of the shaft end-bearing (Fig. 184, no. 11). A simple handwheel adjustment, which is mounted on the base of the cone frame, is used to lift or lower the steel bar that supports the bearing housing. The supporting bar is controlled by either one or two handwheels. If controlled by one, one end of the supporting bar is hinged to the base of the cone frame.

The peripheral speed of the cone should be about 13 m/s, making the speed of rotation of the shaft a function of the diameter of the cone. The larger the diameter of the cone, the lower the speed of the shaft (Fig. 185).

Example

If D = cone diameter = 700 mm (0.7 m), and V = peripheral speed = 13 m/s

$$V = \frac{\pi \times D \times n}{60} \quad (\text{m/s})$$

$$n = \frac{60 \times V}{\pi \times D} = \frac{60 \times 13}{3.14 \times 0.7} = 355 \text{ rpm}$$

Quite often, whitening cones are not properly used. When the machine is only half-filled with rice, the rubber brake will not be able to build up a constant pressure and the rice will jump into the open space between the cone and the wire screen. This will unnecessarily break the rice, and the abrasive coating and rubber brakes will wear unevenly, making proper adjustment and performance of the machine practically impossible. Therefore, it is always necessary to run this type of machine with a fully loaded cone.

Because the whitening cone must run without any vibration, it is important to have this heavy part of the machine properly fixed to the top of the main shaft. To secure a perfect positioning of the cone on this shaft, the top end of the shaft is tapered (Fig. 186, A). How-

FEEDING

AIR

BRAN

RICE
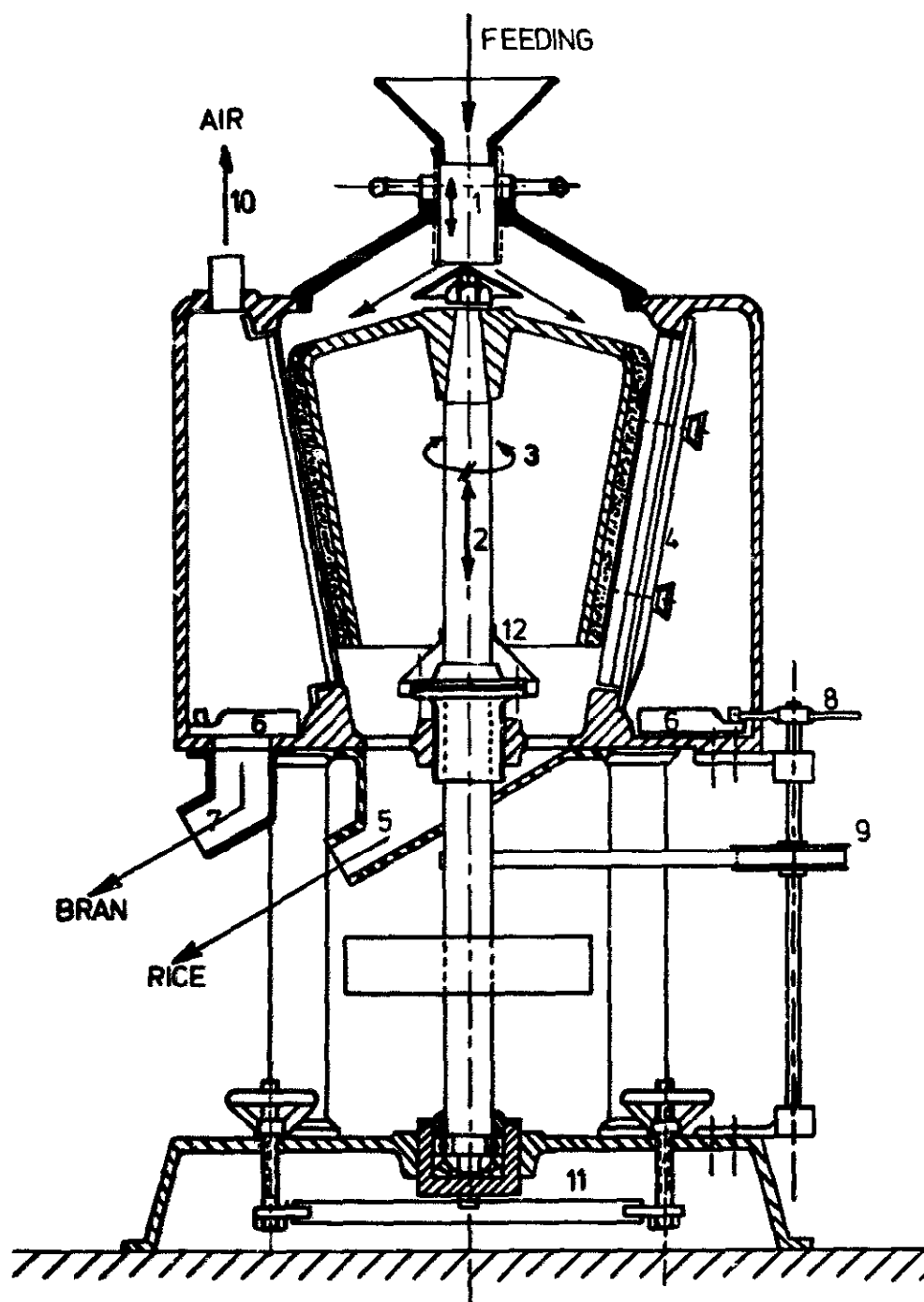
Fig. 184. The vertical abrasive whitening cone.

ever, a small impurity on this part of the shaft or the slightest damage to the tapered surface will make correct assembling impossible and vibration of the cone will result, causing excessive breakage of the rice. This risk is re- duced when the taper of the shaft and cone is limited to two small areas, which still secure the same positioning of the cone on the shaft (Fig. 186, B). When the cone is lifted the clear- ance between the rubber brakes and the cone

FIG. 185. Peripheral speed curve for whitening cone
(V = 13 m/s).

FIG. 186. Tapered end of shaft supporting whitening
cone. (A) Complete taper. (B) Taper
limited to two small areas to minimize
the chance of a small impurity or damage
to the tapered surface interfering with
proper assembly.

is increased and must be readjusted. A similar
adjustment is necessary if the rubber brakes
wear. The rubber brake assembly, therefore,
is made easily accessible. By opening the doors
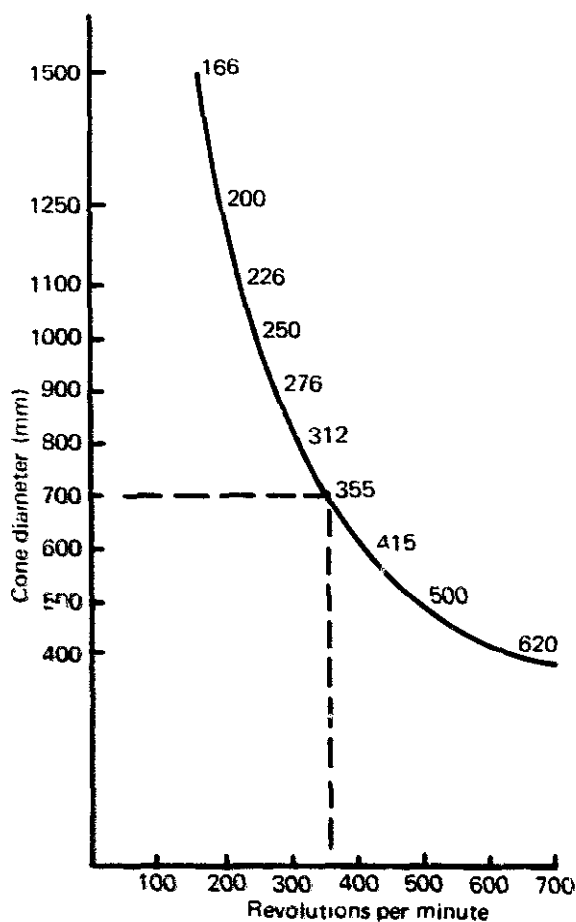of the cone housing the required adjustment
can be mad˄ by a simple handwheel (Fig. 187).

The rep˄cement of worn brakes has also
been made simple, although there are different
methods of fixing the rubber on the clamps.
The most commonly used system abroad is an
external swallow-tail connection between the
rubber and wood that secures a perfect clamp-
ing, leaves a maximum of solid rubber avail-
able for the operation, and makes it possible
to use the wooden clamps continuously (Fig.
188, A). The internal swallow-tail connection
is also used (Fig. 188, B); however, less solid
rubber is made available here and quite often
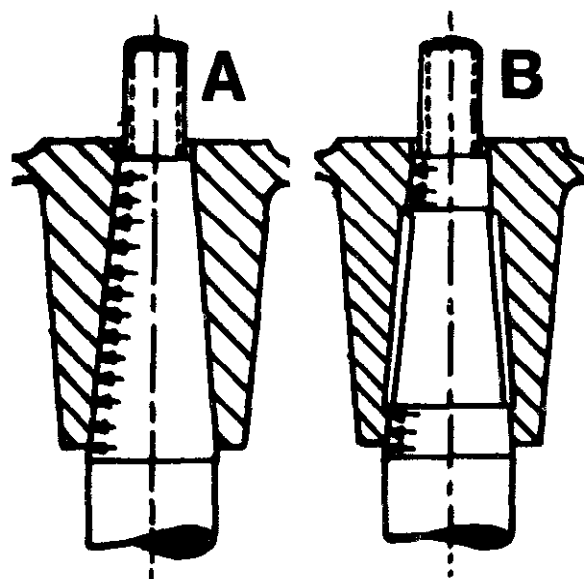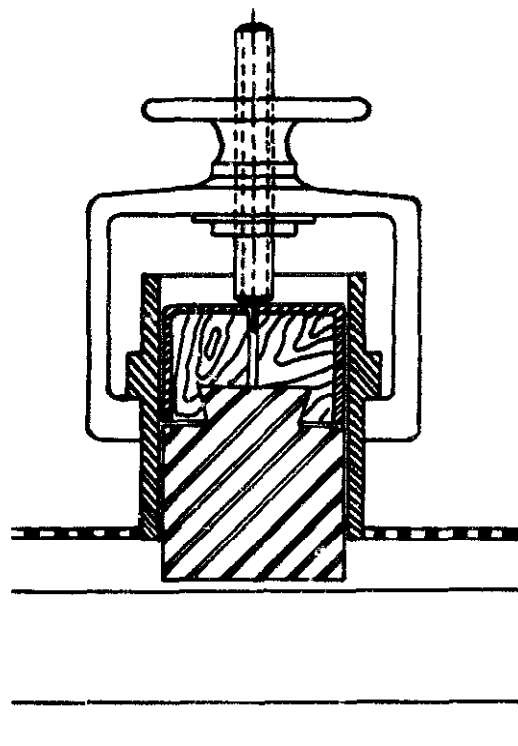the swallow-tailed wooden clamp is damaged

FIG. 187. Simple adjustment mechanism for rubber
brake.

beyond repair. In the Philippines the rubber brake is normally glued onto the wood (Fig. 188, C). This system is not recommended.

New rubber brakes are straight square bars (Fig. 189, A). However, during the whitening process, because of the friction on the rubber when the rice passes between the brake and the cone, the brakes wear out and follow the pattern of the cone (Fig. 189, B). Eventually both the top and bottom parts of the brakes will have a so-called "nose" that disturbs the free flow of the rice and is responsible for unnecessary breakage (Fig. 189, B). These "noses" should be removed regularly.

The wire-screen casing, which follows the shape of the cone is built of three to eight segments, depending on the size of the cone and the preference of the manufacturer. Sometimes the brake assembly is part of the wire-screen segment and is fixed in the frame of these segments (Fig. 190, A). In another system the brake assembly is permanently fixed in the frame of the cone housing and the wire-screen segments fit between the assemblies (Fig. 190, B). The advantage of this system is that the screens can be replaced without disturbing the adjustment of the brakes.

Screen repair or replacement is often necessary. Because of the friction caused by the rice, the wire screen wears out and rice pours through the hole in the screen. This can be determined by checking the bran discharge regularly. When rice is mixed with the bran, it can be presumed that at least one screen segment needs repair or replacement. This replacement can only be done when the machine
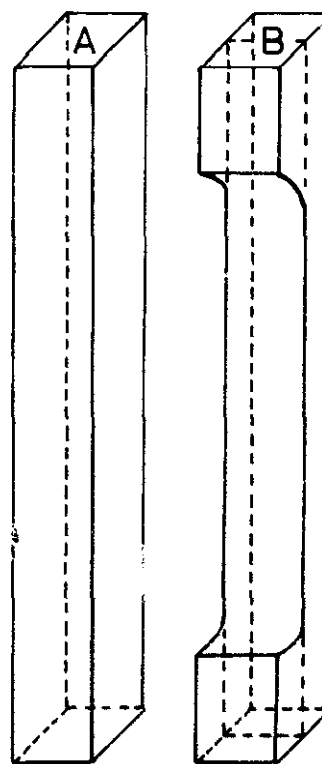
FIG. 189. (A) New rubber brakes are straight and square. (B) The brakes eventually develop "noses" that must be removed to avoid unnecessary rice breakage.

is empty and not running, so a quick replacement system is recommended.

In this machine any vibration in the machine components must be avoided to prevent breakage of the rice. In this respect, proper bearing of the shaft and maintenance of these bearings is very important. What has been mentioned about shaft end-bearings of the under-runner disc huller with respect to construction and maintenance also applies to the whitening cones since the same designs are followed. The same applies to the bronze upper bearing, which mainly absorbs radial forces. For larger diameters of the cone this bronze upper bearing can be replaced by a self-centering ball-bearing assembly (Fig. 191). The entire assembly is clamped on the shaft and moves up and down with the shaft when the whitening cone is adjusted. For this reason the bearing assembly has a grooved guide block (Fig. 191, no. 1), that at the same time houses the self-

FIG. 188. Methods for attaching rubber to wooden clamps. (A) External swallow tail. (B) Internal swallow tail. (C) Glue.

RUBBER BRAKE

A

B
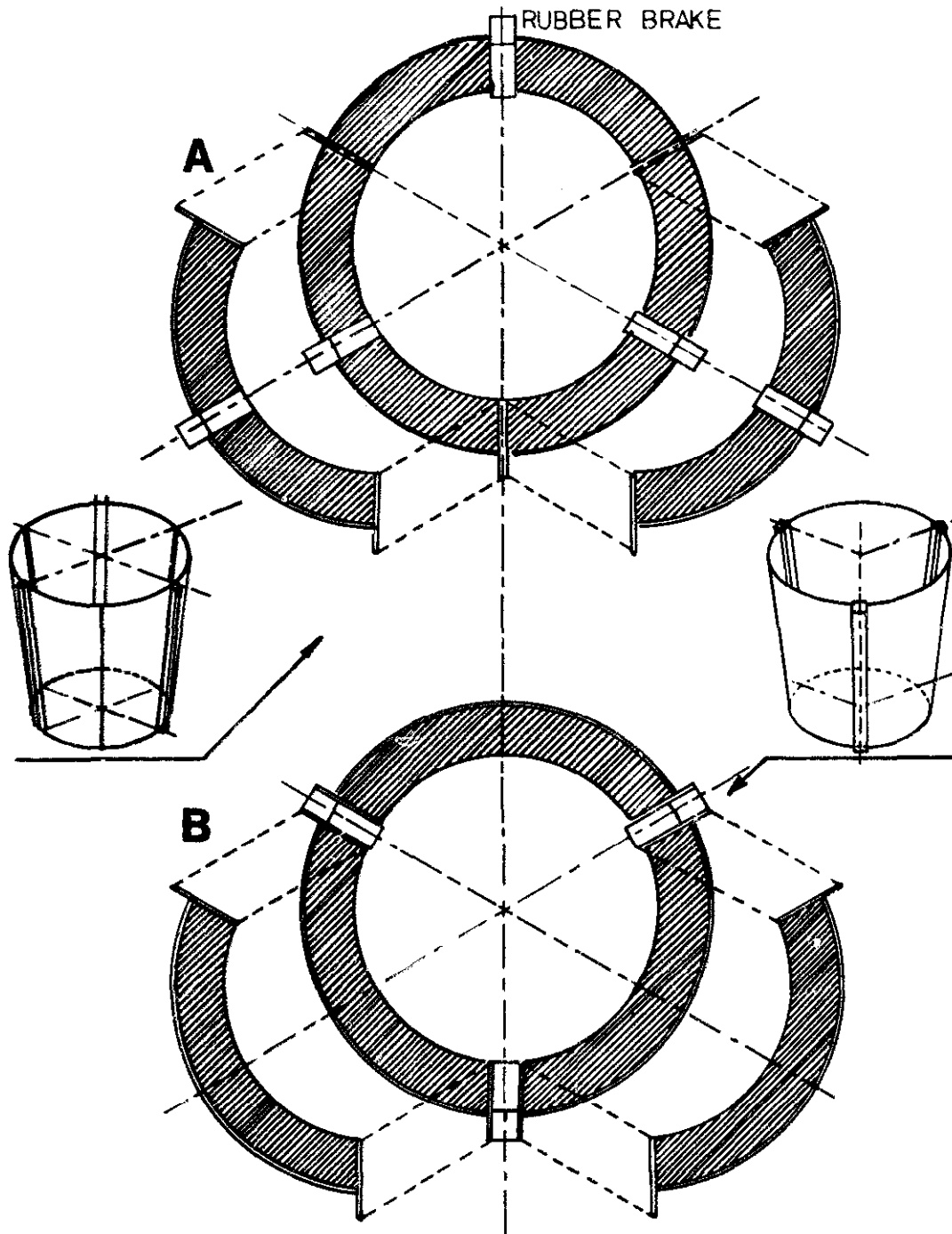
Fig. 190. (A) The brake assembly is part of the wire screen segment and is fixed in the frame of these segments. (B) The brake assembly is permanently fixed in the frame of the cone housing and the wire screen segments fit between the assemblies.

centering ball-bearing (Fig. 191, no. 2). This bearing is clamped on the shaft by a cone-shaped clamp bush (Fig. 191, no. 3). The entire bearing house (Fig. 191, no. 4) is filled with grease and sealed on the shaft by filterings. The bearing assembly is protected against direct infiltration of bran and rice particles by a steel cover, which is fixed on the shaft.

all the rice-milling machines. A clockwise-rotating machine, in this case a whitening cone, causes a clockwise-directed tension in the frame of the mill. When multiplied by more machines, it may cause an unpleasant vibration of the entire mill frame. This effect can be neutralized by rotating the first machine clockwise, the second machine counterclockwise, and so on (Fig. 192).

In many rice mills the abrasive coating is applied to the cone in a rather primitive way so that it is practically impossible to secure a uniformly shaped working surface. However, very simple and cheap tools can be made that provide a perfectly shaped surface of the cone. In this respect two methods are used.

In the first method, with the cone turned upside down, the coating is applied manually and its uniform shape is formed by a rotating scraper (Fig. 193). The second method uses a

FIG. 191. Self-centering upper shaft ball-bearing assembly of the whitening cone.

The cone shaft is normally driven by either a flat-belt or a V-belt transmission, similar to those used for the under-runner disc huller. Therefore, what has been mentioned about flat-belt pulley drives, V-belt transmission drives, and belt adjustment problems of the under-runner disc hullers also applies to the whitening cones. However, because three or more whitening machines are usually installed in a mill, the direction of rotation of the machines sometimes requires special attention.

When mounted on independent foundations, the direction of rotation is of no importance and can be clockwise or counterclockwise for all machines. However, quite often the frame supporting the cone assembly is a part of the entire rice mill frame that supports practically

FIG. 192. Direction of rotation of the whitening cones should be alternately clockwise and counterclockwise for multipass whitening.

FIG. 193. Rotating scraper used to shape the whitening cone after it has been recoated.

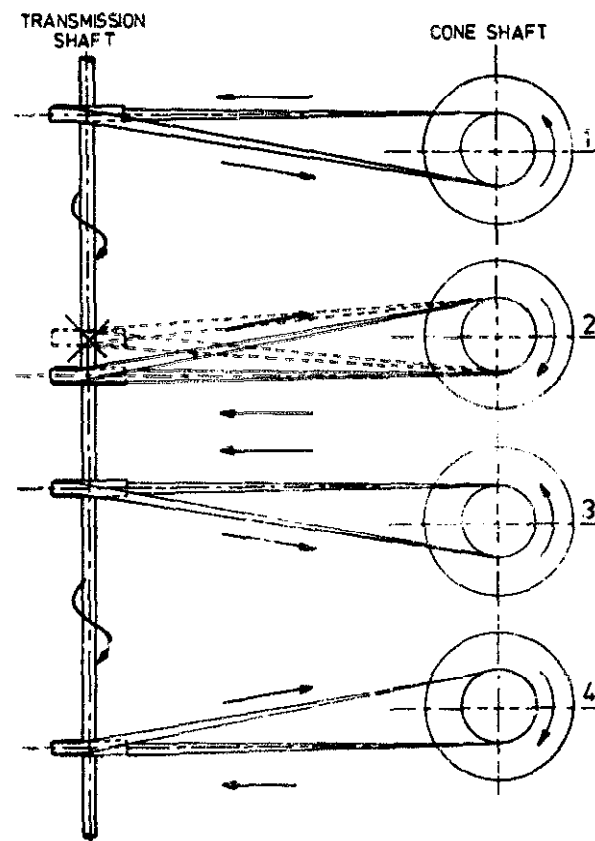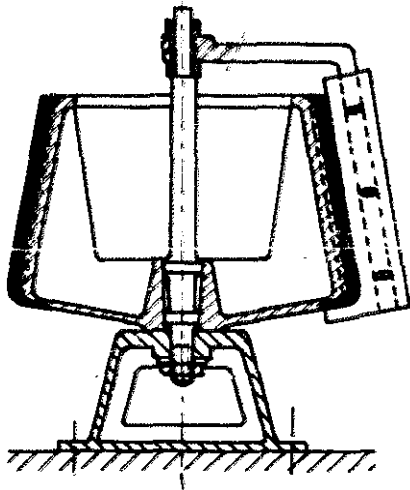special cone-shaped mould, following exactly the pattern of the cone (Fig. 194, no. 1). The coating is poured between the mould and the cone body, is rammed by a simple tool (Fig. 194, no. 2) to eliminate air bubbles, and is rounded by a hand scraper (Fig. 194, no. 3). Any correction to the surface of the abrasive coating is done by simple redressing tools, which can be fixed inside the cone housing (Fig. 194, no. 4). The use of these tools is indispensable for achieving smooth and efficient operation of the whitening cone.

In the Philippines a pure emery composition for the coating of the cones is generally used. Normally this composition consists of 100 weight units emery grit 16 (or sometimes 50 weight units of emery grit 16 plus 50 weight units of emery grit 18), 20 weight unit magnesite, and magnesium chloride brine (30° Baumé). This composition is not used abroad anymore and has been replaced by a new composition that has both better whitening capacity and efficiency and results in longer life of the coating. The recommended composition includes a new component, silicium carbide (carborundum), whose hardness is about two and one-half times higher than that of emery. The recommended composition for cones is: grit (25% emery grit 16, 50% silicium carbide grit 16, and 25% silicium carbide grit 18); 20% magnesite; and 20% magnesium chloride brine (30° Baumé). This com-

position is for the first and second whitening cones. For the third whitening cone the grit part of the composition can be 25% emery grit 18 plus 75% silicium carbide grit 18.

What applies to the positioning of the under-runner disc hullers in a rice mill also applies to the whitening cones; therefore, these machines can be installed on: (1) an elevated foundation (Fig. 195, A); (2) the ground floor level (Fig. 195, B); or (3) working floor level with frame support (Fig. 195, C).

A whitening machine removes the bran from the brown rice by friction, and the friction pro-
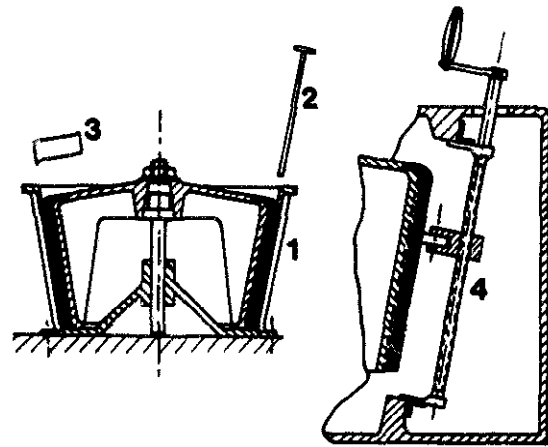
FIG. 194. Special tools for the recoating and redressing of the whitening cone: (1) cone-shaped mould; (2) simple ramming tool; (3) hand scraper; and (4) redressing tool.
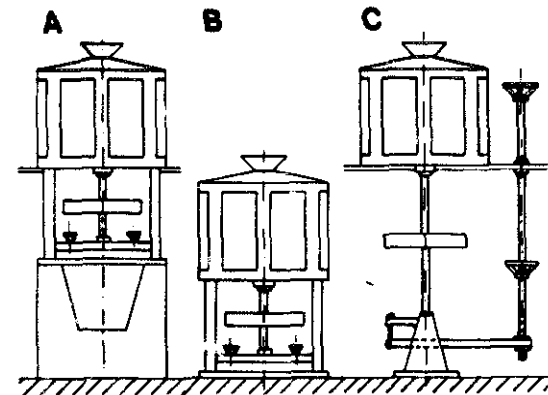
FIG. 195. Different positions for the whitening cone. (A) Elevated foundation. (B) Ground floor level. (C) Working floor level with supporting frame.

SINGLE PASS

RECOVERY LOSS

HEAD RICE

LARGE BROKENS

SMALL BROKENS

RECOVERY LOSS

HEAD RICE

LARGE BROKENS

SMALL BROKENS

FIG. 196. Multipass whitening increases rice mill recovery by reducing the amount of rice breakage.

duces heat. When all the bran is removed in one simple whitening pass, the residence time of the grain is increased, and the clearance between cone and screen is reduced. Consequently, friction is applied to the grain, and the grain becomes hot. Since friction and heat are responsible for breakage of rice, and are to be avoided, it is recommended that the bran layer be removed in three or even more passes. This reduces the residence time of the rice in the machine and allows the clearance between the cone and screen to be increased. The amount of friction is thereby reduced and as a result the temperature of the rice is lowered. This process is called "multipass whitening" and is aimed at increasing rice mill recovery by reducing the amount of rice breakage (Fig. 196). Multipass whitening produces higher rice mill recovery because there is: (1) an increased head rice yield; (2) a reduced percentage of large brokens, and (3) a reduced percentage of small brokens.

Multipass whitening does not involve much more investment than single-pass or double-pass whitening. This is because the capacity of a cone for single-pass whitening is much lower than for multipass whitening because of differences in residence time and clearance adjustment. Thus, for a required capacity the size of the cone needed for single-pass whitening is much larger than the size of the whitening cones used for multipass whitening. For example, if a mill requires a capacity of 1200 kg of rice per hour this can be accomplished by: (1) single-pass whitening with one 1000-mm cone (Fig. 197, A); (2) double-pass whitening with two 800-mm cones (Fig. 197, B); or (3) multipass whitening with three 600-mm cones (Fig. 197, C). For cones 600 mm in diameter the capacities for the different white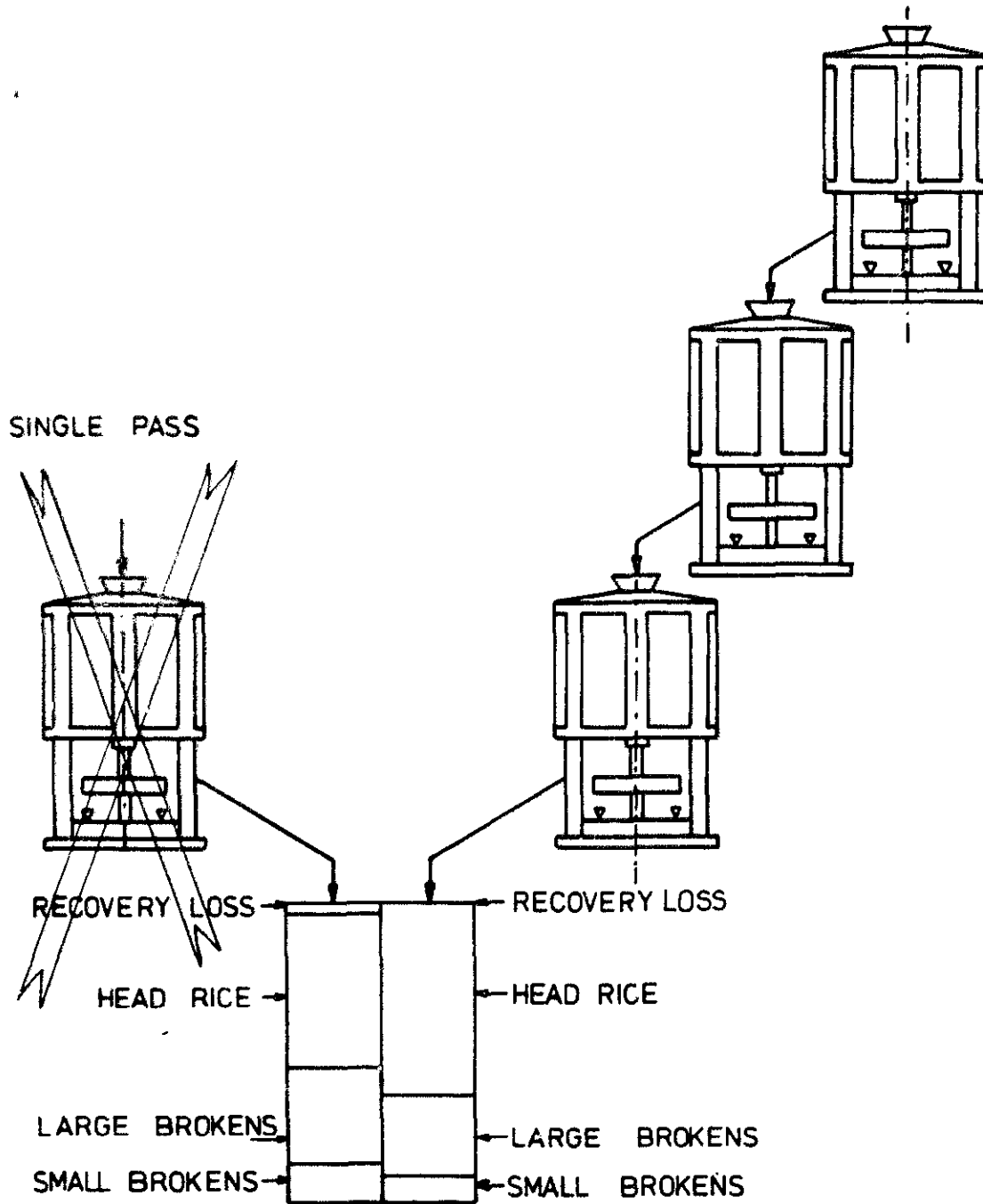ning processes are: (1) single-pass whitening 700 kg/h; (2) double-pass whitening 1000 kg/h; and (3) multipass whitening (three cones) 1200 kg/h.

Compared to the sturdy, solidly constructed vertical whitening cone, the horizontal whitening machine developed by the Japanese is more compact in its construction details. Basically the machine consists of a cylindrical abrasive roll (Fig. 198, no. 2) clamped on a horizontal shaft (Fig. 198, no. 1) that runs at high speed
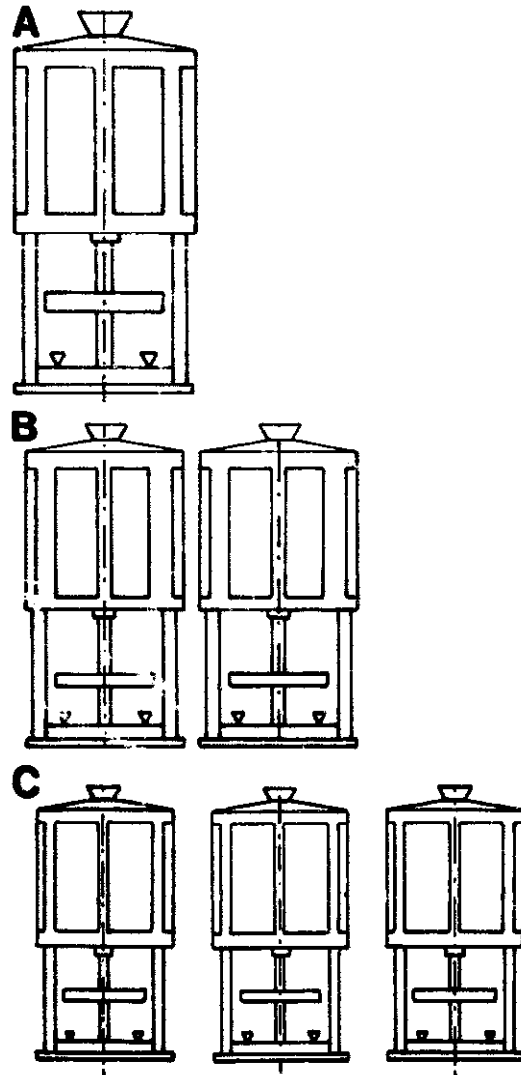
FIG. 197. Three ways of producing 1200 kg of rice per hour. (A) One 1000-mm cone. (B) Two 800-mm cones. (C) Three 600-mm cones.

(about 1000 rpm) in a cylindrical whitening chamber, which is covered with a slotted perforated sheet (Fig. 198, no. 6). A feeding screw (Fig. 198, no. 4), fixed on the horizontal shaft, feeds the rice into the free space between the abrasive roll and the slotted cylinder. A counter pressure is built up in this space by an adjustable valve (Fig. 198, no. 5) fitted in the rice outlet spout of the machine. The counter pressure of this valve, which is controlled by a weight balance, controls the pressure and

VIEW A–B
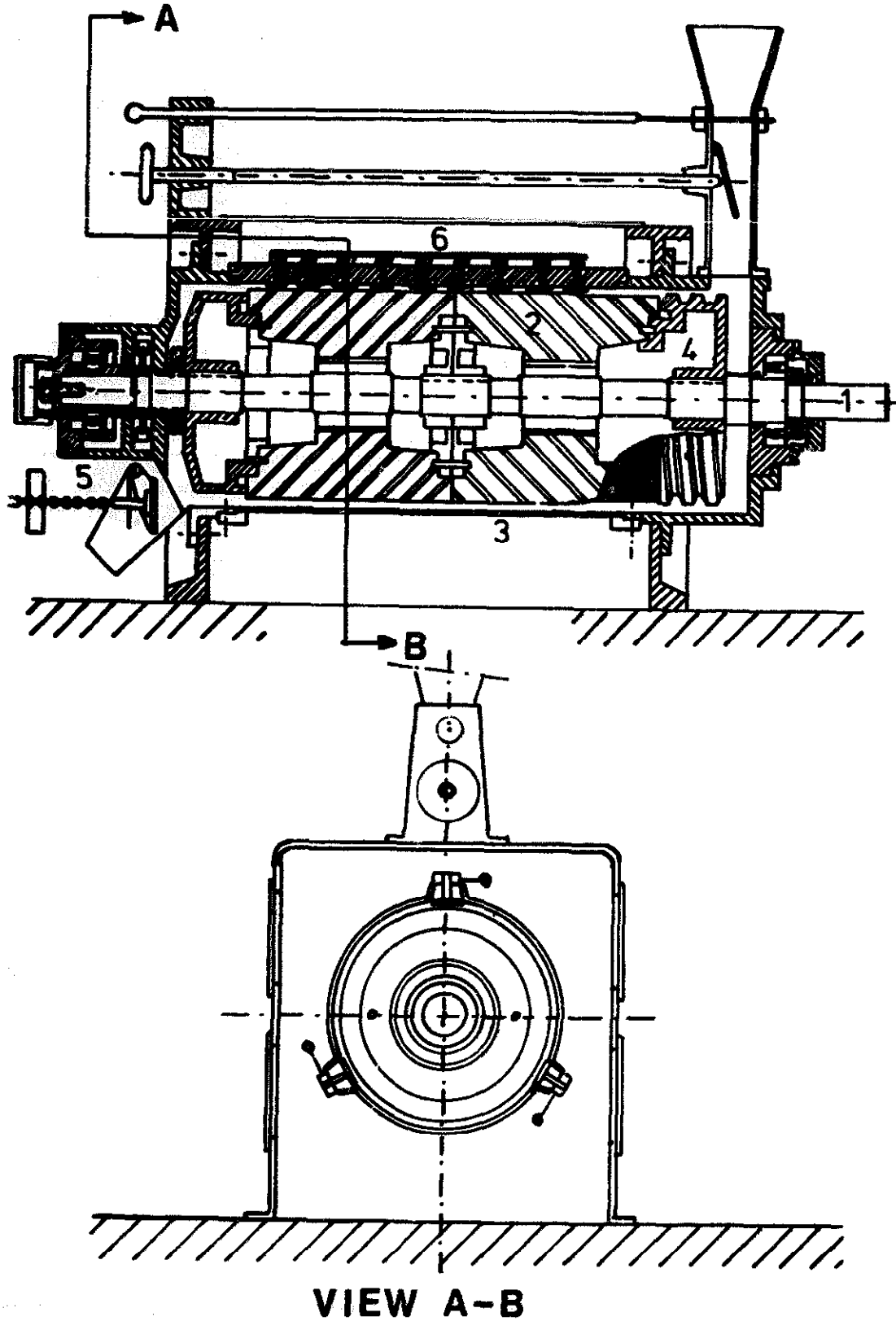
FIG. 198. Horizontal whitening machine (Satake).

friction applied to the rice inside the machine. Over the full length of the cylindrical housing three rows of adjustable steel brakes are installed that can be adjusted from 0° (axial) to 90° (radial) (Fig. 199, no. 1–3). These adjustable brakes direct the position of the rice grain inside the machine during the whitening process to obtain an optimum whitening efficiency.

For a long grain variety the position of the brakes is 0° (Fig. 200, A). The rice grains are lined up in an axial direction and roll under pressure through the whitening chamber. For short grain varieties the position of the brakes is 90° (Fig. 200, B). In this case the rice is lined up in a radial direction and tumbles through the pressure chamber of the machine. If long grain rice is processed in the machine at the 90° adjustment of the brakes the grain will be badly broken.

The brake adjustment has a range between 0 and 90° and the correct angle of adjustment depends on the variety of rice to be processed. This remains a very critical point in the operation of this machine and requires an experienced operator. A disadvantage of this machine is that the clearance cannot be adjusted. Once the diameter of the 250-mm roll is reduced by about 6 mm it must be replaced. The rolls, which are made of grit 32 silicium carbide, cannot be recoated and new supplies from the manufacturers have to be secured continuously.

The Jet Pearler

The jet pearler is a machine that, in a Japanese designed whitening process, is used for the last pass of the rice. Its objective is to remove the final part of the bran layer and simultaneously cool the grain through an airstream of ambient temperature.

It consists mainly of a horizontal, partly hollow, perforated shaft (Fig. 201, no. 1) on which a cast steel cylinder with friction ridges is clamped (Fig. 201, no. 2). Just behind the two ridges the cylinder has a long opening that allows the passage of air. This cylinder runs in a hexagonal chamber (Fig. 201, no. 5) consisting of two half-hexagonal perforated screens with slotted perforations (Fig. 202, A).
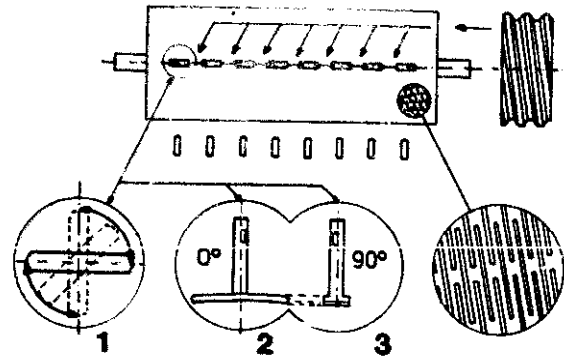
FIG. 199. Cylindrical abrasive roll of horizontal whitener showing the slots in the drum and the adjustable steel brakes.
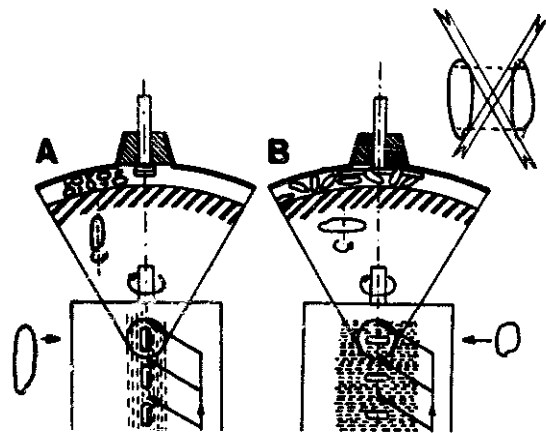
FIG. 200. (A) Brakes of the horizontal whitening machine are positioned at 0° for long grain varieties of rice. (B) The correct setting for short grain varieties is 90°.

A feeding screw (Fig. 201, no. 3), mounted on the solid part of the horizontal shaft feeds the rice into the press chamber of the machine. Here a counter pressure is built up by an adjustable valve fitted in the rice outlet spout of the pearler. A strong airstream is blown by a centrifugal blower (Fig. 201, no. 4) through the hollow shaft and the openings of the cast steel cylinder (Fig. 204, B). The air passes through the rice that is rolling under pressure in the chamber of the pearler and removes the freed bran as it leaves the machine through the slotted screens. The quantity of air blown through the machine can be adjusted by an air sleeve mounted at the air intake side of the blower (Fig. 201, no. 6).
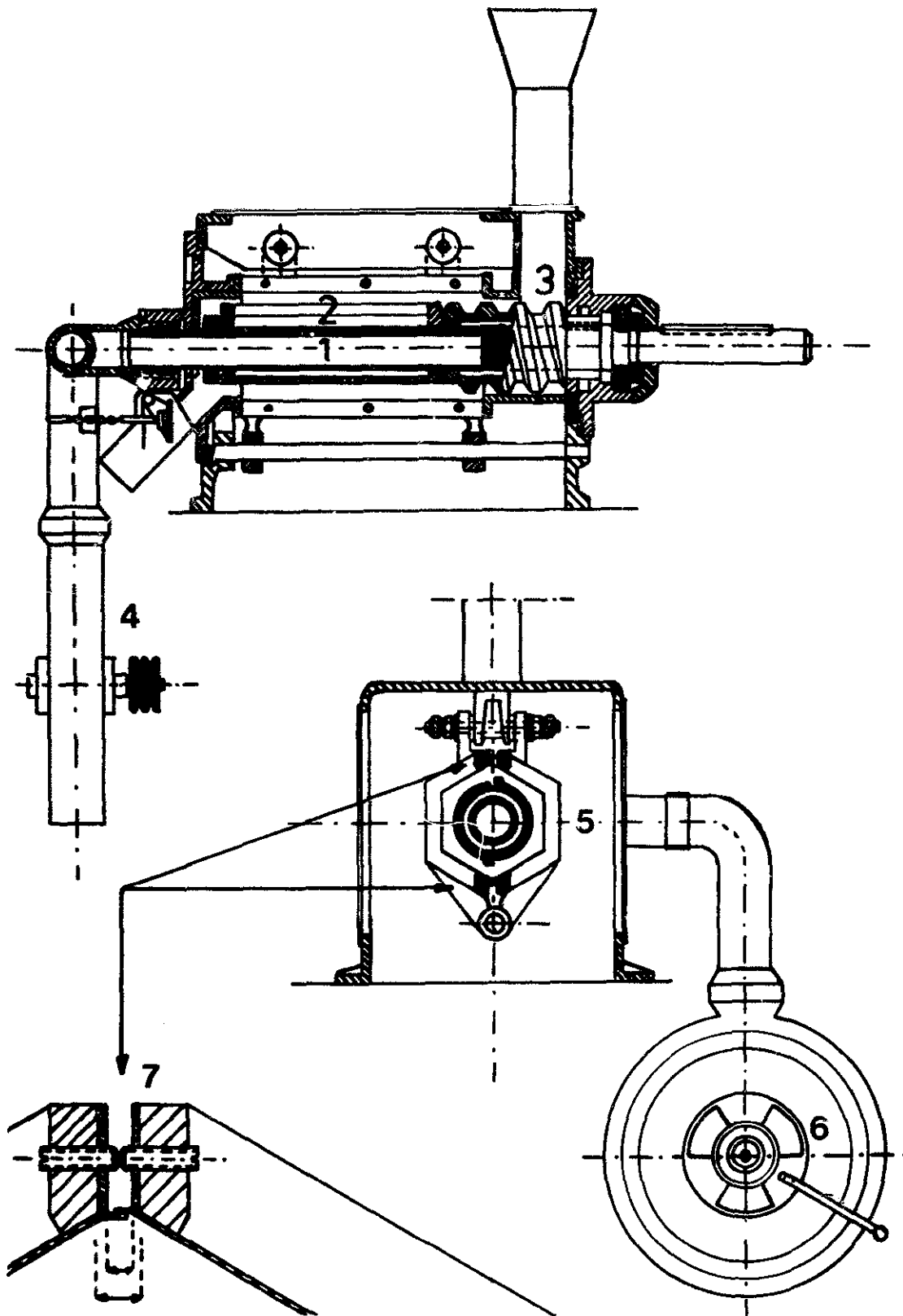
FIG. 201. Details of jet pearler (Satake).
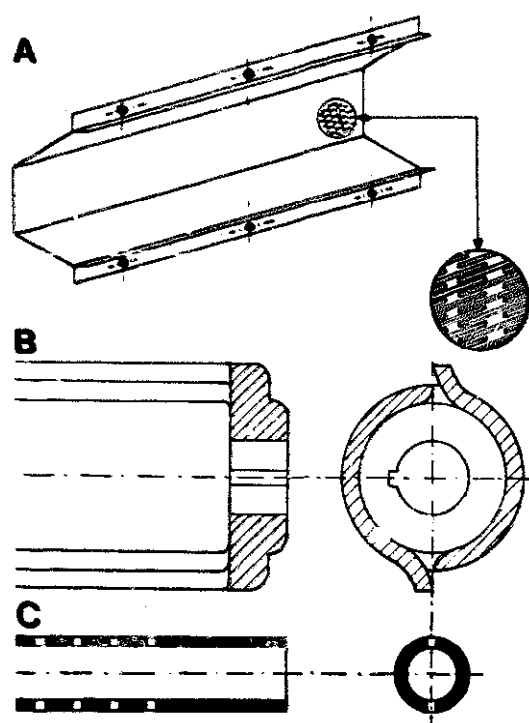
FIG. 202. (A) Hexagonal perforated screen used in jet pearler. (B) Friction ridges of the cast steel cylinder. (C) Hollow perforated shaft that the air stream is blown through.

The clearance between the hexagonal screen and the cast steel cylinder is adjustable by a screw controlling the distance between the two halves of the screen (Fig. 201, no. 7). Although the feeding pressure of the feeding screw is constant, the pressure inside the chamber is variable because the counter pressure caused by the valve in the outlet spout can be varied by adjustment of the counter weights (Fig. 204, A). The actual pressure on the grain is the total of the feeding pressure and the counter pressure.

The rice produced by this machine is free of bran, slightly polished, and cool. However, for medium- and long-grain varieties its performance is not as good as for short grain varieties and there is a considerable increase in the amount of brokens. In addition wear on the screen is considerable and replacement cylinders are quite expensive. Both of these parts are supplied by the manufacturer and a regular supply must be available.

The Vertical Polishing Cone

This machine looks similar to the vertical whitening cone (Fig. 203); however, there are basic differences: (1) the cone itself is made of a simplified steel construction and is covered with wood on which leather strips have been nailed (Fig. 206); (2) no rubber brakes are used; and (3) the speed of rotation of the cone is about 25% lower than the whitening cone.

The feeding of the rice into the machine is identical to the method used for the whitening cone. When the rice enters the space between the cone and the wire screen, it is gripped by the leather strips that roll the grains over each other and against the leather and the wire screen. Under slight pressure the remaining bran particles are removed and the rice becomes shinier or more transparent. This machine produces few brokens and its power consumption is slightly lower than a comparable-sized whitening cone.

The Horizontal Polisher (Refiner)

The horizontal polisher was designed in Japan and actually is based on the same
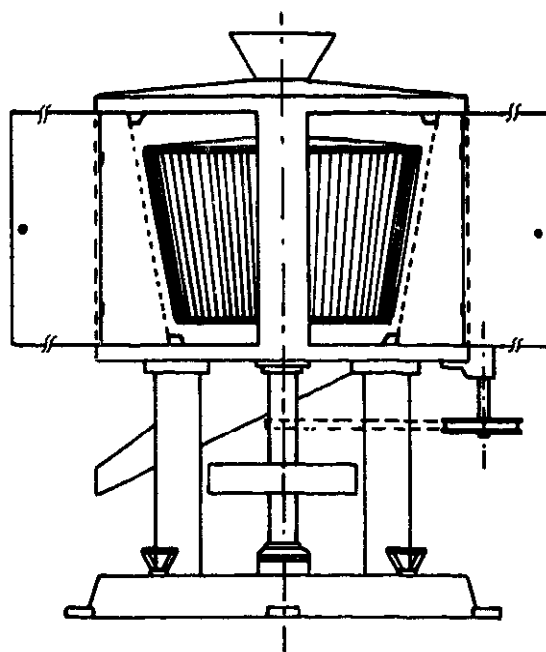
FIG. 203. Vertical polishing cor
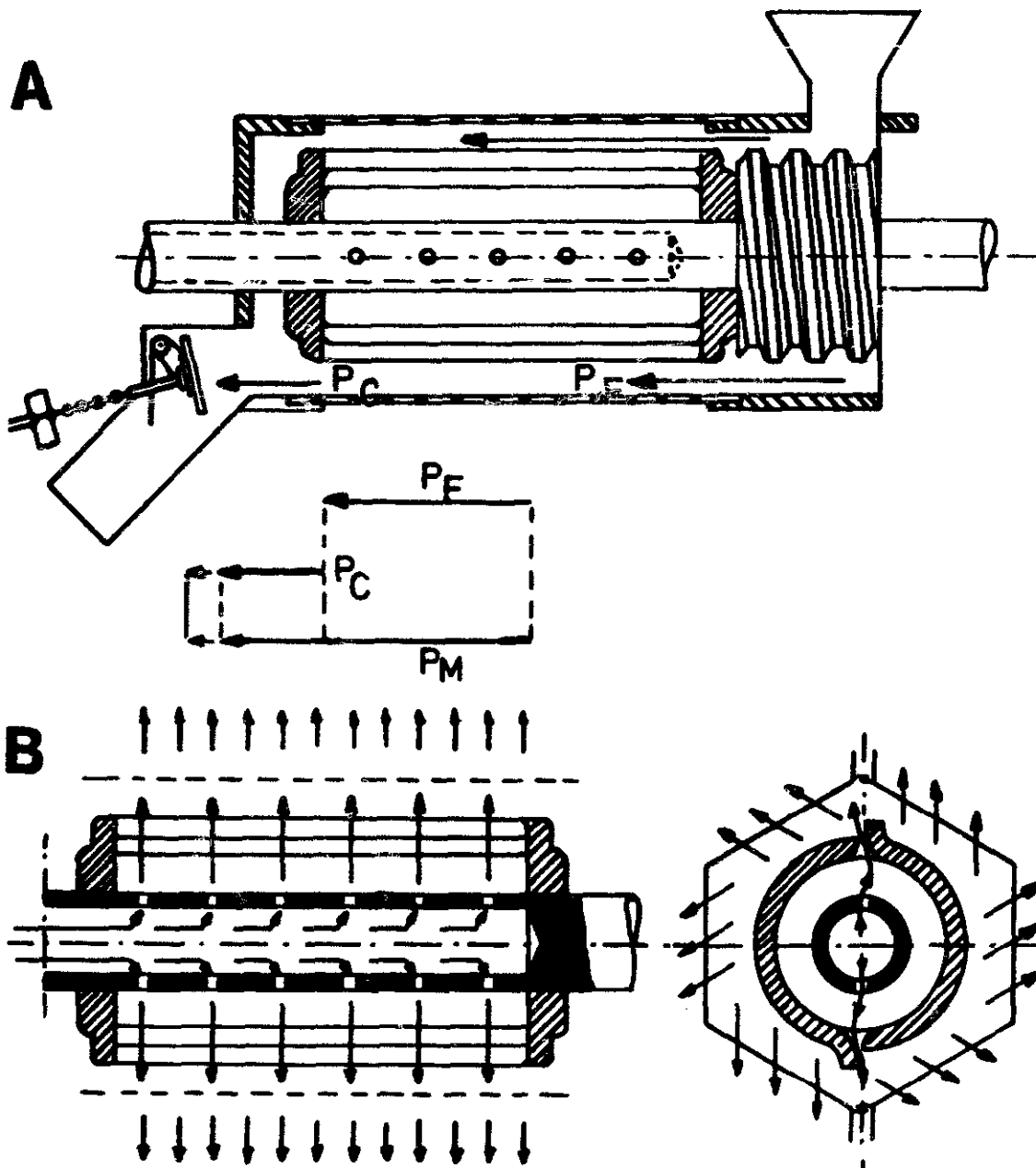
Fig. 204. (A) Counter pressure is regulated by a counter-weighted valve. Milling pressure is the sum of the feeding and counter pressures (P_F = feeding pressure = constant, P_C = counter pressure = variable, P_M = milling pressure = variable). (B) Air is forced through the hollow shaft and openings in the cylinder and removes the bran from the rice.
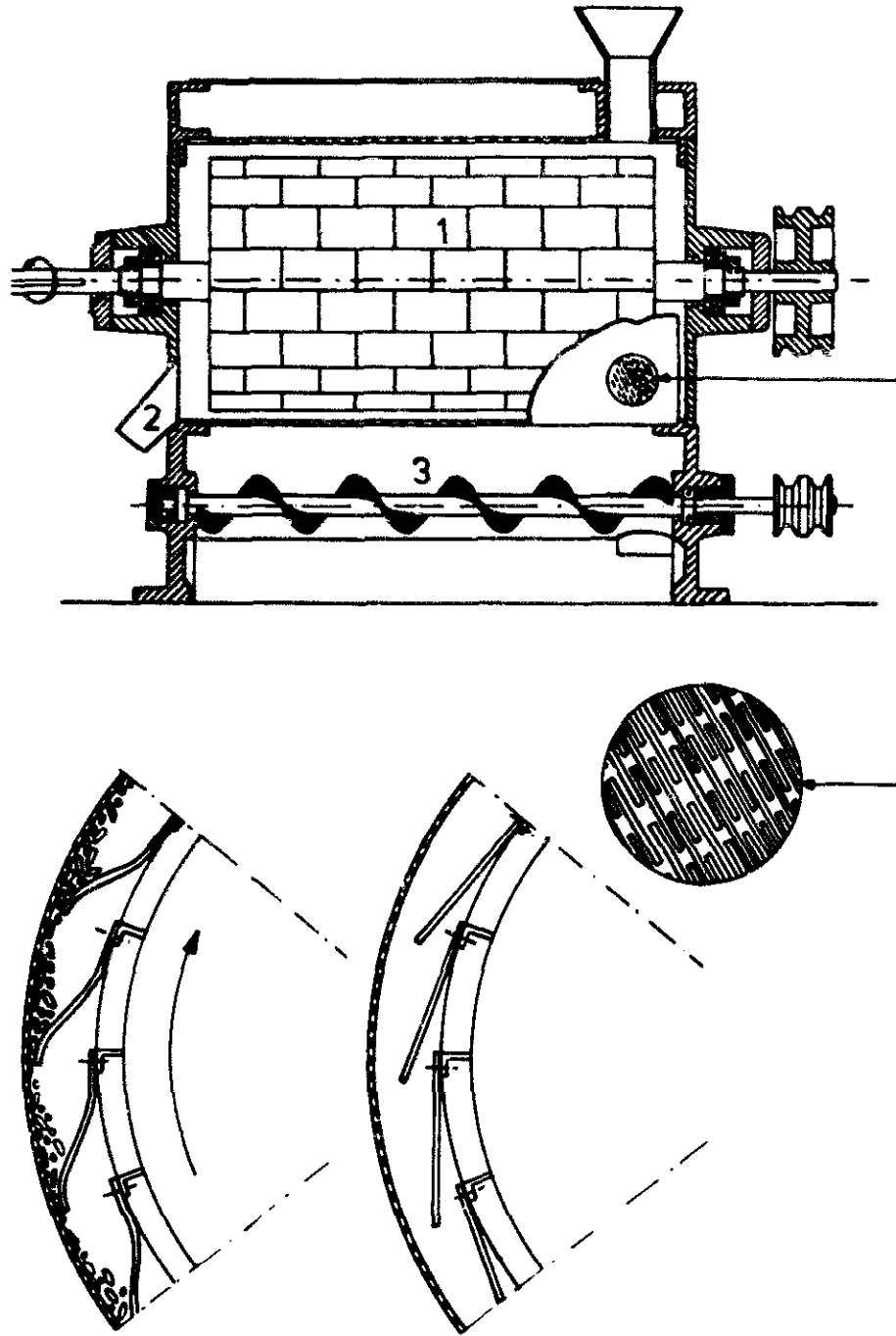
FIG. 205. Horizontal polishing machine (Satake refiner).

A

VIEW A-B

A   B

B
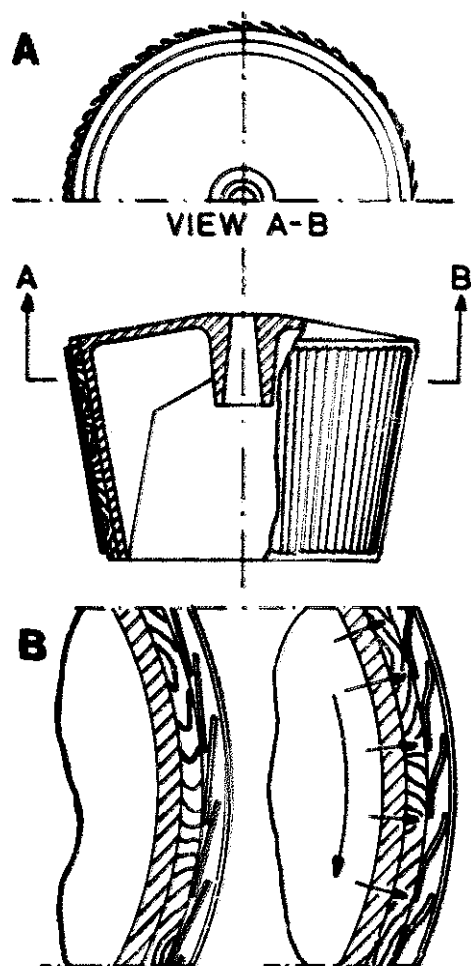
FIG. 206. (A) Cone of vertical polisher is covered with wood that has leather straps nailed to it. (B) Rice is gripped between the leather strips and the screen to remove the remaining bran and to polish the rice.

principles as the vertical polishing cone (Fig. 205).

It consists of a steel cylinder on which a large number of leather strips (8 × 17 cm) are screwed (Fig. 205, no. 1). This cylinder is mounted on a horizontal shaft that rotates inside a cylindrical chamber covered with slotted perforated screens. The polishing process is identical to that of the polishing cone. The rice leaves the machine through an outlet spout and the bran falls through the screens into a V-shaped collector for discharge by a conveyor.

The leather strips can easily be replaced and a local supply can be secured. The horsepower consumption of this machine is low compared with polishing cones of the same capacity, for example: a 2000 kg/h vertical polisher requires about 8 hp and a 2000 kg/h horizontal polisher about 5 hp. — HARRY VAN RUITEN. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Glazing

In some countries there is a special demand for glazed rice. Glazed rice is rice that appears shinier and more transparent because the surface is coated with a thin layer of talc and glucose. The glazing process is more effective on rice that is already transparent by nature than on rice that is chalky or has a white belly. Normally only head rice is glazed; however, seldom is the full head rice production of a rice mill passed through the glazing plant. Therefore, glazing installations have a capacity that is normally much smaller than the head rice production of a rice mill.

Glazing equipment is not installed as a section of the rice mill but is installed as an independent unit in a separate building or location. The main machine in the glazing plant is a large, horizontal, rotating glazing drum.

Rice is normally glazed in batches. The glazing drum is partly loaded with rice and is slowly rotated. White shiny talc powder and

a glucose solution are then added to the rice. About 1–1.2% by weight of the dry talc powder is required (10–12 kg of talc for 1000 kg of the head rice). Glucose is added to the rice as a 1:1 solution with water that is thoroughly mixed and, if possible, slightly heated. The glucose solution is either added dropwise or by a spray mechanism. About a 10% glucose solution is required (100 kg solution for 1000 kg of rice). In the final step of the process the water is evaporated and the glucose and talc remain sticking to the surface of the rice grain. Consequently, from 1000 kg of milled rice, about 1060 kg of glazed rice are produced.

horizontal position on two or three sets of rolls (Fig. 207). The rollers on one side of the drum are fitted on a shaft that is driven by a flat-belt transmission, a V-belt transmission, or an electric motor – gear box transmission.

Rice, already mixed with the talc and the glucose solution, is fed into the centre of one end of the drum (Fig. 207, no. 1). A spiral-like scoop (Fig. 208, no. 1) supports the mixing performance of the rice and gives the rice the correct direction for unloading. After 1–2 h of continuous mixing, the grain is unloaded through endsleeves (Fig. 208, no. 2) and is discharged into an elevator spout or onto a belt conveyor (Fig. 208, no. 3).

The Glazing Drum

Although many types of glazing drums have been designed they are all based on the same principle. Differences may exist in the diameter, length, shape, drive, or the unloading systems but all of the glazing drums are slowly rotating cylinders. The diameter of the drum varies between 600 and 2000 mm, and the length between 1500 and 5000 mm. The peripheral speed (V) of the drum should be about 1.3 m/s. To calculate the required speed of rotation of the drum in metres per second the relationship $V = (\pi \times D \times n) / 60$ is used. For a drum 1300 mm (1.3 m) in diameter the number of rotations per minute (n) is $(V \times 60) / (\pi \times D) = (1.3 \times 60) / (3.14 \times 1.3) = 19$ rpm.

Glazing drums are normally lined with wooden boards, and always rotate in a fully

Simple Glazing Plant (Batch Type)

A simple glazing plant (Fig. 209) consists of: (1) a bin holding the head rice; (2) a small container holding the dry talc; (3) a mixing conveyor in which the rice and talc are carefully mixed for immediate discharge into the glazing drum; (4) a container, which can be heated, that holds the glucose solution that is added to the rice on its way to the glazing drum; and (5) a horizontal rotating glazing drum.

For larger plants a fully automated glazing system can be installed. In this case, three functions of the batch-type glazing drum, mixing, drying, and cooling, are done by three dif-

Fig. 207. End view of the glazing drum showing the input in the centre of the drum (1), the endsleeves for grain discharge (2), and the rollers that the drum turns on (3).
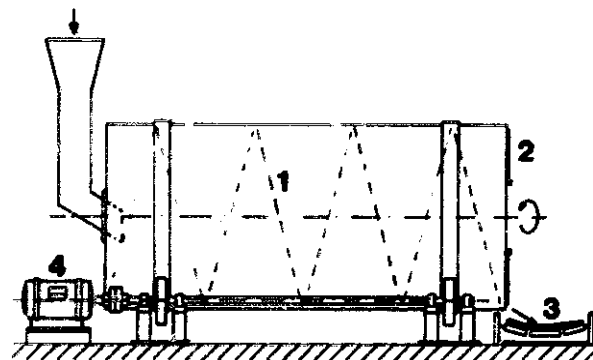
Fig. 208. Cross section of glazing drum showing the spiral-like scoop that aids mixing (1), the endsleeves (2), the belt conveyor for discharge (3), and the electric motor providing the power to turn the drum (4).
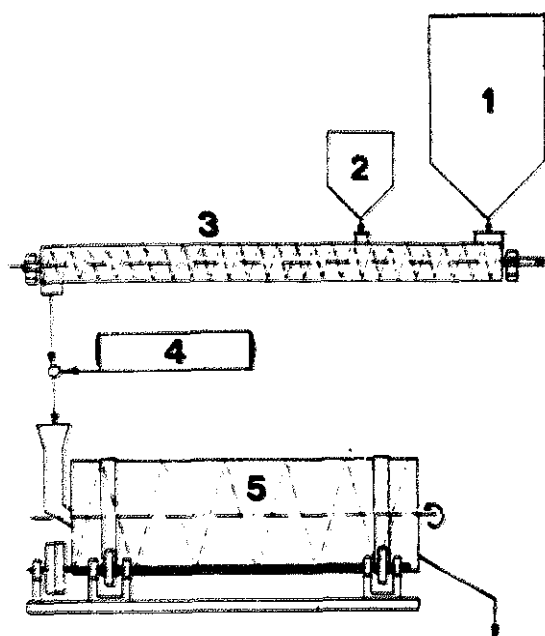
FIG. 209. Components of simple glazing plant (batch type): (1) bin holding head rice; (2) bin holding dry talc; (3) mixing conveyor; (4) container for glucose solution; and (5) glazing drum.

ferent machines. Sometimes melted paraffin is added to improve the glazing performance of the plant.

Fully Automatic Glazing Plant

Such a plant (Fig. 210) can consist of: (1) a bin holding the head rice; (2) a container holding the dry talc; (3) a talc-rice mixing conveyor; (4) a glucose-water solution container; and (5) a glazing drum that, in one slow pass, mixes the rice with the talc and the glucose solution. This drum continuously discharges the grain into a horizontal rotating mixer (6) that is indirectly heated by steam. On its way to this mixer, the rice is sprayed with heated paraffin stored in a heated container (7).

By heating the paraffin it remains in a liquid state and mixes well with the glucose. This ensures an equal distribution of this mixture over the surface of the grain and, at the same time, allows some water from the glucose solu-
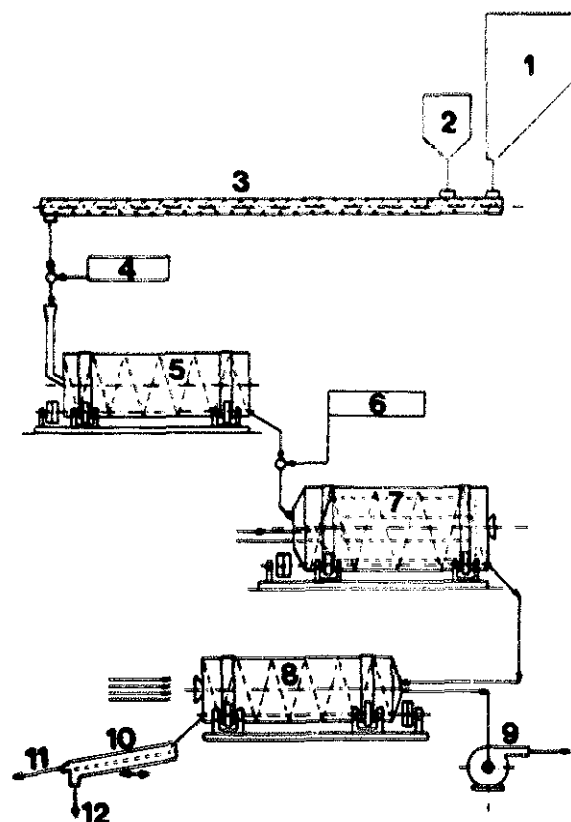
FIG. 210. Components of an automatic glazing plant: (1) bin for head rice; (2) bin for talc; (3) mixing conveyor; (4) container for glucose solution; (5) glazing drum; (6) rotating mixer; (7) heated paraffin container; (8) air-cooled mixing drum; (9) water-discharge fan; (10) oscillating sieve; (11) discharge for grains sticking together; and (12) discharge for loose glazed rice.

tion to be evaporated and partly discharged. The heated mixer continuously discharges the grain into an air-cooled horizontal mixing drum (8), where the air, sucked through the mixer, cools the rice and discharges evaporated water ; the same time (9). This air-cooled mixer . ally discharges the grain onto an oscillating sieve (10) that removes head rice grains that, in spite of the intensive mixing performance, have stuck together as a result of the added glucose and paraffin. This sieve, which is normally covered with a perforated sheet with wide slots (3.5 mm), finally pro-

duces glazed head rice grains sticking together (to be reprocessed) (11) and glazed dry loose head rice grains (12) ready for bagging or packaging. — HARRY VAN RUITEN. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Comparative Performance

The Government of India constituted a committee to study and evaluate the overall performance of seven modern rice mills set up in 1955–1966. The purpose of the committee was to compare the relative performance of these mills with the traditional sheller and huller mills based on yield and quality of rice in the various regions. Starting in 1966, the committee carried out a 2-year program of evaluation studies.

The committee was to determine the extent of the increase in the yield of total and head rice from modern mills as compared with the outturn from the existing-type sheller and huller mills in the respective region or area. The mills were to be used just as they were being operated, without any modification, improvement, or overhauling. Comparison of one modern mill with another was not included in this study.

Mill Equipment

The modern mill machinery, which was of four different makes, consisted of: a paddy precleaning system fitted with sieves, aspiration devices, and a magnetic separator; rubber roll shellers; improved husk and bran aspirators; efficient paddy separators; improved rice whiteners; bran sifters; graders; and auxiliary equipment such as elevators, con-

veyors, cyclones, and automatic paddy and rice weighing machines. The location of the mills, the capacity of the plants, and the type of equipment are given in Table 39. The mill complexes, in addition to the modern milling equipment, included other facilities for mechanical drying of field paddy, modern storage of paddy and rice, and improved parboiling of paddy followed by mechanical drying. Five of the seven integrated modern rice processing units also had silos of different designs and capacity with facilities for cleaning, drying, and mechanical conveying and handling of field paddy. The present discussion is, however, restricted to an evaluation of the mill machinery alone.

Selection of Mills

The general procedure adopted in each area was to select two or three rice mills operating in a particular region and to compare their working with that of the modern mill in that region. As far as possible, existing mills chosen for comparison had capacities similar to that of the modern mill, and representation was given to different types of existing mills such as the huller, sheller, sheller-huller, or sheller-cone-polisher type. The cooperation of the respective mill owners was a prerequisite to the selection of the mill.

Sampling of Paddy

The paddy used for each comparative trial in the different mills was obtained from a homogeneous lot varying from 20 to 50 t obtained by spreading and mixing a single commercial lot of paddy. After thorough mixing of the paddy, it was transferred to gunny bags and the bags were allotted by standard statistical techniques into experimental test lots for the various mills. Each lot represented a run of 1 or 2 h for the respective mills. Normally, there was a minimum of three replications in the earlier studies for each mill. This was increased to five in the studies carried out at Mandya and Raipur.

TABLE 39. Location of mills, capacity of plants, and types of equipment.

Location	Name and address of owner	Size and type of rice mill
Tiruvarur, Thanjavur District, Tamil Nadu	Tanjore District Cooperative Marketing Federation Ltd., Tiruvarur, Thanjavur District	4-t Schule mill from West Germany
Raipur, Madhya Pradesh	Raipur Vikas Khand Sahakari, Vipnan Sanstha Simit, Raipur	2-t Schule mill from West Germany
Tadepalligudem, West Godavari District, Andhra Pradesh	West Godavari District Cooperative Marketing Federation Ltd., Eluru, West Godavari District	4-t Satake mill from Japan
Memari, Burdwan District, West Bengal	West Bengal Apex Cooperative Agricultural Marketing Society, 3-Dalhousie Square, East Calcutta	2-t Satake mill from Japan
Mandya, Mysore State	The Ryots' Agricultural Produce Cooperative Marketing Society, Post Box No. 10, Mandya	1-t Satake mill from Japan
Bikramganj, Shahabad District, Bihar State	Government of Bihar, Patna	2-t Kyowa mill from Japan
Bargarh, Sambalpur, Orissa State	Regional Cooperative Marketing Society Ltd., Bargarh	1-t GDR mill from German Democratic Republic

Milling Procedure

Before each test run for a particular variety of paddy, there was a trial run carried out with the same lot of paddy that was to be put through the mill. This allowed setting of the units, filling of empty spaces of the conveying system, flushing of previous lots of rice, approximating the adjustment of the clearances of the sheller and polisher, and ascertaining that the mill was in a fit condition to undertake the tests. After this trial run, a weighed quantity of paddy from each test run was fed into the mill and records were kept of all the mill products and by-products including the impurities, rice brokens, and different types of bran. In the case of purely huller-type mills, bran could not be weighed separately because the bran and husk were mixed and it was not possible to separate one from the other.

The degree of polish given to rice from the same variety or lot of paddy was fixed at 4% since under the regulations in force, the degree of polish has to be maintained at this level.

The Government of India has enforced this rule to increase the availability of rice. The degree of polish was adjusted by visual comparison to be very nearly the same as that of a standard, prepared for the purpose, using either a laboratory mill or in a few cases a modern mill. Differences often arose in adjusting the degree of polish due to personal variations in visual judgement. To obviate and correct such differences, the bran removed during milling was weighed, analyzed for its content of bran (after allowing for weight of brokens and husk), and suitable adjustments in weight made to ensure that samples so drawn had an equal degree of polish. This method suffered from certain limitations as bran could not be weighed in the case of huller mills. Moreover, some polishing occurs during shelling in disc sheller units and the sheller bran gets mixed with powdered husk, paddy dust, broken rice, and the awns of the paddy. It is, therefore, difficult to measure the sheller bran accurately. However, the amount of real bran in the sheller bran samples was roughly estimated

and necessary allowances were made, while making adjustments for equal degrees of polish.

Laboratory Analysis of Milled Rice

Representative samples of milled rice and milled brokens from each mill prepared by a Boerner sample divider were recombined in the proportion that the mill delivered to derive composite samples of the total mill outturn. These samples were subjected to quality analysis in the laboratory for impurities, bran, and brokens. Based on these data, calculations were made for clean edible rice free from impurities, and also for head and broken rice. Bran samples from the mill were also analyzed by a sieve-cum-aspiration procedure and necessary allowances were made for the amount of husk and brokens, while calculating the true bran weight.

A McGill sheller, a McGill polisher, and a sizing device were used for determining the amount of rice outturn recoverable in the laboratory. This amount was designated as the potential outturn of each representative lot of paddy. The percentage of rice outturn in the test mill was designated as mill efficiency. It was anticipated during the planning of these experiments that these mill efficiency values could also be utilized for the comparison of one modern mill with another. The large amount of data collected during the course of laboratory and mill analyses on various samples of paddy shows that variations do take place from run to run. Unless the laboratory determinations are replicated several times, and an efficient method of removal of unshelled paddy from unpolished rice during shelling is available, comparison of mills in terms of their mill efficiency ratios cannot be regarded as statistically accurate. Although the committee had all the data at its disposal, it was decided not to present the data on mill efficiency ratios for the various mills; therefore, data reported here pertain to direct comparisons between traditional and modern mills.

Calculations

Based on the mill and laboratory data, the percentage of total rice and the head rice out-

turn for each variety of paddy were calculated and all calculations were subjected to statistical analysis. Wherever large variations among replicate determinations were noticed, they were not included in the statistical analysis. Arithmetical average values were presented in such cases. The decision to exclude such mills from this analysis was made by the committee as it was thought that their inclusion would influence the results of statistical analysis of other mills experimented upon in the region.

Calculation of the outturn from huller mills presented certain difficulties because huller mills cannot deliver rice from paddy when the rice is milled to the standard degree of 4% polish used throughout the present experimental runs. The amount of paddy coming out with the rice at this level of polish varied from 5 to 10% in the case of raw paddy and 0.5 to 6.0% in the case of parboiled paddy. This proportion of paddy was subtracted from the rice output to arrive at the outturn; the percentage of paddy in the rice is indicated in parenthesis (Tables 40 and 41).

Economic Comparisons

An economic comparison has been made to determine the effect of differences in rice outturn on investment and operation costs (Table 42). This comparison is for the rice mill only. It does not reflect the cost of returns of mechanical drying, storage, or parboiling. Neither does it reflect the difference in quality of rice outturn, since the market value of the rice was a fixed price.

Summary of Results

Although the average milling outturn of total and head rice obtained for the different mills and the variation in yields are not given in this report, details may be obtained in a Government of India Report (Wimberly 1971).

The data have been statistically analyzed. Where individual variations among replicates were very large, only average results have been presented without testing for statistical sig-

and necessary allowances were made, while making adjustments for equal degrees of polish.

Laboratory Analysis of Milled Rice

Representative samples of milled rice and milled brokens from each mill prepared by a Boerner sample divider were recombined in the proportion that the mill delivered to derive composite samples of the total mill outturn. These samples were subjected to quality analysis in the laboratory for impurities, bran, and brokens. Based on these data, calculations were made for clean edible rice free from impurities, and also for head and broken rice. Bran samples from the mill were also analyzed by a sieve-cum-aspiration procedure and necessary allowances were made for the amount of husk and brokens, while calculating the true bran weight.

A McGill sheller, a McGill polisher, and a sizing device were used for determining the amount of rice outturn recoverable in the laboratory. This amount was designated as the potential outturn of each representative lot of paddy. The percentage of rice outturn in the test mill was designated as mill efficiency. It was anticipated during the planning of these experiments that these mill efficiency values could also be utilized for the comparison of one modern mill with another. The large amount of data collected during the course of laboratory and mill analyses on various samples of paddy shows that variations do take place from run to run. Unless the laboratory determinations are replicated several times, and an efficient method of removal of unshelled paddy from unpolished rice during shelling is available, comparison of mills in terms of their mill efficiency ratios cannot be regarded as statistically accurate. Although the committee had all the data at its disposal, it was decided not to present the data on mill efficiency ratios for the various mills; therefore, data reported here pertain to direct comparisons between traditional and modern mills.

Calculations

Based on the mill and laboratory data, the percentage of total rice and the head rice out-turn for each variety of paddy were calculated and all calculations were subjected to statistical analysis. Wherever large variations among replicate determinations were noticed, they were not included in the statistical analysis. Arithmetical average values were presented in such cases. The decision to exclude such mills from this analysis was made by the committee as it was thought that their inclusion would influence the results of statistical analysis of other mills experimented upon in the region.

Calculation of the outturn from huller mills presented certain difficulties because huller mills cannot deliver rice from paddy when the rice is milled to the standard degree of 4% polish used throughout the present experimental runs. The amount of paddy coming out with the rice at this level of polish varied from 5 to 10% in the case of raw paddy and 0.5 to 6.0% in the case of parboiled paddy. This proportion of paddy was subtracted from the rice output to arrive at the outturn; the percentage of paddy in the rice is indicated in parenthesis (Tables 40 and 41).

Economic Comparisons

An economic comparison has been made to determine the effect of differences in rice outturn on investment and operation costs (Table 42). This comparison is for the rice mill only. It does not reflect the cost of returns of mechanical drying, storage, or parboiling. Neither does it reflect the difference in quality of rice outturn, since the market value of the rice was a fixed price.

Summary of Results

Although the average milling outturn of total and head rice obtained for the different mills and the variation in yields are not given in this report, details may be obtained in a Government of India Report (Wimberly 1971).

The data have been statistically analyzed. Where individual variations among replicates were very large, only average results have been presented without testing for statistical sig-

TABLE 40. The mean average percentage of additional outturn of total rice obtained in modern mills compared with traditional mills in each area.

Area and location of mill	Parboiled paddy[a]		Raw paddy[a]	
	Sheller	Huller	Sheller	Huller
Tamil Nadu (Tiruvarur)	—	—	4.2 (1.8)	5.3 (2.5)
Madhya Pradesh (Raipur)	0.9	2.5 (0.6)	2.7	12.5 (13.0)
Mysore (Mandya)	0.4	2.5 (0.9)	0.8	10.4 (9.8)
West Bengal (Memari)	—	0.3 (0.3)	2.8	6.8 (2.0)
Andhra Pradesh (Tadepalligudem)	0.8	—	2.9	—
Orissa (Bargarh)	1.3	1.5	1.8	1.8
Bihar (Bikramaganj)	—	1.4	—	2.6 (2.3)
Mean average percentage of additional outturn of rice of all areas	0.8	1.6 (0.6)	2.5	6.6 (6.8)

[a]Figures in parenthesis represent the percentage of paddy in the milled rice obtained in the huller mills; they have been subtracted from the milled rice output when calculating rice outturn.

NOTE: The mean average percentage of the additional outturn obtained in the modern mills has been worked out as the arithmetic average of the individual differences obtained from the different varieties of paddy and over different mills.

TABLE 41. The mean average of additional outturn of head rice obtained in modern mills compared with traditional mills in each area.

Area and location of mill	Parboiled paddy[a]		Raw paddy[a]	
	Sheller	Huller	Sheller	Huller
Tamil Nadu (Tiruvarur)	—	—	12.4 (1.8)	18.5 (2.5)
Madhya Pradesh (Raipur)	2.0	6.2 (0.6)	6.2	24.7 (13.0)
Mysore (Mandya)	0.8	8.5 (0.9)	3.1	20.1 (9.8)
West Bengal (Memari)	0.9	1.0 (0.3)	5.0	10.4 (2.0)
Andhra Pradesh (Tadepalligudem)	0.1	—	1.9	—
Orissa (Bargarh)	2.5	2.5	7.6	10.0
Bihar (Bikramganj)	—	2.5	—	6.9 (2.3)
Mean average percentage of additional outturn of head rice of all areas	1.3	4.1 (0.6)	6.11 (1.8)	15.1 (6.8)

[a]Figures in parenthesis represent the percentage of paddy in the milled rice obtained in the huller mills; they have been subtracted from the milled rice output when calculating rice outturn.

NOTE: The mean average percentage of the additional outturn obtained in the modern mills has been worked out as the arithmetic average of the individual differences obtained from different varieties of paddy and over different mills.

nificance. Studies with parboiling and sheller mills could not be included in every case as these facilities were not available at some locations at the time of evaluation. A summary of the average increase in milling outturn of total and head rice for each modern mill over sheller and huller mills for raw and parboiled paddy is given in Tables 40 and 41.

Conclusions

The modern mills have an overall increase in total rice outturn averaging 2.5% (0.8–

4.2%) over sheller type units and 6.6% (1.8–12.5%) over huller units with respect to raw paddy. In the case of parboiled paddy, the corresponding increase in total rice yields from the modern mills averaged 0.8% (0.0–1.3%) over the sheller mills and 1.6% (0.3–2.5%) over the huller units.

The increase in head rice yield for raw paddy in the modern mills as compared with existing sheller mills averaged 6.1% (1.9–12.9%), as compared with huller mills, with a corresponding average increase of 15.1% (6.9–24.7%). For parboiled paddy, the correspond-

TABLE 42. Costs and returns in Indian rupees of different types of rice mills (each mill has 1 t/h capacity and mills 6000 t annually).

	Modern mill	Disk sheller	Huller
Investment cost[a]	90 000	65 000	22 500
Annual operation cost[b]	66 400	50 400	49 200
Paddy cost[c]	3 000 000	3 000 000	3 000 000
Total annual investment	3 066 400	3 050 000	3 049 200
Annual sales[d]	3 360 000	3 264 000	3 120 000
Annual returns	293 600	213 600	70 800

[a]Indian rupees: Rs. 7.5 = $1.00.
[b]Operation cost includes: power, labour, maintenance, depreciation, and interest. Huller rice mill, Rs. 8.20/t of paddy; disk sheller rice mill, Rs. 8.40/t of paddy; and the modern rice mill, Rs. 11.07/t of paddy (this includes Rs. 16 000/year for rubber rollers).
[c]Each rice mill mills 6000 t of paddy per year at Rs. 500/t.
[d]Rice sales at Rs. 800/t of rice. Total milling recovery of modern mill is 70%, of sheller mill 68%, and of huller mill 65%.

ing increase over sheller units averaged 1.3% (0.8–2.5%) and over huller mills 4.1% (1.0–8.5%).

Apart from giving significantly higher outturn of total edible rice and head rice, the modern mills yielded rice of superior quality with less brokens and a negligible incidence of foreign matter. — JAMES WIMBERLY, IRRI – Ford Foundation Sri Lanka, Rice Processing Project, Colombo, Sri Lanka.

HANDLING
and CONVEYING

Methods

and

Systems

Harvested grain is transported, threshed, cleaned, and moved to a grading point, either manually in bundles or in sacks, or mechanically by combines that simultaneously accomplish the intermediate processes of threshing and cleaning while in transit. Tractor-drawn endless conveyors may also be used.

In tropical countries, simple grain cleaners are needed during threshing, before and after drying, and prior to milling and processing. Conventional winnowers popular in Asia clean grain by exposing it for a short duration to a high velocity airstream. These winnowers do not satisfactorily remove large straw, chaff, and unfilled grain from mature grain.

A popular winnower design in Asia consists of a paddle-type blower in a wooden housing, which directs the air against grain falling from a hopper. Baffles are used to separate the impurities from cleaned and semicleaned paddy. Semicleaned paddy is recycled through the winnower for further cleaning. The use of high air velocities to obtain a satisfactory degree of cleaning results in excessive loss of grain with the impurities.

Grain cleaners popular in the industrialized countries clean the grain in two stages: (1) the grain passes through a set of oscillating screens to remove the larger impurities; and (2) the grain falls through a high velocity air blast to remove the lighter impurities. Oscillating screens are often a source of mechanical problems and do not perform well when excessive amounts of straw and other large impurities are present in the grain. The short-duration exposure of the grain to the air blast does not satisfactorily remove all the unfilled, immature kernels.

Grain (especially seed grain) is moved in sacks as well as in bulk. The sack moving equipment establishes a connection between stories of the granaries and is used in part for sack loading of vehicles. Automatic loaders and lift trucks are used on the farms of large seed-producing firms and at railway goods stations, but the use of these machines is uneconomical within small agricultural enterprises (United Nations 1960).

The capacity of the vehicles serving the granary determines the maximum number of vehicles (30 an hour) that can be used, given proper organization. Immobilization due to waiting, turn-around, and movement of vehicles, together with stoppage, account for 30–40% of working time. The economic efficiency of vehicle operation is also influenced by the nature of the handling equipment in the granaries.

Large farms permit full use of vehicles and power loading devices. On small farms, physical labour is made easier by the use of a simple winch-operated mechanical shovel, which has a maximum capacity of 5–10 t/h for a motor rating of 4.5 kW.

However, in traditional rice countries of Asia, the following methods still prevail (FAO 1967–1968). Transportation of stack paddy is by shoulder poles for short distances. Over long distances the paddy is transported by means of boats, sledges, buffaloes, tractor-drawn carts, and in some cases by small hand-drawn carts mounted on bicycle wheels. Assuming an average production of 2.4 t of stack paddy per hectare, the transportation to remove the crop from 1 ha requires approximately 60 shoulder-pole loads; 30 sledge loads; 6 ox-cart loads; or 12 hand-operated cart loads.

When electrical energy is available many machines can be conveniently located on the farms. However, in developing countries rural electrification is limited and small gasoline engines are generally used. Small low-head hydraulic plants may become useful.

The handling of bulk grain in rice mills involves the movement of large quantities of material in both the horizontal and vertical directions. The rate at which grain is handled depends upon the capacity of the storage

facility and the type of operation being con-
ducted. The conveying equipment must be
selected and sized to meet the requirements of
each particular operation.

A conveyor is a mechanism that moves ma-
terial from one location to another in a con-
tinuous manner. Bulk grain handling systems
utilize one or more of the following types of
conveying equipment: (1) screw conveyor; (2)
chain conveyor; (3) belt conveyor; (4) bucket
elevator; (5) vibrating conveyor; (6) pneumatic
conveyor; and (7) lift trucks.

Screw Conveyor

The screw conveyor is one of the oldest and
simplest methods of moving bulk materials. It
is a helix formed from a flat steel bar mounted
on a pipe or shaft that is equipped with sup-
porting brackets and bearings (Fig. 211). This
screw operates in a U-shaped trough for hori-
zontal conveying jobs, and in cylindrical tubes
for vertical or inclined movement. The screw
conveyor is simply constructed, inexpensive,
and because it can be used in any position, it
is easily adaptable to congested conditions.

Capacities of conveyors in cylindrical hous-
ings depend upon the auger diameter, operat-
ing speed, and angle of inclination (Fig. 212).
Horsepower requirements are greatest with
augers operating at angles of 30–60°.

Chain Conveyor

Chain conveyors are made in a variety of
types for a variety of purposes. They are slow-
moving and are often characterized by high
power requirements. The drag or scraper con-
veyor is one of the common types. Depending
upon the use to be made of the elevators, drags

FIG. 211. Helix of screw conveyor

of varying shapes are mounted between two
chains that are driven over end sprockets. The
conveyor may operate horizontally or on a
maximum inclined plane of about 45°. The
capacity of such a conveyor should be in-
creased by using larger flights rather than by
increasing the speed.

Belt Conveyor

A belt conveyor is an endless belt that oper-
ates between two pulleys and is carried by
idlers that support the belt and its load. It is
mechanically efficient, especially with anti-
friction idlers. Its power requirement is low,
it is dependable, and it will handle practically
any type of material. If the belt is the proper
size and has the correct idlers, ear corn, grain,
and even bagged seed can all be handled on the
same unit. The belt can be self-cleaning but
usually is not in storage facilities. The initial
cost of a heavy-duty, high-capacity installation
is rather high; on the other hand, many small
units employed in storage and milling facilities
are relatively inexpensive.

The essential parts of a belt conveyor are the
belt, the drive and the driven pulleys, the
tension adjustment, the idlers, and the loading
and discharging devices. The belt must be flex-
ible enough to conform to the shape of the
pulleys and idlers, strong enough to carry the
load, and wide enough to deliver the capacity
wanted. The drive should be at the discharge
end of the belt and may be a conventional type
of belt drive. The diameter of the drive pulley
must be large enough to provide adequate con-
tact with the belt. An idler can be used to pro-
vide more wrap contact with the drive pulley.
The take-up or tension adjustment may be
by manual or automatic screws on the foot
pulley or on the idling pulley.

In simple installations, on short conveyors
and with narrow belts, the load-carrying por-
tion of the belt may be a smooth wood or steel
surface; whereas, in installations involving
heavy loads or long distances, anti-friction
idlers support the belt. When the belt is
"troughed" by conforming to the shape of the
load-carrying idlers, the width and cross-
sectional shape of the trough determine the
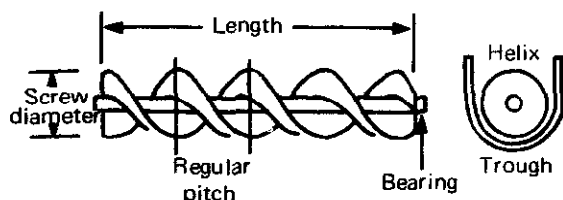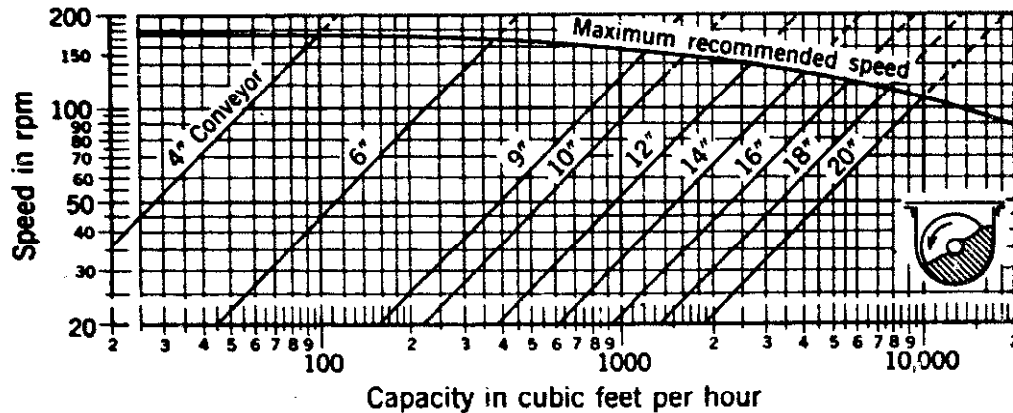
FIG. 212. Relationship between capacity and speed of a screw conveyor.

load that can be placed upon the belt (Fig. 213). Because of the cost of anti-friction idlers and the high per foot cost of wide belts, the majority of belt conveyors used in small facilities are supported by the floor of a flat-bottomed trough with vertical or angled sides that increase the capacity. Although the belt is self-cleaning, the trough often is not. Belt elevators may operate on an inclined plane of about 15°, but if the belt is equipped with flights the angle may be increased.

Material may be discharged over the end of the belt or along the sides by using diagonal scrapers or by tilting the belt. The most satisfactory way to empty a troughed belt is to use a tripping mechanism. Such a mechanism consists of two idler pulleys that cause the belt to take the shape of an S (Fig. 214). The material is discharged over the top pulley and to the side by a chute. Trippers are usually mounted on tracks so that they can be positioned any place along the length of the belt.

Tripslingers, with a high-speed reversing belt that gives left or right 90° discharge, are available to spread the grain over a wider area. Storage capacities can be substantially increased with this type of unit.

FIG. 213. Troughed and flat idler pulleys for belt conveyors. The straight pulley is used for the empty belt return and infrequently for carrying the load.

Bucket Elevator

If a belt or a chain conveyor was placed in a vertical position and buckets were attached to it at regular intervals, the result would be a bucket elevator (Fig. 215). A bucket elevator consists of: (1) a belt or chain(s) with buckets; (2) head and foot pulleys or sprockets; and (3) a method for feeding and discharging the load. The assembly is usually, but not always, enclosed by a steel or wood casing. The up- and down-legs may be enclosed in the same or separate casings. This kind of elevator is widely used in industry, in grain handling, and in seed processing. Belt-
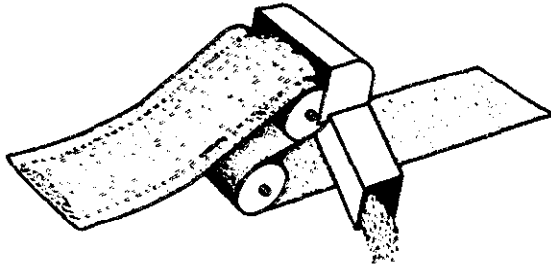
FIG. 214. Operational principle of the tripper.

type bucket elevators are quiet, efficient, and long-lasting. The chief disadvantages of some designs are: (1) the speed may damage the seed; and (2) enclosed units are difficult to clean. Feeding may be accomplished on the down- or up-leg in some types, on the up-leg only in other types. The belt can be tightened either by screw or by gravity on the foot or head pulley; however, for belts handling grain and seed the adjustment is usually on the foot pulley.

Based upon the method of discharge, bucket elevators may be classified into four types.

Centrifugal Discharge

This is the type most commonly used in the handling of free-flowing materials. Because discharge from the buckets is dependent upon both centrifugal force and gravity, the shape of the bucket, the speed and radius of the head pulley, and the position and angle of the chute must all be in the proper relationship for efficient operation. Elevators operated slower or faster than the speed for which they were designed cause back-legging, and excessive speed results in increased damage during pick-up and discharge.

If the foot pulley is smaller than the head pulley it is desirable to fill on the up-leg side of the elevator above the centreline of the foot pulley, because centrifugal force is zero on the portions of the belt not in contact with the pulley.

Bucket shapes vary with the manufacturer. They are ordinarily constructed of steel, less frequently of plastic or fibreglass. Centre spacing of the buckets depends upon their size, shape, belt speed, and the diameter of the head and foot pulleys.

Positive Discharge

The buckets on a positive or perfect discharge elevator are usually mounted on a pair of chains. They move slowly and are designed so that the material drops, without benefit (or interference) of centrifugal force, from each bucket to a chute positioned to accept the discharge. In some designs the material is scooped from the boot, whereas in others it is fed directly into the buckets. This elevator is often used on materials that are light, friable, easily damaged, or do not discharge readily from a centrifugal elevator.

Continuous Buckets

In this elevator the buckets are usually mounted as close together as possible on a chain(s). During discharge the material flows over the specially shaped bottom of the preceding bucket. This is a slow moving elevator that will handle a variety of materials, the most common being sand and gravel.

Internal Discharge

This is a continuous-type elevator in which loading and discharge take place from the inside of the bucket line rather than from the periphery. The buckets are so designed and positioned that they overlap during loading. Both loading and discharge may be accomplished from either side of the elevator. Some elevator designs use one foot and one head shaft, others are equipped with one foot and two head shafts, and still others have two foot and two head shafts. Some elevators are cased, some are not.

Vibrating Conveyor

Vibrating conveyors, also called oscillating or shaker conveyors, move materials uniformly in a continuous flow along a metal trough. The trough is mounted on rigid inclined toggles and is usually driven by a constant stroke eccentric drive. The horizontal motion resulting from the eccentric is transformed into an upward and forward pitching action by the
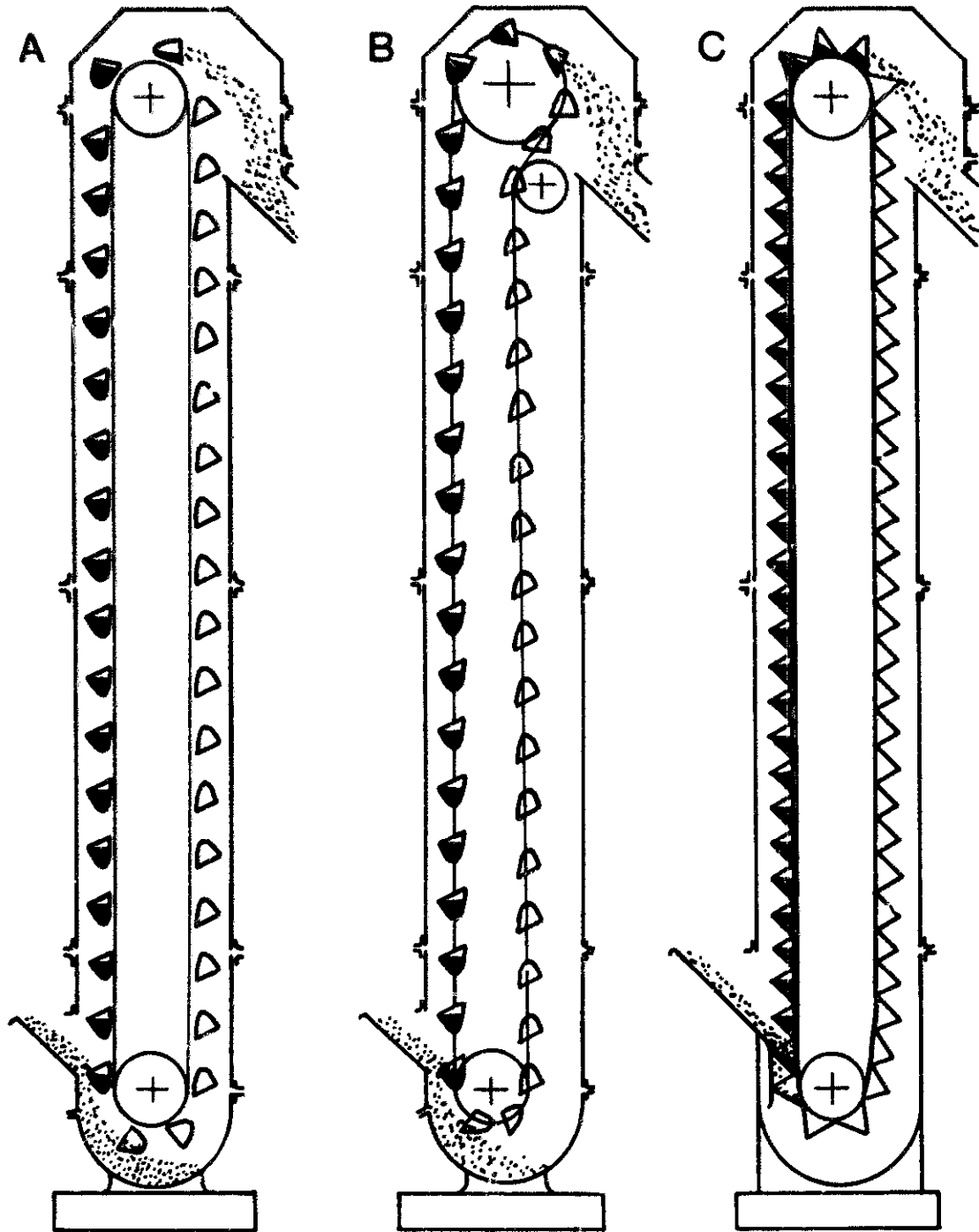
FIG. 215. Bucket elevators: (A) spaced-bucket centrifugal-discharge; (B) spaced-bucket positive-discharge; and (C) outside discharge, continuous.

inclination of the toggles. The material to be conveyed moves up and forward with each vibration while the trough returns backward and down. The result is a series of rapid pitching actions that produces a total net movement of the material toward the discharge end of the trough. Short feeding-type conveyors are sometimes powered by an electromagnet that can produce differing rates of vibration depending upon the rate of feed desired.

Pneumatic Conveyor

A pneumatic conveyor is a device that conveys materials as a result of a high velocity airstream. It has certain advantages that make it a suitable means for handling grain: (1) it is self-cleaning; (2) it has few moving parts; and (3) it may be installed around present equipment. This type of conveyor for grain, however, has two major disadvantages: (1) low mechanical efficiency; and (2) high probability of material damage.

The pneumatic conveyor is composed of: (1) conveying pipes and elbows; (2) equipment for entering grain into the systems; (3) some means for separating grain from the airstream; and (4) a fan or blower. These conveyors are classified with respect to the static pressure within the pipe, namely, negative or positive. The system is negative when the pressure in the conveying pipe is less than atmospheric pressure because the air-moving device is installed on the exhaust end of the system. The system is positive when the fan is installed upstream of the point where grain enters the pipe and the pressure is greater than atmospheric pressure.

Lift and Carrying Trucks

Lift trucks have several advantages that should be considered. With an adequate number of well-constructed and properly-sized boxes or trailers, they can double both as conveyors and as storage units. A lift truck is especially useful where a large number of lots are to be handled. Boxes or wagons equipped with perforated false floors provide excellent temporary storage bins prior to storage and processing. Lift boxes will substitute for a large number of permanent bins and will make it unnecessary to handle uncleaned grain in bags. By the use of pallets, the truck that carries the boxes can also transport and stack the bagged milled grain. — JAMES M. BECK. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

IMPLEMENTATION

Communication

The entire rice industry is made up of people. People produce the rice grain, process it, market it, and also eat it. Therefore, the technology of increasing rice productivity and minimizing postharvest losses in Asia must include the social technology of influencing human behaviour. In communication parlance, storage bins, columnar driers, and cono mills are the hardware of the rice processing technology. Equally important is the software, or the managament of human resources in the rice processing industry. These human resources are not only the people who will run the modern rice plants but also those who now operate existing processing facilities and even those who plant rice and eat rice. The art and science of getting all these people to understand, accept, adopt, and promote the improved rice processing technology come under the general heading of communication.

You may be saying to yourself, "But that's extension she's talking about." Yes, it is also extension I am talking about because extension is communication in the agricultural context. By communication, we mean that process by which individuals and social systems interact and affect or influence each other. Extension, therefore, is communication, but communication is not extension alone.

The kind of communication we are interested in aims at achieving certain objectives. Call it purposive or persuasive communication; call it development communication or agricultural extension, if your target is the rural family; call it advertising if you are wooing the consumer. In business circles it is called public relations or human management. The different names describe the same process: affecting or influencing people for some purpose of the communicator.

Using the communication approach, we can look at most situations as communication situations that can be analyzed into three basic parts: a source; a message; and a receiver. Linking these three horizontally, we already have a simple communication model. We can add another element to this model – the channel. The relationship between source, message, channel, and receiver can be verbalized in yet another way: "Who says what to whom through which channel." Implicit in this relationship is the communicator's purpose, which is to achieve some effect.

Our simple model can accommodate communication acts of different types. Communication can mean a face-to-face talk with a farmer, a whole extension service trying to promote better living for its clientele, or a national government preaching the gospel of development to all sectors of the citizenry. The communication process works essentially the same way for a barrio teacher teaching arithmetic to third graders or, at a higher level, for the educational hierarchy of a nation socializing its young population.

You can consider a training course as a communication situation where you are the receiver and the lecturers are the communication source. The message is the entire gamut of the rice processing technology that you are exposed to. When the training is over, you, in turn, become the source of the same message. Then you may ask yourself this question in preparation for the job you have to do: "To what groups of people; where; with what existing state of innovation awareness; what indigenous leadership/communication structures; what available material resources plus planned project inputs; and what existing socioeconomic practices; must the new ideas, attitudes, and specific techniques on rice processing be conveyed; when in relation to the project's target phrases; by whom and using what media?" (Childers and Vajrathon 1969).

This question breaks down into several steps: (1) identifying the groups of people that you must reach, including those who will adopt the rice processing technology as well as those who may influence, or provide the means that will make possible, the decision to adopt its various components; (2) assessing each group's state of knowledge and attitudes about rice processing; (3) assessing their habits and practices in relation to rice processing and allied

areas; (4) assessing their physical and economic resources; (5) identifying their leadership and communication patterns; (6) deciding what other material resources you must put in to augment existing ones; (7) designing the set of messages for each group that will help change its state of knowledge and attitudes, and/or teach it new skills about rice processing; (8) deciding the best combination of methods, strategies, and channels that will effectively transmit each set of messages; and (9) deciding the sequence of these activities and scheduling them in your project timetable.

Steps 1 to 5 have to do with your receiver or audience. As the terminal link in the communication chain and, therefore, the most crucial, the receiver of your message merits your most detailed study. A cardinal rule of communication is "know your audience." Only by knowing your audience can you devise suitable strategies that can affect or influence them.

It is often said that people are unpredictable creatures. This is true to a certain extent, but is sometimes said when what is meant is that people are not rational creatures. They are not always moved by reason or what to us seems reasonable; however, when we dig deeper, we find that people do have reasons for what, on the surface, seems unreasonable behaviour. It is by studying people as individuals and as members of groups that we can ferret out the reasons why they resist change.

When you offer people something new, when you introduce an innovation, more often than not you are asking them to exchange the familiar for the unfamiliar. If change does not go against practices backed by deep-seated attitudes and values, it will be relatively easy to communicate, but if it strikes at a practice or idea that is embedded in the way of life of a people, so that replacing it will wrench at the whole fabric of the social system, then it is natural that people will resist the change.

In Laguna, for example, rice stalks are harvested long because this is required for hand-threshing with the hampasan. On the other hand, many imported threshers are designed to process rice stalks cut short. The Laguna harvester has no reason to cut the stalks short since this would double his work. What is more, there would be no need to,

unless the farm owner mechanizes his threshing, and he may not be prepared to do this for several reasons.

To harvest his crop, the farm owner contracts a group that also weeds the crop in the bargain. If he mechanizes his threshing, he loses his weeders. He also deprives his neighbours of their livelihood which, again, he may not be prepared to do because he has a social conscience or because he wants to keep his neighbours' goodwill. Besides, does he really need a thresher? He may feel that for his present volume of produce, a manual thresher does well enough.

A small Laguna farmer, therefore, under the present scheme of things, may not feel any need for a mechanical thresher. But a small, cheap drier may be something else. The small farmer who, season after harvest season, anxiously scans the skies for signs of impending rain that, in a matter of hours, can destroy the labour of months, does not need much convincing about the worth of a small drier. This small farmer may feel a distinct need for a small drier. He may feel little need as yet for a mechanical thresher. He must, therefore, be made to feel a need for a thresher, and this is where motivation comes in. What combination of incentives can make the small farmer feel that life would not be complete without a thresher? Motivational research is an indispensable element in most business circles. It is no less needed in the rice industry.

The technology of improved rice processing is a whole complex of recommended practices that can be broken down into several aspects: harvesting and threshing, drying, milling, and storage. Each aspect, by itself, requires a different set of knowledge and skills, not to mention attitudes. Each aspect has to contend with a different set of established practices brought about by the prevailing economic and social conditions. Adoption may, therefore, be slow and may need to wait until the economic environment becomes more favourable.

In view of the complexity of the rice processing technology, it probably should not be propagated all at once in its entirety, or in its chronological sequence, at the village level. We probably should identify the aspect that seems most needed in a village and start with

it. The other aspects can be emphasized as the village people begin to feel the need for them, they begin to be dissatisfied with the old methods, and the situational factors change.

Insofar as possible, the first of your series of innovations should be introduced with as little dislocation of community life as can be managed. A thresher that is less efficient than other types but complements present work patterns may not only be accepted faster but may be more economically feasible, given the nature of the local economy. The more sophisticated machines, although undeniably more efficient, may be more than the economic and social fabric of the community can bear. This may mean, when necesary, adapting and modifying the technology to suit actual village conditions. It will also mean formulating a different set of recommendations for large and small farmers.

In communicating the rice processing technology, a point to remember is that channels of communication can mean people no less than the so-called mass media. Indeed, for some audiences, personal channels may be more accessible or may be more familiar and, therefore, more credible. In most cases, village-based technicians, farmers' associations, and trained local leaders will constitute the main communication "media" through which .the gospel of improved rice processing will be transmitted in the villages. The communication materials that need to be prepared are intended to reinforce and supplement their personal efforts.

It bears repeating that the technician's behaviour at all times can greatly influence the adoption of recommended practices. People may resist an innovation when it is actually the innovator that they are resisting. The technician's role should be to guide and advise. The people themselves must make the decision so that they will commit themselves to, and accept responsibility for, these decisions.

There are no pat recipes for the communication of the recommended rice processing technology; there never are when people are involved. But you cannot erase the people from the planning boards of the rice industry just because they cannot be categorized as exactly as grades of rice. For complex though they may be, people remain the real hope of

the rice industry. — NORA C. QUEBRAL. *Department of Development Communications, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Design Criteria

It is ironic that the new rice technology, while expanding total output significantly, may inadvertently lead to concomitant increases in the level of grain losses. Continued reliance on production, processing, and marketing systems employing traditional techniques may maintain the same percentage of output losses but at higher quantitative levels. Emerging problems of this type, which involve processing and marketing systems, are often labeled second generation problems because their emergence stems primarily from the increased output of the improved varieties (Falcon 1970).

This section addresses itself specifically to the problems of modernizing and upgrading the rice milling industry. More precisely, it is an attempt to critically assess the efficiency and economics of existing rice milling technologies. The objectives are to determine the potential for technical improvements in existing systems and, where feasible, the efficacy of initiating activities to design and develop new technologies that will increase efficiency and reduce losses. The analysis is confined principally to milling equipment and does not include an evaluation of issues related to storage or drying.

The first section contains a description of existing milling technologies now used in the Philippines; the second section examines some important structural characteristics of the rice processing industry in the Philippines; the third section is devoted to an economic evaluation of alternative milling systems; and the last section is an attempt to synthesize the results

into a series of recommendations relating to research on the design, development, and/or modification of milling equipment.

Rice Milling Technologies

Milling methods in the Philippines can be classified loosely under four broad headings: hand huiling; Engleberg mills; cono mills; and "modern" or rubber roller mills. The first category, because of its declining use in the Philippines, is not considered in this analysis. It should be recognized, however, that this technique is still widely used in other countries, most notably in Indonesia (Timmer 1972). For the remaining three categories, there exists a wide range of variation within mill types both in milling capacity and in the composition and configuration of individual milling systems.[5] Figure 216 illustrates some possible combinations.

Engleberg Huller (Kiskisan)

The Engleberg huller removes husk and bran in a single operation. Paddy is fed into one end of a hollow cylinder containing a rapidly rotating fluted roller. Axial movement of materials is accomplished by an integral, truncated screw conveyor located at the point where the paddy enters the mill. The lower half of the hollow cylinder is composed of slotted sheet metal. Husking is the result of the shearing action on the grain produced by the movement of the roller flutes past a stationary blade. The combination of rapid rotation, high pressure, and inter-grain contact results in removal of both hulls and bran as material moves axially through the machine. Hulls, bran, and broken rice pass through the perforated screen in the lower half of the cylinder while milled grain is discharged at the terminal end of the mill. Some control over the degree of milling may be achieved by adjustment of the distance

---

[5]In analyzing processing technologies, the elements that make up a milling system should be evaluated independently to allow precise determination of areas where improvements will result in maximum benefits.

between the static blade and the rotating fluted roller.

A variety of accessories may be added to the Engleberg mill. Two common attachments are a polisher composed of a rotating cylinder with leather strips attached to the periphery, which rotates in a perforated housing, and a simple husk aspirator.

If the area to be serviced is small and localized, if transportation facilities are poor and costly, and if quality standards are not critical, use of the Engleberg huller may represent a viable economic alternative. Use of this mill results in relatively low recovery rates, a high percentage of broken grains, mixing of bran and hulls, and a relatively high power requirement per unit of milling capacity. Total rice recovery from this method is generally less than 60% by weight, with head rice composing less than 50% of the total milled rice. The kiskisan does offer the advantages of simplicity in design, ease of maintenance, and local manufacture in the Philippines.

Cono

A second alternative, which processes the greatest share of rice entering the commercial market, is the cono system. It usually consists of one or more under-runner disc sheller units operated in conjunction with a number of vertical cone polishers. The hulling section of the cono mill consists of two cast iron discs that are coated with an abrasive composition material, usually emery stone. The upper disc remains stationary during operation while the lower disc rotates. Materials are fed into a central opening and centrifugal action causes radial movement of the paddy into the space between the discs. Contact of the grain with the two stones removes the husk from the grain. The machine has provisions for vertical adjustment of the clearance between the two discs, allowing a good level of precision in husk removal. Nonuniformity in grain size will result in some rough rice emerging from the machine. Unhulled paddy must be separated from the brown rice and recycled through the huller.

Bran is removed in a separate process in the cono system. The most commonly used ma-

KISKISAN (Engleberg) (WITHOUT POLISHER)

```
                    ┌──────────────┐
                 ┌─▶│ Hulls, Bran  │
┌────────────┐   │  └──────────────┘
│ Rough rice │───┤
└────────────┘   │  ┌──────────────┐
                 └─▶│ Milled rice  │
                    └──────────────┘
```
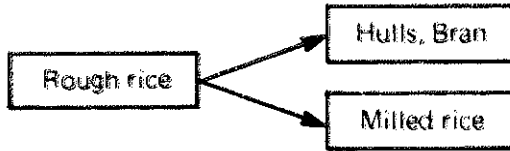
RUBBER-ROLLER SHELLER & KISKISAN (Engleberg) (WITH POLISHER)

```
                    ┌──────────┐                      ┌────────────────┐
                 ┌─▶│  Hulls   │                   ┌─▶│ Polished rice  │
┌────────────┐   │  └──────────┘   ┌─────────────┐ │  └────────────────┘
│ Rough rice │───┤              ┌─▶│ Milled rice │─┤
└────────────┘   │  ┌──────────┐│  └─────────────┘ │  ┌────────────────┐
                 └─▶│Brown rice│┤                  └─▶│      Bran      │
                    └──────────┘│  ┌─────────────┐     └────────────────┘
                                └─▶│ Hulls, Bran │
                                   └─────────────┘
```

DISC-CONO (SMALL)

```
                    ┌──────────┐
                 ┌─▶│  Hulls   │
┌────────────┐   │  └──────────┘   ┌─────────────┐
│ Rough rice │───┤              ┌─▶│ Milled rice │
└────────────┘   │  ┌──────────┐│  └─────────────┘
                 └─▶│Brown rice│┤
                    │Rough rice││  ┌─────────────┐
                    └──────────┘└─▶│    Bran     │
                                   └─────────────┘
```

DISC-CONO (LARGE)
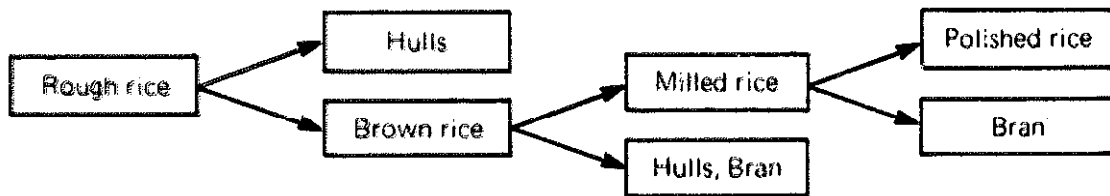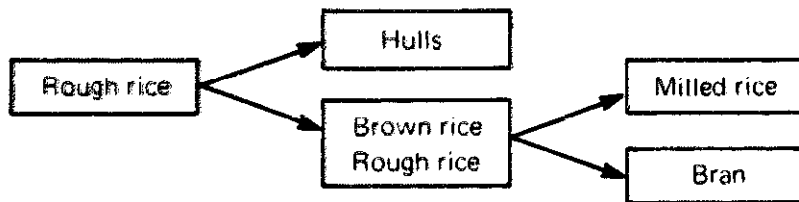
```
                          ┌──────────┐     ┌─────────────┐
                       ┌─▶│Brown rice│──┬─▶│ Milled rice │
                       │  └──────────┘  │  └─────────────┘
┌────────────┐         │                │  ┌─────────────┐
│ Rough rice │─────────┤                └─▶│    Bran     │
└────────────┘         │                   └─────────────┘
      ▲                │  ┌──────────┐     ┌──────────┐      ┌─────────────┐
      │                └─▶│Brown rice│──┬─▶│Brown rice│───┬─▶│ Milled rice │
      │                   │Rough rice│  │  └──────────┘   │  └─────────────┘
      │                   └──────────┘  │                 │  ┌─────────────┐
      │                                 │  ┌──────────┐   └─▶│    Bran     │
      │                                 └─▶│Rough rice│──┐   └─────────────┘
      │                                    └──────────┘  │
      └──────────────────────────────────────────────────┘
```

Fig. 216. Some alternative rice milling systems.

chine is the vertical cone pearler. Consisting of an emery-coated inverted cone that rotates in an enclosed perforated screen housing, the machine removes bran by a carefully controlled abrasive action on the brown rice, which occurs between the composition stone and perforated screen. Milled rice passes out the bottom of the machine.

Produced in the Philippines, the cono installation produces an appreciably higher recovery rate (up to 68% by weight) than the Engleberg huller. In addition, head rice recovery is also higher, bran and hulls are separated, and the degree of milling can be more closely controlled. The capacity of these installations ranges from less than 100 to 1000 cavans of paddy per 12-h day. Unlike the kiskisan, mill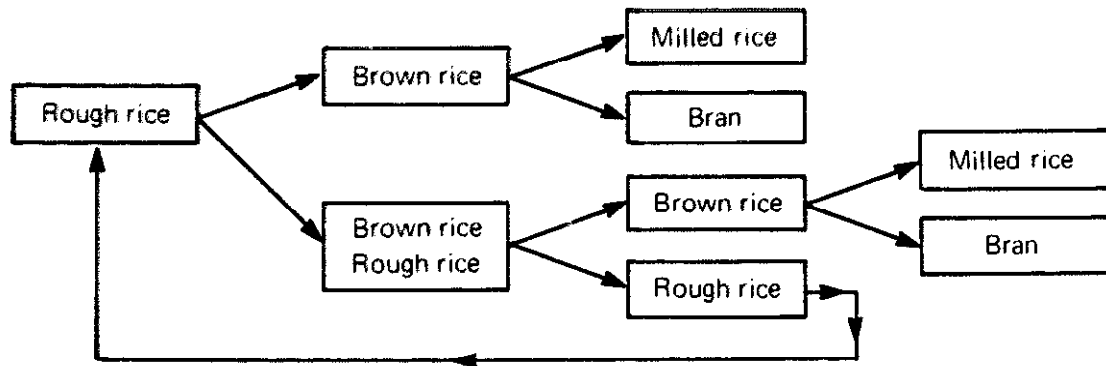s in this category are more fully attuned to commercial markets. A greater percentage of their business is derived from buying, processing, and selling milled rice as compared to the kiskisan, which is largely a custom milling operation.

Modern Systems

The third general category of milling equipment is the modern rubber roller technology developed in Japan. The most distinguishing element in this system is the sheller, which consists of two closely spaced rubber rollers rotating in opposite directions and at different speeds. A shearing action is created on the hull of the rough rice by contact with the rubber rollers. The actual removal is accomplished by a differential displacement action that removes the husk from the grain. As in the case of cono installations, variation in grain size will cause some unhusked paddy to pass through the machine. Operated in conjunction with an aspirator and paddy separator, it is possible to recycle unhulled paddy through the machine to achieve complete hulling.

When correctly adjusted, this method produces the highest total recovery and best head grain yields. Installations employing this technology are available in many sizes, ranging from below 100 to over 5000 cavans per 12 h of operation. In spite of its high technical efficiency, however, high initial investment costs combined with a lack of demand for high-quality rice have retarded diffusion of this technology in the Philippines.

Milling Efficiency

Figure 217 is an attempt to generalize the pattern of milling efficiency for the three milling systems described above. The numbers employed in this illustration should not be accepted uncritically as there exists considerable variability, both among milling technologies and between mills of the same type, in the rates of milled rice recovery and head rice yields. It is generally recognized, however, that the rubber roller sheller produces the highest recovery rates and the greatest proportion of head rice, the under-runner disc sheller (cono) is second, and the Engleberg (Kiskisan) huller gives the poorest results. Note also that the level of efficiency may be affected by the moisture content and variety of the grain, the method and speed of drying, the precision with which adjustments are carried out on the elements in the milling system, and the extent to which the practice of parboiling is utilized.

Equipment Investment Costs

Table 43 presents some typical machinery acquisition prices for a range of kiskisan and cono installation. These values do not include the cost of land, buildings, transportation equipment, and miscellaneous items that make up a complete processing system. Lack of widespread use of the rubber roller technology precludes its inclusion in the local cost data contained in Table 43.

The Engleberg huller ranks lowest in terms of total investment requirements and investment cost per unit of rated capacity. There is also a discernible downward trend in the cost per unit of capacity for both the cono and Engleberg machines as capacity increases. The same is also true to a lesser degree for the power requirement per cavan of capacity as size increases in both categories.

Structure of the Philippine Rice Processing Industry

Figure 218 depicts the distribution of milling capacity and mill numbers between the Engle-
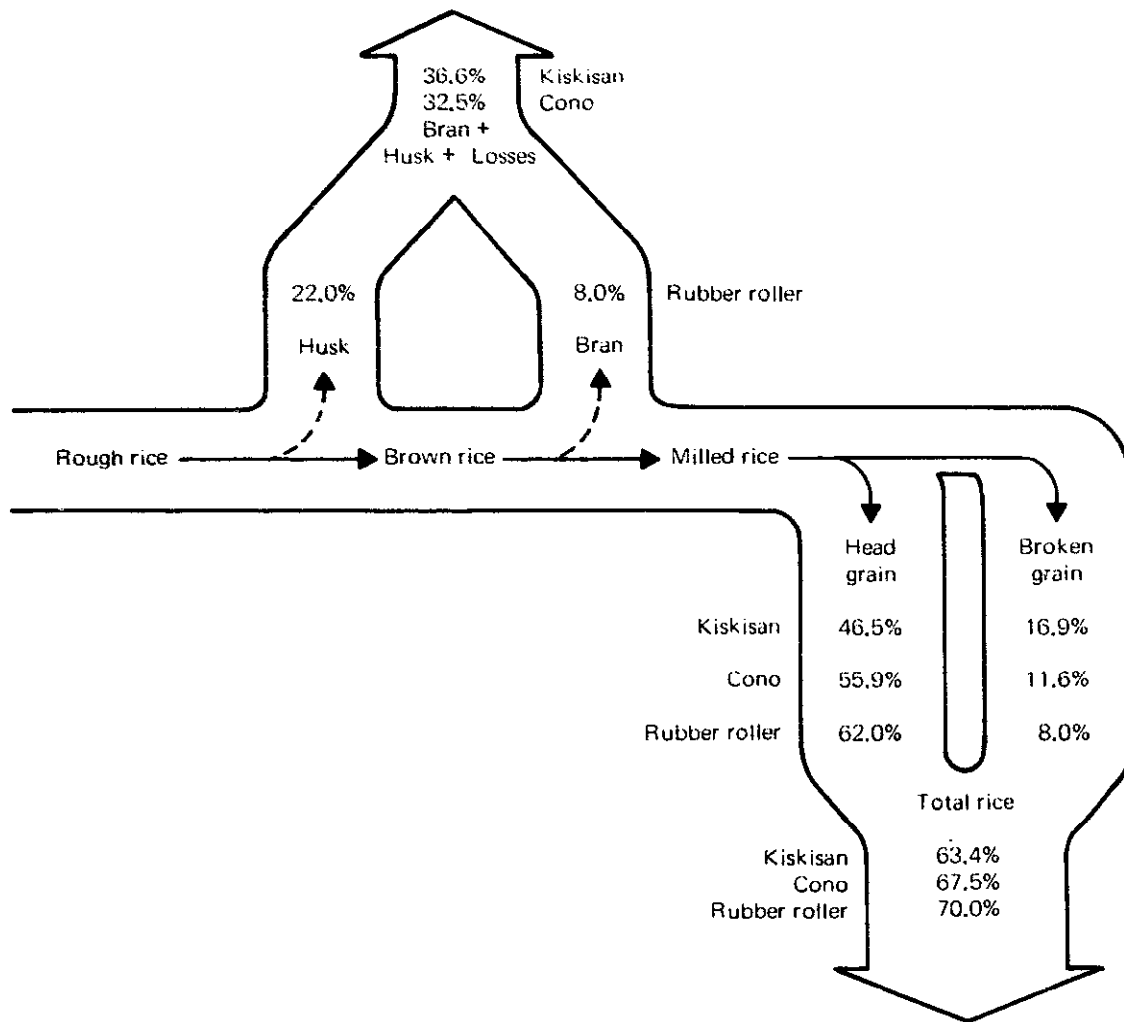
FIG. 217. Recovery efficiency for three rice milling systems.

berg and cono systems. Whereas the data supporting the absolute precision of the numbers shown are subject to question, the magnitude and pattern of the distribution between alternative milling types seem consistent with other independent estimates (Mears and Marquez 1972). The kiskisan represents 80% of the number of mills and 53% of industry rated capacity. The larger average size of the cono installations accounts for this seeming disparity.

From Table 44, it is possible to draw some conclusions regarding the concentration of both milling capacity and number of mills. Examination of the data for the cono installations indicates that both numbers and capacity

are heavily concentrated in the Central Luzon and Southern Tagalog regions. This is in contrast to the kiskisan installations that are more evenly distributed throughout the country. As mentioned previously, the cono tends to be oriented towards milling activities involving the purchase of paddy and sale of milled rice to commercial centres; whereas, the kiskisan relies heavily upon small lot household milling for the bulk of its income. Consequently, when transportation facilities are lacking and markets are small and/or isolated, the kiskisan finds wide application. The growth of cono capacity and concentration seems to have exceeded paddy supplies in some areas. Barker's study on cono installations in Laguna Prov-

TABLE 43. Average investment costs for kiskisan and cono rice mills, by capacity.

Capacity (cavans/12 h)	Engine size (hp)	Average price[a] (pesos)	Power (hp/cavan of capacity)	Investment cost[b] (pesos/cavan of capacity)
Kiskisan[c]				
30–100 ⎫ with	5–12	1789.00	0.167–0.12	113.19
120–180 ⎭ polisher	16–20	2896.00	0.133–0.11	72.13
30–100 ⎫ without	5–12	897.50	0.167–0.12	99.48
120–180 ⎭ polisher	16–20	1545.00	0.133–0.13	67.63
30–100 ⎫ with	5–12	1574.00	0.167–0.12	109.88
120–180 ⎭ blower	16–20	2413.00	0.133–0.11	68.91
40–100 ⎫ without	5–12	967.00	0.125–0.12	93.36
120–180 ⎭ blower	16–20	1765.00	0.133–0.11	64.59
30–100 ⎫ with	5–12	2246.00	0.167–0.12	120.22
120–180 ⎭ polisher, sifter	16–20	3417.00	0.133–0.11	75.60
40–100 ⎫ with	5–12	2011.00	0.125–0.12	108.28
120–180 ⎭ blower, sifter	16–20	2971.00	0.133–0.11	72.63
Cono[d]				
50–100	15–24	16 799.00	0.300–0.24	376.37
150–250	25–30	36 417.00	0.167–0.12	286.08
250–350	32–45	47 481.00	0.128–0.13	260.65
350–450	45–55	56 936.00	0.128–0.12	219.13
450–700	60–80	83 601.00	0.133–0.11	193.14
700–1000	90–140	146 027.00	0.129–0.14	204.10

[a]Prime movers (diesel engines) are priced separately (pesos): 5–12 hp = 5568.50; 16–20 hp = 7923.00; 15–24 hp = 11 429.00; 25–30 hp = 20 800.00; 32–45 hp = 30 715.00; and 50–90 hp = 27 455.00.
[b]Taken at midpoint of capacity range and includes cost of prime movers.
[c]Source: A survey of six major equipment suppliers by the Agricultural Engineering Department, IRRI.
[d]Source: A survey of seven major equipment suppliers by the Agricultural Engineering Department, IRRI.
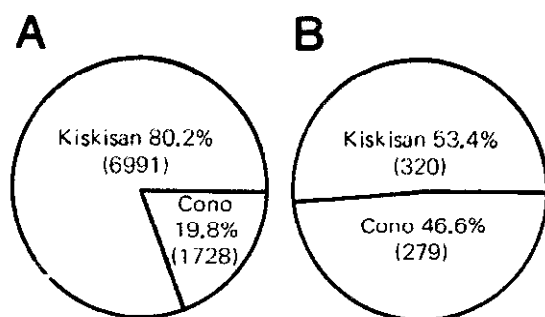

FIG. 218. Percentage distribution of rice mills by number and rated capacity, Philippines, 1968: (A) percentage distribution of number of rice mills; (B) percentage distribution of capacity of rice mills (thousands of cavans per day).

ince indicates that the concentration of mills has resulted in excess capacity in the province (Barker and Dozina 1970).

Rice Quality

In the Philippines, the two principal factors influencing consumer preferences for rice are variety and the visual appearance of the rice grain (International Rice Research Institute 1970). In 1968 the Philippines introduced a complete rice quality classification system that was largely patterned upon FAO standards. Quality determination of milled rice includes analysis of: (1) the variety; (2) the standard through classification; and (3) the moisture content.

The general criteria for grade classification (2 above) include: (1) intrinsic character; (2) degree of milling; and (3) Philippine Standard grades ranging from Grade 1 (the best grade) to Grade 5. The grades indicate percentage of head rice recovery, percentage brokens, a

TABLE 44. Rice milling capacity by mill type and region, Philippines, 1968.[a]

Region	Cono				Kiskisan				Cono + Kiskisan			
	Number	Percentage of total number of cono mills	Capacity (cavans/ 12 h)	Percentage of total capacity of cono mills	Number	Percentage of total number of kiskisan mills	Capacity (cav.ns/ 12 h)	Percentage of total capacity of kiskisan mills	Number	Percentage of total number of mills	Capacity (cavans/ 12 h)	Percentage of total capacity of mills
Ilocos	7	0.4	1 325	0.5	1186	16.9	39 377	12.3	1193	13.7	40 702	6.8
Cagayan Valley	63	3.6	11 685	4.2	526	7.5	25 975	8.1	589	6.8	37 660	6.3
Central Luzon	768	44.4	146 595	52.5	960	13.7	61 311	19.2	1728	19.8	207 896	34.7
Southern Tagalog	291	16.8	33 904	12.2	1222	17.5	55 382	17.3	1513	17.4	89 286	14.9
Bicol	116	6.7	17 974	6.4	658	9.4	33 474	10.5	774	8.9	51 448	8.6
Western Visayas	114	6.6	24 073	8.6	992	14.2	39 639	12.4	1106	12.7	63 712	10.6
Eastern Visayas	186	10.8	8 917	3.2	468	6.7	20 422	6.4	654	7.5	29 339	4.9
Southern and Western Mindanao	97	5.6	19 206	6.9	724	11.1	34 359	10.7	871	9.9	53 565	8.9
Northern and Eastern Mindanao	86	5.0	15 269	5.5	205	2.9	10 201	3.2	291	3.3	25 470	4.3
Total	1728		278 938		6991		320 140		8719		599 073	

[a]Source: Rice and Corn Administration, Quezon City, Philippines.

description of the kernels, and the presence of foreign matter.

Philippine Grade No. 1 milled rice is comparable to Thailand's rice grade of white-rice 5% (fifth from the top grade) and United States Grade No. 2 (second from the best grade). The maximum broken grain tolerance for Philippine Grade No. 1 is 10%; for Thailand Grade No. 5, 5–7%; and for U.S. Grade No. 2, 7%. The percentage of broken grains is an important factor affecting quality by international standards. Variety and grain appearance seem to be the most important quality factors by domestic standards (Barker and Dozina 1970).

Figure 219 illustrates that part of the Philippine quality classification system for grading rice based on the percentage of broken grains. This graph should be read in conjunction with Tables 45 and 46 to develop a full appreciation of the impact of local milling technologies on rice quality. The output of kiskisan mills rarely contains less than 50% broken grains, with many mills producing less than 40% head rice. Cono mills, when properly adjusted and maintained, can produce samples containing up to 90% head rice. The rubber roller technology has the potential of supplying output containing in excess of 90% head rice.
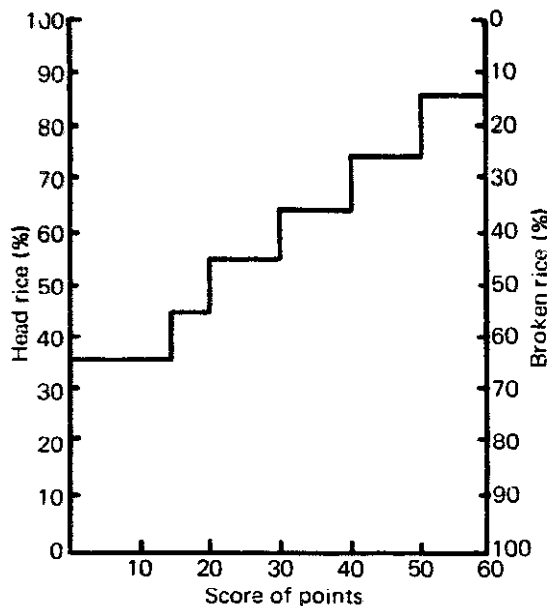
Consumer demand obviously perpetuates the present system of archaic, inefficient mills producing a low-quality rice. An increase in quality consciousness would go far towards upgrading the quality of rice sold in the Philippines. It would also have the concomitant effect of increasing total rice recovery rates because of the more efficient technology necessary to produce a quality rice.

Economics of Milling

One of the most important decisions confronting a rice processor is the selection of a milling system that conforms with the technical, economic, and physical conditions of his market. Because of the magnitude of the financial and human resources that are dependent on this decision, care should be exercised to ensure that the final choice of plant equipment is optimal. In the preplanning stage, the investor should take cognizance of: (1) the volume of demand for milled rice; (2) the product characteristics that the market requires, i.e. quality, form, variety, location, and timing of product delivery; (3) the volume of paddy and site of the area from which supplies will be procured and the probability of an assured supply; (4) the transportation costs for shipping paddy and milled rice; and (5) the range of processing technologies available and their cost and performance characteristics.

Capacity

A major determinant of the economic viability for any rice mill is the degree of capacity utilization. When large-capacity mills are operated at output levels significantly below rated capacities, average total cost per unit of output is high. Similarly, when operations are maintained at levels in excess of design capacity, repair, maintenance, and administrative costs will increase, resulting in a decrease in plant efficiency and a rise in costs.

To illustrate the importance of size in the selection of processing installations, a series of budgets was prepared depicting a wide range of capacities within each equipment category

FIG. 219. Point allocation method for grading based on percentage of brokens under Philippine rice quality classification system.

TABLE 45. Standard grade requirements for Philippine milled rice.[a]

Grade	Brokens (max) (%)	Binlid (max) (%)	Head rice (min) (%)	Yellow and damaged kernels (max) (%)	Chalky kernels (max) (%)	Paddy (max number/ 500 g)	Other varieties (max number/ 500 g)	Red rice (max) (%)	Foreign matter (max) (%)	Moisture content (max) (%)	Size of brokens
1	10	none	90	0.25	trace	none	2	none	none	14	Less than ¾ of a kernel
2	20	none	80	0.5	5	1	4	trace	0.5	14	Less than ¾ of a kernel
3	30	0.5	70	0.75	15	2	5	0.5	0.75	14	Less than ⅔ of a kernel
4	40	1.5	60	1.0	25	2	7	1.0	1.0	14	Less than ½ of a kernel
5	50	3.0	50	3.0	30	4	15	5	2.0	14	Less than ½ of a kernel

[a]General requirements: (1) no mixture of varieties; (2) free from unpleasant and/or repulsive odor; (3) free from insect infestation; and (4) the unit of trading shall be in kilograms or tonnes.

TABLE 46. Description of classification standards used for Philippine milled rice.[a]

	First class	Second class	Third class (brown rice)
Milling degree	Polished milled rice with shiny, smooth edge; no streaks or lines; foreign matter and bran from 0 to 0.5%	Polished milled rice with slightly smooth edge; with 2–3 streaks, brownish colour or spots, and rice bran sticking to the kernels	First stage in the milling where only the husk is removed, leaving a thin layer of the seed coat; very rough, brownish, and full of lines

	Type I	Type II	Type III
Type	Long grain, length shall be above 5.9 mm	Medium grain, length ranges from 5.0 to 5.9 mm	Short grain, length shall be below 5.0 mm

Fancy	Special	Ordinary	Inferior
The kernels have a flinty uniform appearance, glossy, shiny, translucent, or creamy white	The kernels exhibit desirable uniform white, creamy white, or light gray colour	The kernels exhibit a white to dull white or light gray colour	Milled rice with coloured pericarps (due to handling and storage)

[a]Source: U Thet Zin. Rice Inspection and Grading Covering the Sampling, Inspection, Grading and Certification. Paper prepared for the FAO International Food Technology Training Centre, Central Food Technological Research Institute, Mysore, India, March, 1971.

(Table 47). The results of this exercise are shown graphically in Fig. 216–220. Figure 220 illustrates the total costs of kiskisan installations over an annual output range of 0–12 000 cavans. Within this range, three discrete mill sizes were chosen for detailed analysis. The medium-sized mill, rated at 30 cavans/day, requires 7400 cavans/year, and the largest, rated at 50 cavans/day, must process 7700 cavans to cover all costs. Note that the milling fee charged (in the case shown, one peso per cavan of paddy milled) has an appreciable effect on the level at which these mills can be profitably operated. An increase in the milling fee, which reflects the average of income derived from both custom milling and sales of rice and binlids, has the effect of lowering the required level for profitable operation. Changes in any of the components which make up the total cost curve, such as the price of machinery, fuel, wages, and interest rates, will change the level and/or slope of the curves resulting in shifts in the break-even point.

Figure 221 illustrates a series of total cost and revenue cur·es for the cono type installation. In this case, the break-even levels for each mill size are considerably higher than for the kiskisan units. This is to be expected, given the higher fixed cost component for each of these installations. A similar trend is evident in Figure 222 depicting the modern milling system.

Figures 223 and 224 are average total cost curves for the operation of mills within the kiskisan and cono categories, respectively. Comparing these figures demonstrates that there are economies to be derived both from operating mills at or near rated capacity and from moving from mills with lower to those with higher annual capacity. There is also an indication that as one moves from the kiskisan to the cono technology, some economies of size are possible, particularly in the larger cono mill sizes. Note again that underutilization increases costs because the fixed cost (investment) component of average total cost remains high. It is only when installations approach design capacity that the operator is able to minimize this element of total cost. When cost minimization is the primary determinant of plant size, it may be more economic to invest in a smaller unit that will be operated at or near rated capacity than to install a unit that will be operated with excess reserve capacity.

The Composition of Costs and Flexibility in Plant Utilization

Figure 225 is an attempt to depict graphically the nature of the average total cost curves

TABLE 47. Estimated investment and operational costs for alternative rice milling technologies.

	Kiskisan			Cono			Modern (rubber roller)		
	Small (15 cavans/ day)	Medium (30 cavans/ day)	Large (50 cavans/ day)	Small (86 cavans/ day)	Medium (160 cavans/ day)	Large (240 cavans/ day)	Small (2 t/h)	Medium (5 t/h)	Large (10 t/h)
I. Investment cost[a]									
Buildings and machinery	8 516	15 677	23 818	30 494	51 104	52 320	120 800	302 000	604 000
Land	2 430	3 550	3 930	14 210	16 572	23 428	56 776	96 640	271 800
Transport equipment	570	1 140	1 900	3 500	6 550	9 800	17 640	31 752	47 628
Miscellaneous	45	90	150	300	580	880	1 760	3 344	5 016
Total investment costs	11 561	20 457	29 798	48 504	74 806	86 428	196 976	433 736	928 444
II. Operational costs[b]									
A. Fixed costs:									
Depreciation	711	1 135	1 667	4 574	7 666	9 848	18 120	45 300	90 600
Interest	511	941	1 429	1 830	3 066	3 139	7 248	18 120	36 240
Maintenance	360	480	600	650	1 000	1 500	1 950	4 875	9 750
Insurance	200	375	420	1 276	2 010	2 771	3 828	9 570	19 140
Taxes	163	266	304	1 331	1 746	2 358	5 856	9 952	18 392
Total fixed costs	1 945	3 197	4 420	9 661	15 488	19 616	37 002	87 817	174 122
B. Variable costs:									
Labour	2 160	2 400	2 880	8 340	16 140	21 120	29 820	37 920	46 020
Fuel and oil	756	1 510	2 057	3 560	5 022	6 570	14 170	28 340	56 678
Electricity	72	108	144	576	720	864	2 016	2 880	4 320
Total variable costs	2 988	4 018	5 081	12 476	21 882	28 554	46 006	69 140	107 018
Variable cost/cavan	0.83	0.56	0.42	0.60	0.57	0.50	0.35	0.21	0.16
Total operation costs	4 933	7 215	9 501	22 137	37 370	48 170	83 008	156 957	218 140
III. Annual capacity (cavans)[c]	3 600	7 200	12 000	20 640	38 400	57 600	130 752	326 400	653 760
Unit cost at capacity	1.37	1.00	0.79	1.07	0.97	0.83	0.63	0.48	0.33

[a]Investment costs: (1) buildings and machinery—based on price lists of 7 major rice mill manufacturers and dealers surveyed by Agricultural Engineering Department, IRRI, 1972 (see Table 43); (2) land—10 pesos/m² for kiskisan mills, 20 pesos/m² for cono and modern mills; (3) transport equipment—includes costs for trucks and jeeps that may be bought brand new or second hand; and (4) miscellaneous—office and plant supplies and fixtures.

[b]Operational costs: (1) Fixed costs: (a) depreciation—on buildings is calculated at 5% and on machinery at 10%. The life of the machine is quoted by manufacturers to be about 35 years; (b) taxes—include real estate tax, BIR taxes, and license. (2) Variable costs: (a) labour—wages paid for a mill operator and a labourer-helper at 240 and 180 pesos/month, respectively. Number of helpers varies with size of mill (cono and modern mills include in their staff an accountant, assistant manager, secretary, drivers, and security guards); (b) fuel and oil—based on diesel oil consumption at specified horsepower capacity (0.29 pesos/litre; (c) electricity—based on daily electricity consumption to light the rice-mill area (0.25 pesos/kWh).

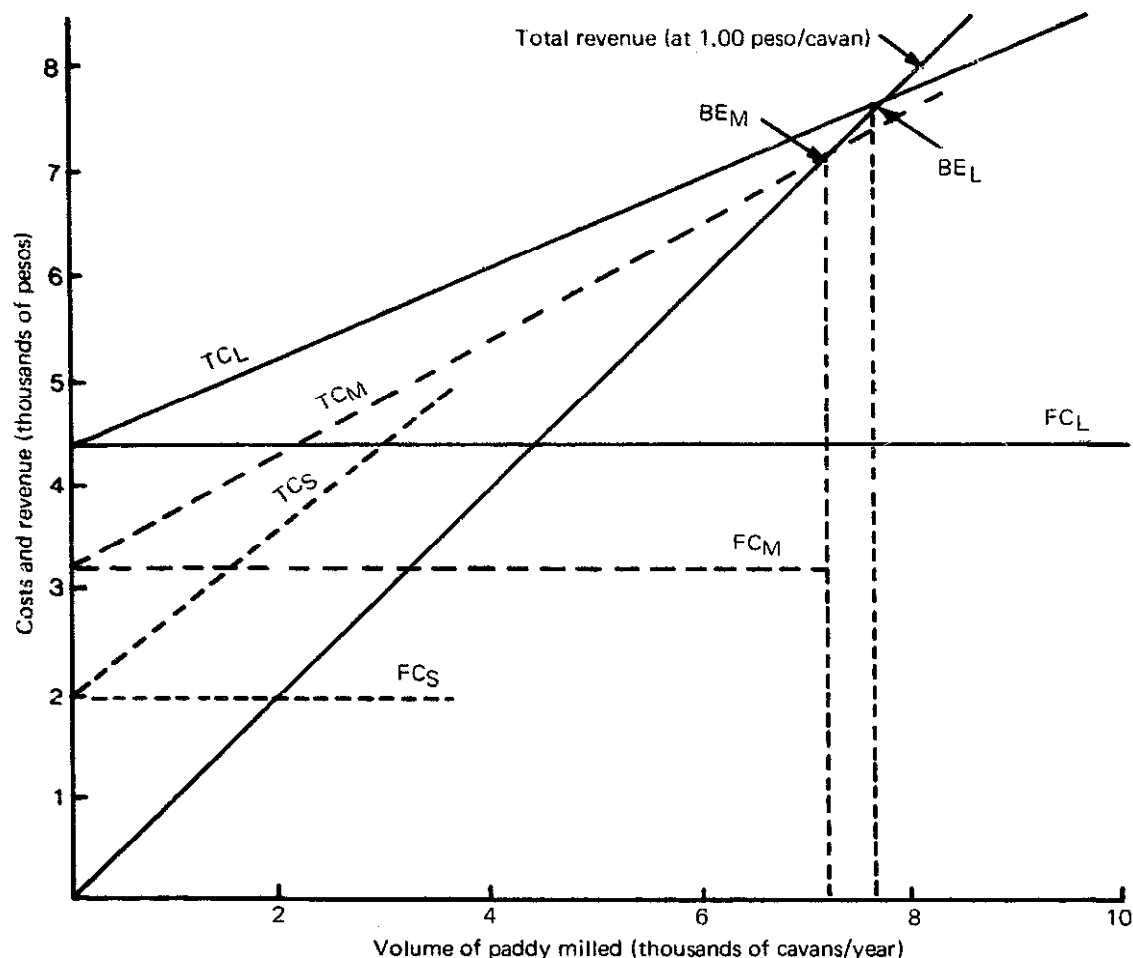[c]Annual capacity is the volume of paddy milled daily for 240 days in a year.

FIG. 220. Estimated total cost and revenue curves for three alternative sized kiskisan rice mills, Philippines, 1972: TC = total cost; FC = fixed cost; BE = break-even point; S = 15 cavans/day; M = 30 cavans/day; and L = 50 cavans/day.

for different sized milling units within two distinct milling technologies. Because the modern milling technology is relatively more capital-intensive, its fixed cost component is higher than the fixed cost for traditional technologies of comparable size. This causes a more rapid decline in the individual average cost curves for the new technology. For similar reasons and because there is relatively less flexibility to adjust variable costs in the new, as contrasted to the old, milling methods, a relatively steeper rise in the cost curve is observed when rated capacity is exceeded. The result is a narrowly defined range of output over which minimal costs may be achieved. The relatively gradual slope of the curves depicting the traditional technologies makes their average total cost

less variable over a wider range of output conditions.[6]

Increasing Milled Rice Recovery

From the previous discussions related to levels of milling efficiency and relative rates of recovery, there appears to be considerable scope for increasing the output of milled rice by improving the recovery efficiency of tradi-

_____

[6] A more complete conceptual framework needs to be developed to make comparative analysis between traditional and modern systems possible and eventually operational. Uma Lele's work on rice milling in India is an example (Lele 1970).
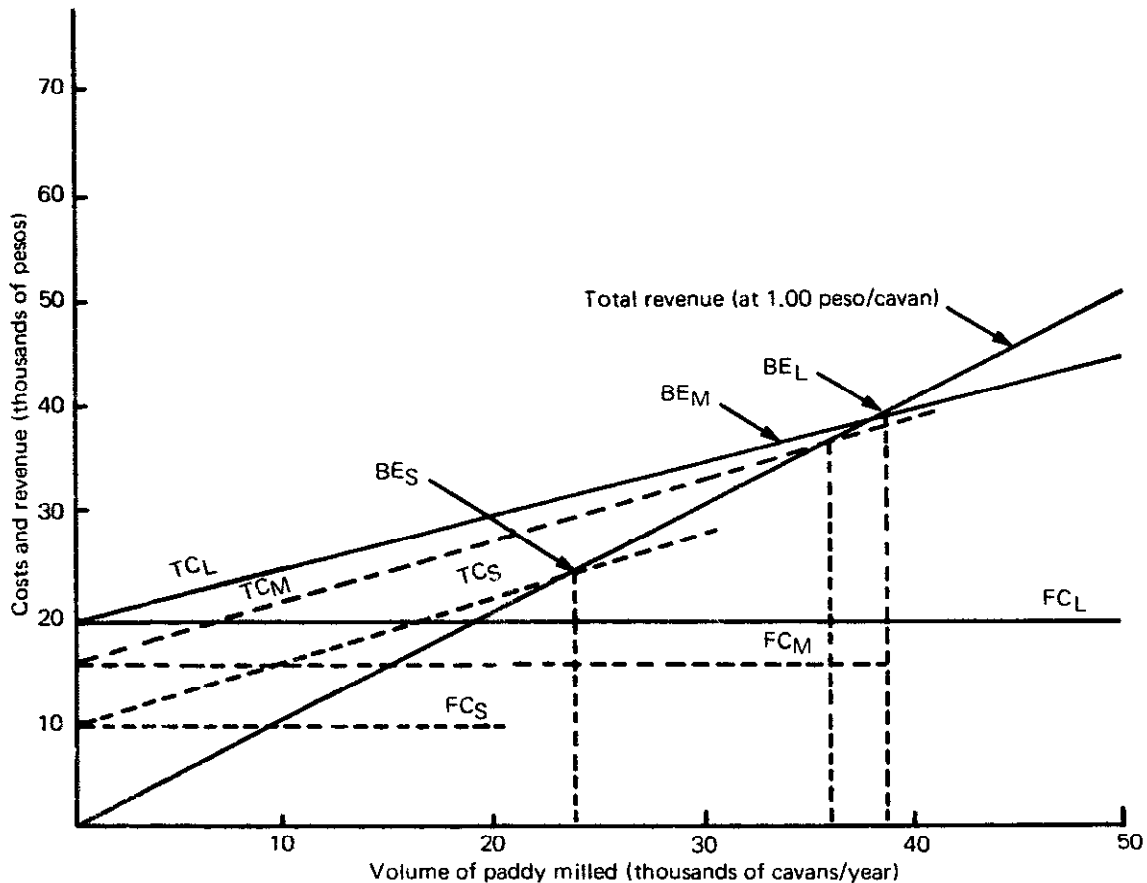
FIG. 221. Estimated total cost and revenue curves for three alternative sized cono mills, Philippines, 1972: TC = total cost; FC = fixed cost; BE = break-even point; S = 86 cavans/day; M = 160 cavans/day; and L = 240 cavans/day.

tional milling technologies. As an example of the potential for increasing recovery, consider the case of a kiskisan with a capacity of 12 000 cavans/year as compared to a cono mill with an annual capacity of 20 000 cavans. Suppose the kiskisan and cono had initial total milled rice recovery rates of 60 and 65% by weight, respectively. Further suppose that it is possible to increase recovery rates for both mills to 70%. Comparing the results in Figure 226, we find that the total increase in recovery is 1200 cavans for the kiskisan, as compared to 1000 cavans for the cono. The explanation for the higher increase achieved by the kiskisan lies in the greater range for increased efficiency embodied in the kiskisan technology. Figure 227 shows the increased income derivable from increases in milling recovery for the two mills.[7]

Net income increases from 29 200 to 116 200 pesos for the cono, and from 21 360

to 74 160 pesos for the kiskisan, as recovery rates rise from 50 to 70%. This represents an increase in net income of 298% for the cono and 247% for the kiskisan. To take a less extreme example, consider the effect on income of increasing milling recovery from 65 to 68%. In this case, net income increases from 95 200 and 60 920 pesos to 108 400 and 68 880 pesos for the cono and kiskisan, respectively. These are increases of 13.9% for cono and 13.1% for kiskisan. Even small changes in recovery efficiency have large effects on both output and income.

[7]The following prices and costs are assumed for these calculations: paddy 35 pesos/cavan; bran 35 pesos/kg; binlids 0.80 pesos/kg; milled rice 1.30 pesos/kg; milling cost for kiskisan 0.79 pesos/cavan; milling cost for cono 1.11 pesos/cavan.
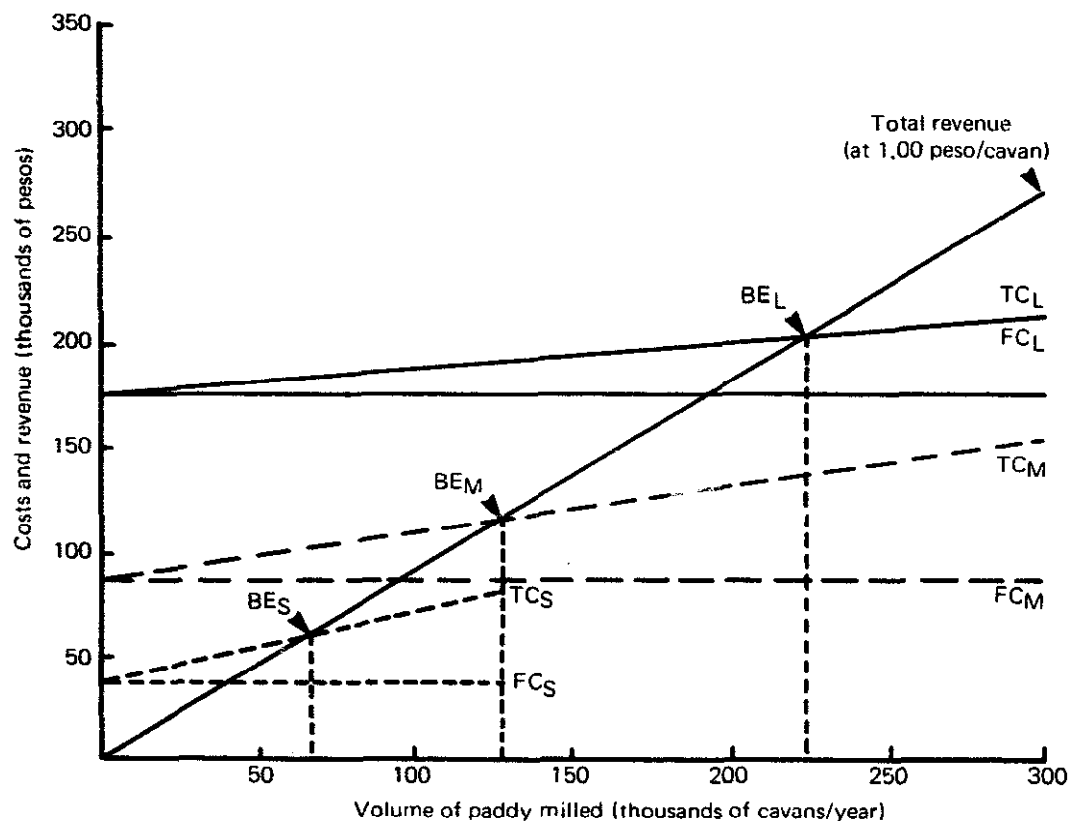
FIG. 222. Estimated total cost and revenue curves for three alternative sized modern rice mills, Philippines, 1972: TC = total cost; FC = fixed cost; BE = break-even point; S = 2 t/h; M = 5 t/h; and L = 10 t/h.

Design Parameters

Based on the evidence presented in the preceding sections, it is evident that there exists considerable scope for improving the performance of the rice processing industry in the Philippines. It is the purpose of this final section to synthesize some conclusions regarding the nature of innovations or improvements that might be made and the means of implementing these changes.

As they now exist, traditional milling technologies embody some potential for improvements without major investments in new capital equipment. Van Ruiten (1971) has demonstrated that improved maintenance and use of quality materials in the manufacture of milling equipment can have an appreciable effect on performance. In particular, utilization of improved composition stones, precleaning equipment, multipass whitening, and finer ad-

justments on the cono mill can result in increases in total rice recovery. Arboleda and de Padua (1965) have demonstrated that adjustments on the Engleberg huller also make possible increased recovery rates and higher head yields.

Regardless of the source of improved milling technology, whether from upgrading existing techniques through refinement and modification or the introduction of new designs, there must be a concomitant effort to upgrade the incentives for employing innovations that result in higher recovery and better quality rice. The common practice in the Philippines of using volumetric measures in merchandising milled rice tends to perpetuate a milling system that produces large percentages of broken grains. Because of the differences in the density of broken versus whole or head rice, the total weight of one ganta of brokens will be greater than a ganta of head rice. Many consumers
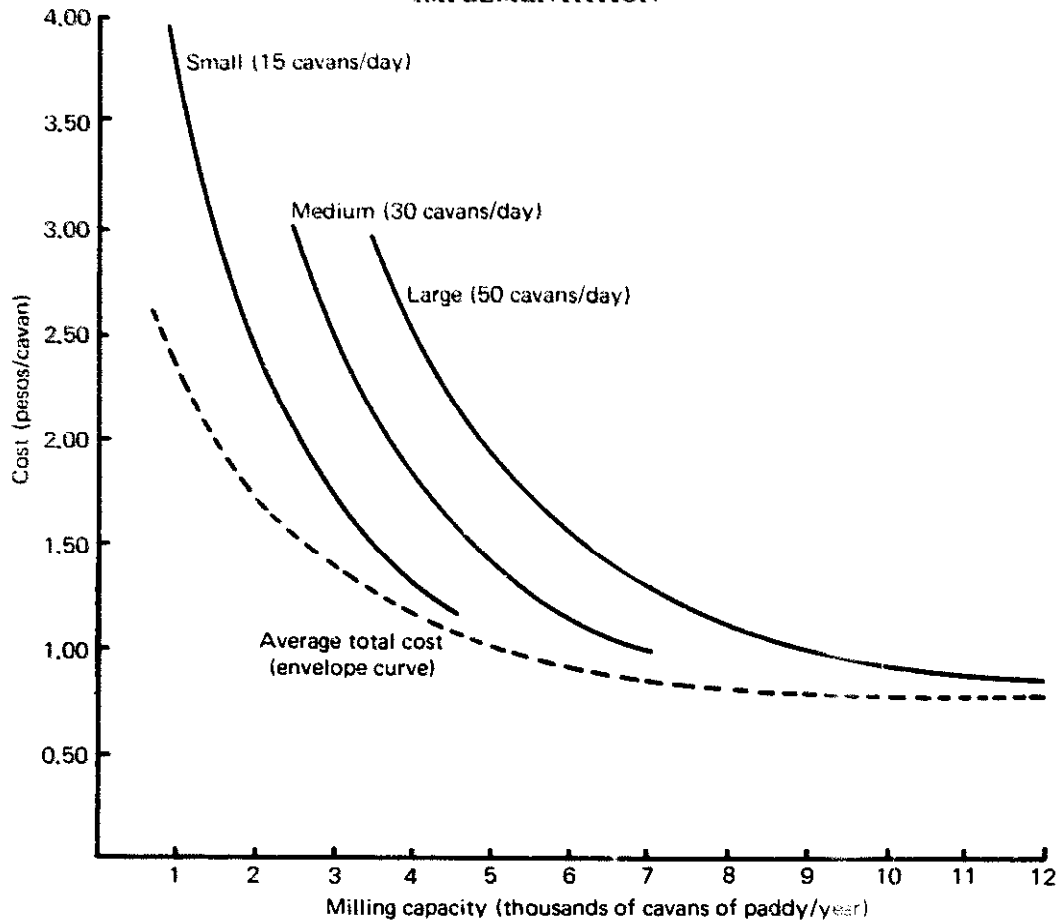
FIG. 223. Estimated total average cost curves for three alternative sized kiskisan rice mills, Philippines, 1972.
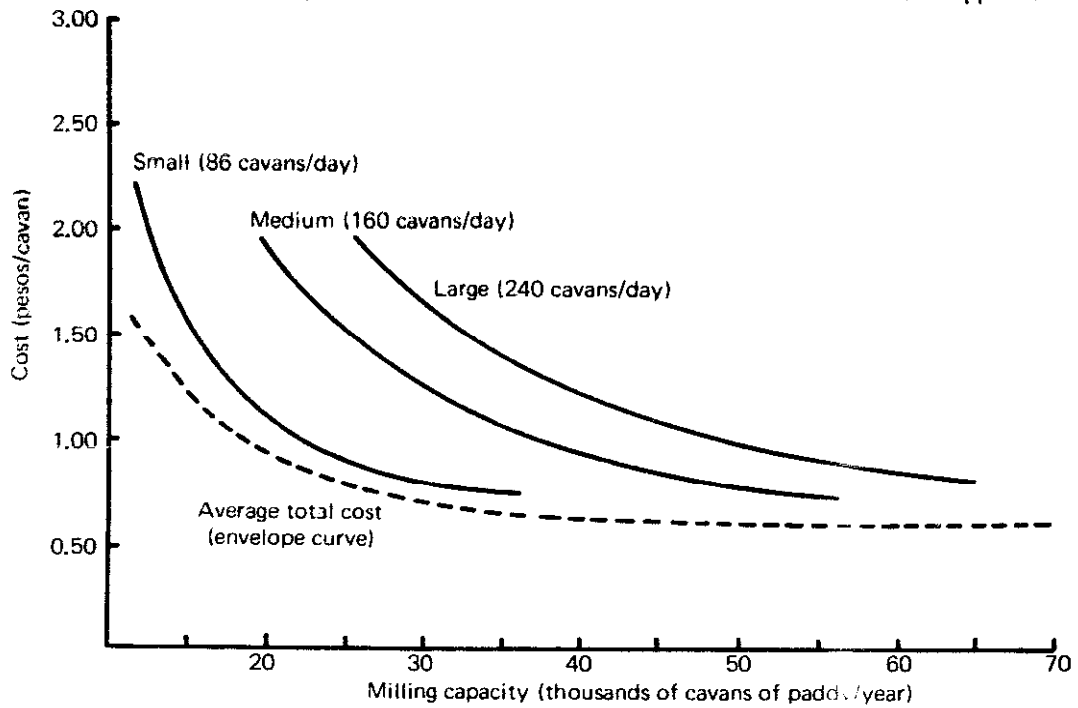

FIG. 224. Estimated total average cost curves for three alternative sized cono rice mills, Philippines, 1972.
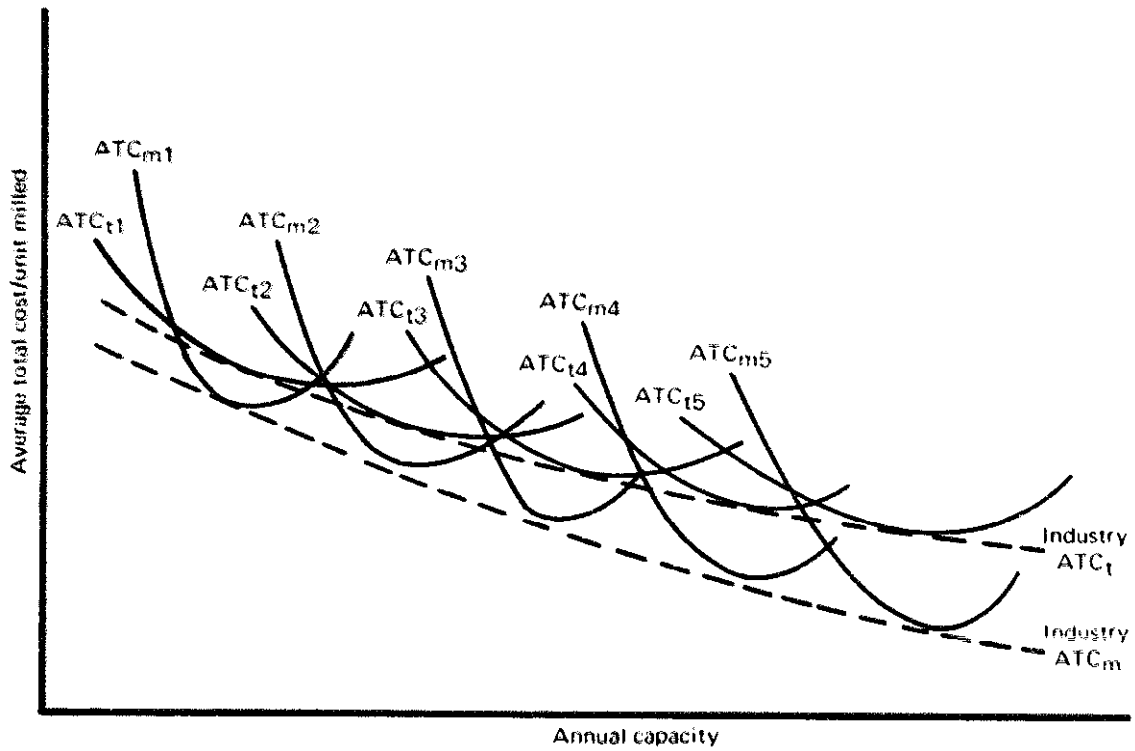
FIG. 225. Hypothetical average total cost curves for two alternative rice processing systems: ATC = average total cost; m = modern milling installations; and t = traditional milling installations.
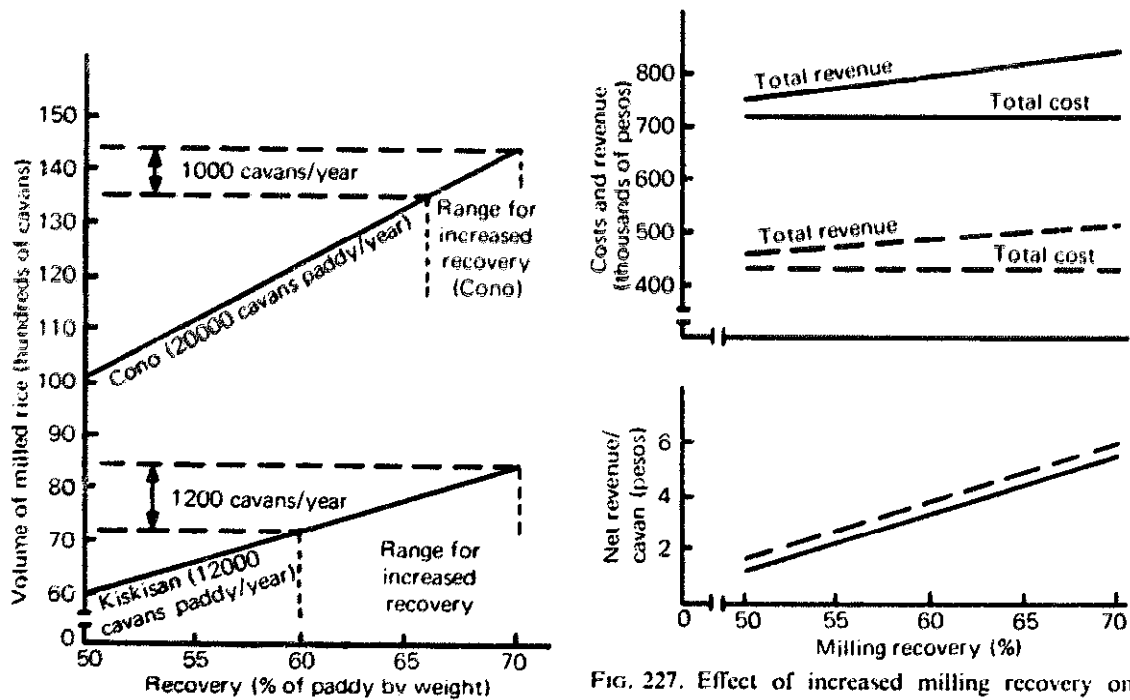

FIG. 226. Effect of increased milling efficiency on total rice recovery.

FIG. 227. Effect of increased milling recovery on total and net average revenue: ———— cono (20 000 cavans/year); — — — — kiskisan (12 000 cavans/year).

state a preference for broken rice for this reason. Another area requiring attention is the practice of paying for the milling service with the bran, binlids, and hulls. When the miller receives payment in bran and binlids, he has no incentive to decrease the number of broken grains because this practice results in a higher quality bran and more binlids from the milling process.

The present price of animal feed has risen to a point where most millers are receiving cash instead of bran and binlids in payment for milling services. The mixture of bran, binlids, and masticated rice hulls that emanates from the Engleberg huller is used as animal feed for both hogs and chickens. In the absence of an assured supply of cheap feed grains, the present practice of utilizing the high quality by-product mix from Engleberg mills will persist. These are policy related questions that deserve the attention of the industry and of the government.

To establish criteria for the design and development of new rice milling equipment, it is necessary to examine the concentration and distribution of rice milling capacity by mill size. Figure 228 contains cumulative frequency distributions showing total industry rated capacity and total industry utilized capacity. Superimposed on this chart are the ranges over which the kiskisan and cono type installations operate. Note that approximately 70% of the rated capacity falls within the size range of kiskisan installations; whereas, the cono installations cover approximately 50% of the range. The increasing segment of the frequency function from 40 to 110 cavans/day contains approximately 50% of the industry rated capacity. It is this range that appears to offer the greatest potential for design and development of new milling technologies. Note also that there appears to exist about 25% excess capacity in the milling industry, although it seems to be about evenly distributed over the entire range of mill size.

With increased commercialization, it appears appropriate to move towards the upper end of the range selected for improved equipment and concentrate development efforts there. This allows realization of some economies of size in milling operation, while at the
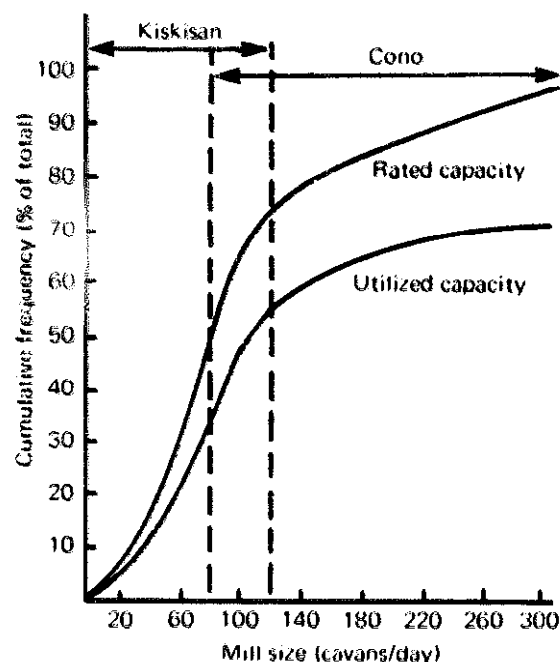

FIG. 228. Distribution of milling capacity by mill size, Philippines, 1970.

same time keeping initial investment requirements at a level comparable with existing milling technologies. Employing the information contained in Tables 43 and 47 in conjunction with the above data, a suggested set of general design parameters are: (1) capacity 80–100 cavans/day; (2) power required 596–670 W (0.8–0.9 hp) per cavan of capacity; (3) total power 5960–7450 W (8–10 hp); (4) investment cost 60–80 pesos/cavan of capacity (including engine); (5) total investment 4800–8800 pesos; and (6) variable costs 0.35–0.40 pesos/cavan of output. Utilizing these general and very rough estimates, it remains an engineering problem to determine the feasibility of such a design.

It is obvious that the above estimates are contingent upon the level of wages and prices now in effect. Changes in the economic environment or policies affecting the economic environment may change the level and/or composition of these estimates. — BART DUFF AND IDA ESTIOKO. *Department of Agricultural Engineering, International Rice Research Institute, Los Baños, Laguna, Philippines.*

Agribusiness Management

By definition, concepts are mental images abstracted from perceptions. As an analytical device, they are helpful in facilitating understanding and appreciation. They are a way of looking at things and, therefore, they can vary with different viewpoints.

In this section, some of the concepts of the structure and the linkages of the rice industry as well as the trends towards its integration are defined. The concepts are projected from a management standpoint and they regard the rice industry as a complex business that must be well understood to be managed. They are macro in dimension and it is hoped that although general in nature, they will offer a helpful frame of reference for the identification and solution of rice problems at the industry and firm levels.

Background

In the beginning, traditional agriculture was exemplified by a self-contained farmer who was both producer and market for his produce. He prepared and planted his land with his own seed, relied upon nature for the needed water, harvested, threshed, stored, and finally processed the harvest to meet his subsistence requirements. As with crops, the pattern was the same in the case of the animals he domesticated and raised.

With time, however, the technological revolution dispersed and distributed the functions of the farmer. His capacity to till the land increased, and so did his market, which expanded beyond himself and his family. These functions, providing the inputs on the farm, the farm operations, the assembly, transportation, storage, drying, processing, and selling of the produce, began to be performed by other firms that increasingly grew in size and number (Fig. 229).

The technological revolution was partly a product of population. The increasing numbers of people inevitably called for new ways of feeding them. At the same time, they constituted a widening market that encouraged the revolution of food production and distribution into complex agribusiness commodity industries.

In the agricultural economies of Asia, one can recognize commodity industries at various stages in the continuing movement that is changing the commodity industries. One such industry is the rice industry, which is supplying the staple food for hundreds of millions of people in this part of the world.

Structure and Character

The commercial rice industry may be generally viewed as vertical in structure with the following components: the input suppliers and distributors; farmers; processors; wholesalers; retailers; and consumers (Fig. 230). In each of these components, there are many firms operating, each one pursuing its activities with some degrees of independence, sometimes complementing each other, sometimes competing or contending with each other. They interact, and the events that occur in one component affect the events occurring in the others. Logically, the entire structure must be balanced and coordinated to be viable. Bottlenecks in one of the components retard industry growth. Balance and coordination enhance industry development.

In most countries in Asia, the millions of rice farmers generally own and operate 2 ha or less of land. This fact has certain implications. It complicates the coordination of the entire industry, suggesting that the grouping of rice farmers into cooperatives, associations, or other forms of business organization is imperative. The fragmentation of land ownership is a constraint on the distribution of inputs and the spread of technology, causing inconvenience, raising costs, and lengthening target time-periods. Also, assembly of the
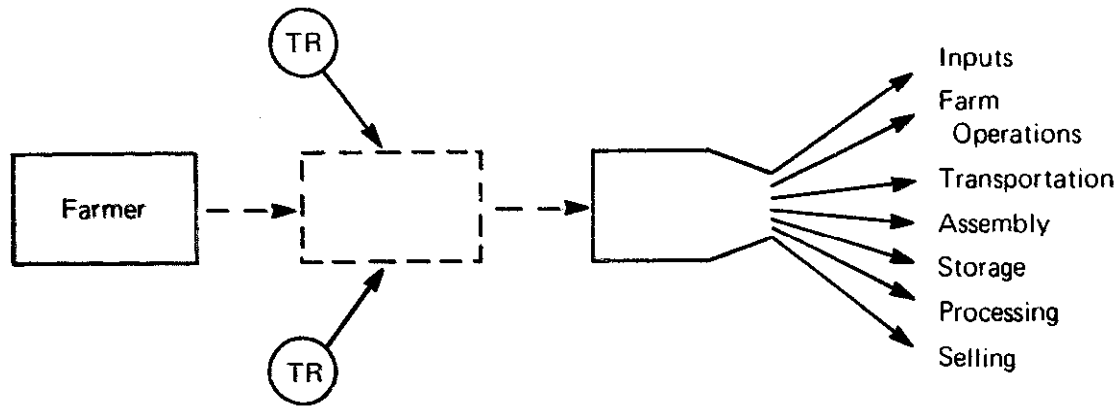
FIG. 229. The evolution of traditional agriculture to an agribusiness status (TR = technological revolution)

produce becomes a tremendous task. The small size of the farm units puts a big question mark on efforts to develop viable credit systems that will enable farmers to buy and use technology inputs, and limits each farmer's absorptive capacity for losses during the bad years.

In these regions, rice has traditionally been a seasonal crop, with the main harvest occurring during half of the year and secondary harvest during the rest of the year. This is partly due to the generally common monsoon climate and the natural difficulty of developing irrigation systems that will make adequate water available, particularly during the dry season. This coincidence of cropping seasons heightens the risk to Asian countries when adverse weather conditions prevail during the main cropping season. It is responsible for the marked difference in rice prices between the troughs during months of heavy supply and the peaks during the lean months. In deficit-producing countries, supply and price stabilization thus become quite a vexing problem.

The advent of the high-yielding varieties that are insensitive to photoperiod has made it possible to even the supply curve because they can be planted at any time, given the water requirements. But this is possible only to a certain extent because irrigated areas are relatively limited compared to the total hectarage devoted to rice, and the expansion of irrigatable areas is naturally a slow process.

The setting of the industry is a double-edged situation. The industry is located in the rural areas where the majority of the population is, and this gives it real importance in terms of the need to develop purchasing power in the countryside, which will expand the markets for the goods turned out by the industrial sector. But most governments are welfare-oriented as they run economics where poverty and low incomes are of major concern, and prices must, therefore, be kept low to be within the easy reach of the common man. Subsidies to please the producer or the consumer are not substantial enough and may not continue for long because they have to be financed by income transfers from the other sectors of the economy that, in most cases, are still unable to generate income for transfer on a continuing basis.
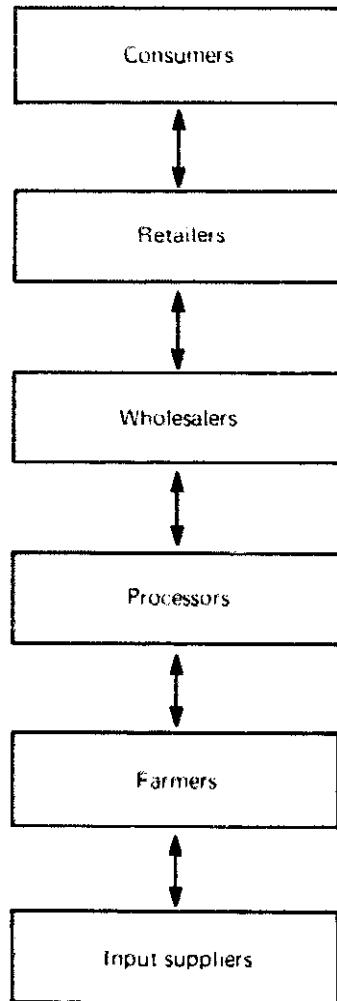
Fig. 230. Commercial rice industry structure.

Milled rice, the main product of the industry, reaches the market in different grades. The quality of the grain is related to varietal characteristics and milling efficiency. The more transparent the grain, the less chalky it is, the higher its milling degree, the more head rice it has, and the higher its price is in the world market. But in the rice-importing countries of Asia, indigenously grown rice is sold as turned out by the local mills, with hardly any distinguishing differences in head rice and broken rice ratios and relying more on distinction between varieties for price differentiation.

Technology

Rice production technology advanced tre-mendously in the 1960's, rapidly spreading the high-yielding varieties and the packages of practices they called for. The work to improve the technology in terms of better physical grain quality, higher protein content, wide spectrum resistance to disease, and adaptability to a wide range of conditions is bound to continue for many years.

But, already, there is widespread realization that advances in rice production technology have accentuated or created second generation problems with regard to harvesting, processing, and marketing. These problem areas are currently receiving more attention than ever before.

Post-production problems were noted as early as two decades ago. For instance, the existence of the inefficient kiskisan single-pass mills was regarded as one of the causes of perennial rice shortages in the Philippines. Because volume recoveries were as low as 45% and they processed a substantial portion of the national rice production, they were logically regarded as a deficit factor. Their recovery efficiency rate was about 10% below that of the more efficient cone-type mills used by commercial millers, and the annual shortages in rice rarely beyond 10% of the estimated annual production. In 1971, a survey conducted by the Asian Productivity Organization in 14 Asian countries disclosed that the working average physical losses in grain marketing was about 16.5% (Table 48).

The attention being focused on post-production rice problems is bound to improve the technology of processing and marketing. Improvement would result in diminished physical losses in rice handling or, in another sense, in increased supply of grain and more economic returns to the rice industry.

Linkages

The structure of the rice industry has many linkages. Besides its own components along the route of the industry's product flow, there are other organizations whose functions affect the industry in all its phases. These are organizations engaged in: research, training and extension; agricultural supply; credit; infrastructure

TABLE 48. Estimated grain losses in marketing (Stevenson 1970).

Process	Average percentage grain loss
Field transportation	2.0
Drying	2.0
Drying-to-storage transportation	1.5
Storage	4.0
Storage-to-processing transportation	1.0
Processing	5.0
Packaging for distribution	0.5
Transportation in distribution	0.5
Total	16.5

building; price stabilization; program coordination; and policy making (Fig. 11). Because of the multifarious relationships among these linkages, coordination problems push for integration at the industry and firm levels.

Integration

At the industry level, integration as a process takes the form of umbrella organizations attempting to simplify planning and implementation or of agencies pursuing development or stabilization programs.

In the Philippines, the National Food and Agriculture Council (NFAC) is an umbrella that covers agencies belonging to the Depart-
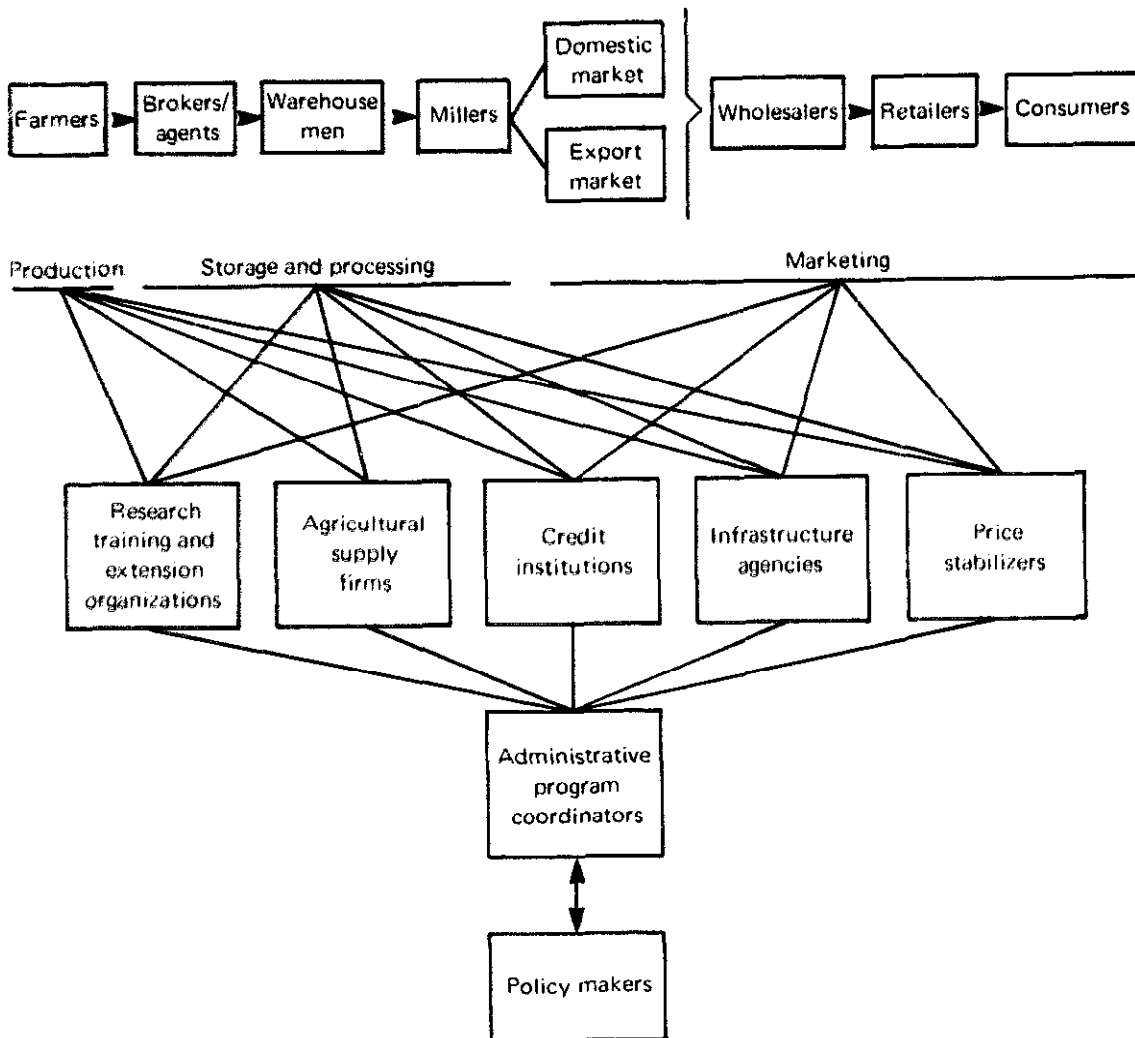

FIG. 231. Product flow and linkages in the rice industry.

ment of Agriculture and Natural Resources as well as other agencies whose responsibilities bear on the rice industry. These other agencies include the Rural Bank Department of the Central Bank, the Philippines National Bank, the Development Bank of the Philippines, the College of Agriculture of the University of the Philippines, the Food and Nutrition Research Council, the National Grains Authority, and government trading organizations. As a co-ordinating and integrating body, NFAC makes instant decision-making possible with respect to problems affecting rice production, processing, and marketing.

The National Grains Authority itself is an integrating body. In its function of stabilizing the prices of rice, it is charged with the maintenance of a floor or support price for paddy rice and a ceiling price for milled rice. In the performance of this responsibility, it should influence the behaviour of rice producers, processors, and merchants in a manner that will distribute equitably the margins associated with the growing and marketing of rice, and at the same time, ensure for the consumers, directly or indirectly, reasonably priced rice at any time of the year.

The Development Bank of the Philippines is administering a $14.3 million lending program for the modernization of rice processing facilities in the Philippines. The terms and conditions of the lending program and the campaign to promote the program are aimed at private processors for the improvement of their existing physical plant or the building of new ones in places where they are needed.

The cooperatives are integrative in nature. As an organizational scheme, they are expected to enhance the flow of technology, reduce the costs of inputs, prevent cut-throat competition, provide facilities that make for economies of scale, facilitate the acquisition and use of credit, and develop markets for the produce of its members.

At the firm level, integration is occurring in the rice industry in two ways: (1) in-plant

vertical integration in which milling facilities increase their components from single-pass processing to multi-stage processing, in certain cases involving the use of driers, cleaners, in-bin ventilators, aspirators, separators, polishers, pearlers, graders, and packaging equipment (Fig. 232); and (2) production-marketing integration toward the development of rice districts in which the rice central is the main component, supported by satellite country elevators or stations (Fig. 233).

In-plant vertical integration is occurring in various degrees. In a number of countries in Asia, the single-pass mills are slowly being replaced by two-stage compact mills involving dehusking and polishing. The cone-type mills are being improved in certain components, particularly the cleaners, separators, polishers, and graders. A few installations have already been set up that include all the trappings of a modern mill plus auxiliary plants that use rice by-products such as an oil extractor, a bran pelletizer, and a power plant fueled by rice husks.

Production-marketing integration is seen in cooperatives or in confederations of cooperatives plus some processors corporate in form that are trying to encompass as many of the functions as possible that are involved in rice farming and marketing. Such integration is usually accompanied by in-plant integration. It is capital intensive and requires operation at relatively high volume.

Integration offers economies of scale and allows control of the operations at each stage. But it requires sophisticated management to successfully handle all stages of the operation so that a sufficient supply of the right quality is available to keep the processing plant at profitable capacity utilization rates and maintain the firm's foothold in a sensitive and dynamic market. The promised rewards are high, and so are the risks. — J. D. DRILON. *Southeast Asian Regional Centre for Graduate Study and Research in Agriculture, College, Laguna, Philippines.*

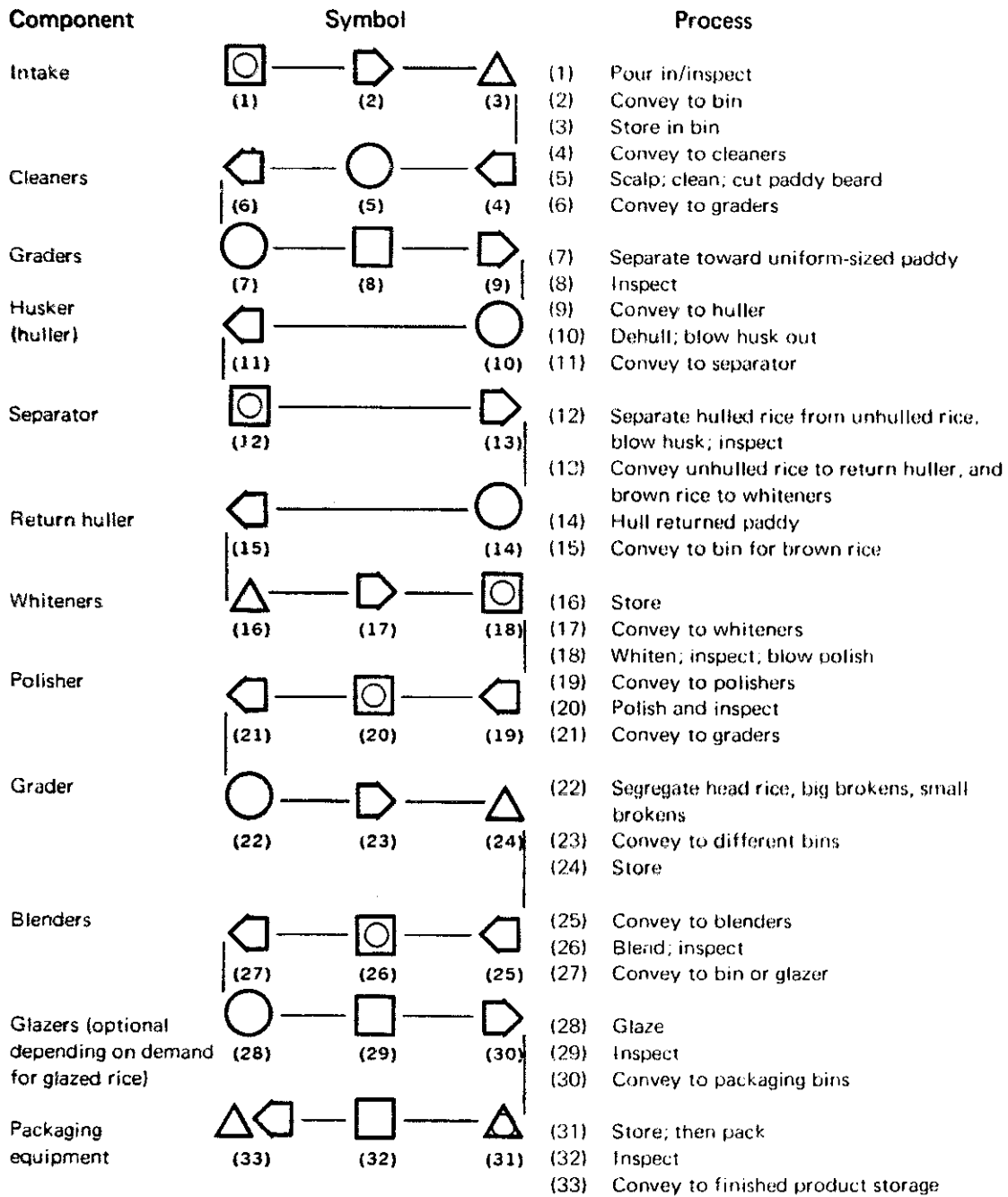| Component	Symbol	Process
Intake	(1) (2) (3)	(1) Pour in/inspect (2) Convey to bin (3) Store in bin
Cleaners	(6) (5) (4)	(4) Convey to cleaners (5) Scalp; clean; cut paddy beard (6) Convey to graders
Graders	(7) (8) (9)	(7) Separate toward uniform-sized paddy (8) Inspect (9) Convey to huller
Husker (huller)	(11) (10)	(10) Dehull; blow husk out (11) Convey to separator
Separator	(12) (13)	(12) Separate hulled rice from unhulled rice, blow husk; inspect (13) Convey unhulled rice to return huller, and brown rice to whiteners
Return huller	(15) (14)	(14) Hull returned paddy (15) Convey to bin for brown rice
Whiteners	(16) (17) (18)	(16) Store (17) Convey to whiteners (18) Whiten; inspect; blow polish
Polisher	(21) (20) (19)	(19) Convey to polishers (20) Polish and inspect (21) Convey to graders
Grader	(22) (23) (24)	(22) Segregate head rice, big brokens, small brokens (23) Convey to different bins (24) Store
Blenders	(27) (26) (25)	(25) Convey to blenders (26) Blend; inspect (27) Convey to bin or glazer
Glazers (optional depending on demand for glazed rice)	(28) (29) (30)	(28) Glaze (29) Inspect (30) Convey to packaging bins
Packaging equipment	(33) (32) (31)	(31) Store; then pack (32) Inspect (33) Convey to finished product storage

FIG. 232. Flowchart of a modern rice mill illustrating in-plant vertical integration: ○ operation; △ storage; □ occasional inspection; → transporting or conveying; and ◎ combined operating/inspection.
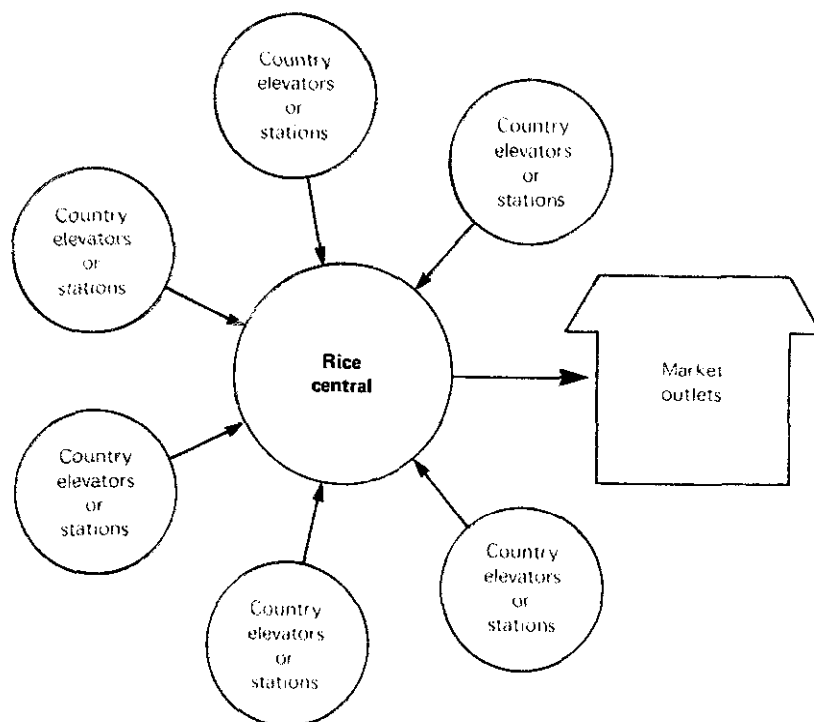
FIG. 233. Rice central concept, which results from production-marketing integration.

Cooperatives

The two main problems in the grain industry are low productivity and low farm income. These problems are due to the interaction of such factors as small farm size, lack of operating and working capital, inadequate credit institutions in the rural areas, inefficient postharvest practices including marketing, low levels of education, and a general lack of useful information, and negative attitudes and social values. To minimize, if not eliminate, such problems, the main aim of the Philippine government, as a matter of national policy, is to expand and accelerate agricultural and food production to meet the food requirements of its rapidly increasing population, to raise the traditional agricultural export production, to increase its foreign exchange earnings, and to increase the supply of raw materials for industrial processing.

The grain industry is the most important industry in the Philippines in terms of hectarage planted, number of people employed, and share of the gross national product. Advancement in the grain industry, therefore, spells agricultural progress and development. It is, therefore, essential that the grain industry have a lion's share of the resources available for economic and agricultural development. In the Philippines, rice and corn production is the first priority in food production programs. The in-industry is given massive financial support. For agricultural production loans alone, the total amount extended from 1966 to 1971 to paddy farmers was 2.4962 billion pesos; for paddy marketing, 482.8 million pesos; and for processing, 118.0 million pesos.[8] With the recent move of the Philippine National Bank to participate fully in the supervised credit

---

[8]Agricultural Credit Report. Prepared by ad hoc committee to study the agricultural credit system in the Philippines.

scheme for the production of rice, it is expected that there will be significant increases in the amount of credit for rice production and marketing. Together with credit extension, a number of programs have been instituted by the government to bring about desirable changes in agricultural production, the marketing system, and the standard of living of the rural population. One of the most significant programs is the development of agricultural cooperative institutions through which needed services are available to cooperative members.

Role of Cooperatives in Economic Development

Cooperatives as an instrument of economic development are in the forefront to promote not only economic prosperity but also social equity. In one historic meeting, the International Labour Organization in 1966 strongly recommended that the establishment and growth of cooperatives should be regarded as one of the instruments for economic, social, and cultural development as well as human advancement in development countries.[9] Cooperatives should be established and developed as a means of: (1) improving the economic, social, and cultural situation of persons of limited resources and opportunities; (2) increasing personal and national resources by encouragement of thrift and the sound use of credit; (3) increasing national income, export revenues, and employment by a fuller utilization of resources; (4) improving social conditions and supplementary social services; and (5) helping to raise the level of general and technical knowledge of their members.

His Excellency, President Ferdinand E. Marcos of the Republic of the Philippines, speaking before Asian cooperators, emphatically said: "Cooperatives are institutions of human beings with a firm and faithful commitment to the achievement of social justice and economic democracy on the strength of voluntary action to satisfy common economic and social needs of people. They are peculiarly

suited to the economically weak and small for whom indeed they have been conceived. Propelled by the power of self-help and self-reliance, cooperatives can be effective means of rationalizing of credit both with respect to generation of funds and to their efficient management. As institutions of people they can replace or at least balance the institutions of private property that today constitute the citadels of the status quo. They can thus bring about the revolutional change that the temper of the times demands."[10] In view of this idea, President Marcos would like to solve socio-economic problems by convulsing the country with the cooperative approach.

Characteristics of Agricultural Cooperatives

Agricultural cooperatives, like the grain cooperatives, are democratic institutions whose control rests on the membership and whose main objective is to provide efficient services to members to effect savings and increase net income. The common purposes of organizing grain cooperatives in Asia are to increase farm productivity and income and, ultimately, to improve the quality of living in the rural areas. Under efficient management, cooperatives may help to safeguard the consumers' as well as the farmers' economic independence.

Through his cooperative, a farmer is linked with markets; he learns to adapt his production goals to market requirements and also learns new techniques that are important for undertaking new profitable enterprises. A multipurpose agricultural cooperative may also provide for a limited number of consumer goods and social services.

In general, the benefits of cooperation not only improve the economic situation of farmer-members, but they also tend to improve the market conditions for all farmers because, if the cooperatives are well organized and managed, private firms and merchants will

---

[9]Recommendation 27. International Labour Conference, 1966. Fiftieth Session (mimeographed).

[10]"A Cooperative Ideology for New Asia." Paper read by President F. E. Marcos, President of the Republic of the Philippines, at the opening ceremony of the First Asian Conference on Agricultural Credit and Cooperatives in Manila, December 1–10, 1970, Manila, Philippines, p. 22.

have to readjust their price policies if they do not want to lose all their customers to co-operatives. Thus, unreasonably high collection and distribution margins can be reduced by cooperative action. Cooperatives, therefore, may break monopolistic or oligopolistic situations. Primary cooperatives may organize secondary or tertiary federations that may enter new markets and processing and/or distribution activities. As a consequence, it is apparent that the agricultural cooperative movement may constitute a rationalizing and welfare instrument in a national economy. A system of agricultural cooperatives may even run its own marketing and price stabilization schemes.

Grain Cooperatives in the Agricultural Sector

Nowhere in the agricultural sector is the demand for development more urgent than in the grain industry. In the rural economy, there is the pressure of population growth, clear evidence of unemployment and underemployment, and serious limitations of employment opportunities. There is, however, an intense appreciation of the fact that the rural economy can improve only through increased grain production. The grain industry is important not only because the countries need to feed a vast and growing population but also because the grain industry depends on a large segment of the population for its livelihood. Since the grain industry is very important, it spells agricultural progress.

Grain cooperatives, as economic and social institutions, have vital roles to play in the drive for development and agrarian reform since it is the grain industry that is primarily covered by land reform in the Philippines. Cooperative organization appears to be the only feasible and worthwhile method of putting the small amortizing owner of very little or no means on his legs and assisting him. In cooperation with others he may become self-reliant, strong, and dignified. If the huge reservoir of potential entrepreneurs, leadership, and talent available among the mass of people in the rural areas is to be activated and utilized through demo-

cratic methods, cooperative efforts ought to be embraced by all peace-loving people.

In the Philippines, grain cooperatives (rice and corn) are the most numerous. As of June 30, 1969, out of 652 agricultural cooperatives with a total membership of 362 637 farmers, 376 were grain cooperatives with 252 139 members and a paid-up capital of 6.4 million pesos. Of the 376 grain cooperatives, 153 and 19 were active and semi-active, respectively.

The Role of Government in Cooperative Development

The problem of agricultural development is so obvious and so intensely demanding that governments cannot wait for cooperative institutions to develop by themselves on the basis of individual initiative and self-reliance. In fact, the member countries of the International Labour Organization have been encouraged to formulate and carry out a policy under which cooperatives receive aid and encouragement of an economic, financial, technical, or legislative nature, without adversely affecting their independence. One of the resolutions in the First Asian Conference in Agricultural Credit and Cooperatives was to strengthen the cooperative movement through administrative and financial assistance from the government.

Cooperatives in the more advanced countries, such as Denmark, have emerged and prospered with a minimum of government intervention and support. In this region, however, governments have to play a more aggressive role in providing a climate that is conducive to the healthy growth and development of cooperatives. It would not be sufficient for the government to help farmers organize and to provide financing and supervision to cooperatives. Initially, governments will have to carry the burden of providing opportunities for cooperative members' education and for management training. This can be done through the regular educational institutions, the agricultural extension services, and the state-financed training institutions. As cooperatives become stabilized and financially sound, then they can, and should, carry out their own educational and training programs through

their federations or national organizations.

A preferential government policy towards cooperatives will facilitate the full development of the movement. However, for the cooperatives to cover most farmers quickly, support through subsidy or through tax exemption privilege might be allowed during the initial stages of cooperative development. Care should, however, be taken that cooperatives are not used as agents of governments for assistance programs to agriculture that might run counter to the legitimate cooperative purpose and be implemented outside the cooperative framework. This may hasten the death of the cooperative movement. Undue reliance on government controls and subsidy programs creates an artificial atmosphere that may destroy instead of build up cooperatives once such programs are withdrawn.

Specific Functions of Grain Cooperatives

Grain cooperatives may contribute to the objectives of agricultural development and rural employment by serving as: (1) instruments for capital formation through which loans are issued to rice and corn farmers; (2) agents for procurement and distribution of quality farm supplies, at cost, to farmer members; (3) agents for the orderly and efficient marketing of farm products; and (4) instruments for the implementation of the government program for the development of the grain industry.

Saving and Lending in the Grain Cooperatives

The mobilization of available capital within the economy, including agriculture, requires an efficient network of credit institutions that will bring about the progressive shrinkage in size of nonmonetary areas. Authorities on farm credit agree that the credit institutions that are designed to serve the rural sectors, including rice and corn farmers, must be built on a solid foundation if they are to be of lasting benefit. For people to accept them, their operations should be suited to the traditions, habits, customs, and set ways of the rural people and must conform to the idiosyncrasies of rural living

that have insured the growth and survival of indigenous leaders, such as the face-to-face relationships, the informal and simplified procedure, and the efficiency of loan releases. Not only must they be financially stable on rational commercial lines and operate in an atmosphere of growth, but they must also help, stimulate, and promote the initiative of rural people for greater savings and render to them technical guidance for more effective utilization of borrowed funds.

It is believed that cooperative credit institutions are the best possible form of credit institutions for rice farmers, more than 73% of whom cultivate not more than 3 ha. Cooperative management officials are usually more familiar with the local conditions, which is essential for a successful local lending institution. In general, rice cooperatives in the Philippines have failed in their lending operations because the local committees, which were supposed to be the extension arms of the cooperatives, did not perform their functions effectively.

Another basic reason for failure is the lack of understanding of the basic principles of cooperatives. To lift farmers from hardships, credit, together with other assistance, must be extended and should be tied to a planned program of increased agricultural production. This is necessary because, if the loans are linked with traditional agricultural practices, the credit will have no economic impact. In this connection, cooperative credit must be supervised to ensure that the loans are used wisely and effectively, and result in maximum benefits to the farmer-borrowers. Essential to the success of the supervised credit program of a cooperative are: trained farm management technicians who can assist farm borrowers in preparing farm and home plans; careful selection of borrowers; appropriate loan policies and procedures; continuous research and experimentation; and adequate financing.

Provisions of Agricultural Inputs

With the Green Revolution, "package technology," including technical inputs, has become a critical and a decisive factor. If charges

for fertilizers, insecticides, improved tools, and other agricultural inputs remain prohibitive, the full effects of other policies favourable to increasing farm production and rural progress cannot be achieved. For instance, the IRRI varieties will only yield the maximum quantity if correct dosage of fertilizer, chemical, and water has been applied to the rice fields.

Cooperatives in some countries have been able to overcome these pricing difficulties. Concentration of demand and supply is one inherent advantage of cooperatives over other forms of economic organization. By concentrating the requirements of the members for farm production, cooperatives can avoid some of the costs due to small and irregular purchases by individual farmers. In cooperatives, economy in operation is easily attainable. Furthermore, large discounts for these bulk purchases mean savings to members as a result of low prices. Cooperatives that are primarily interested in the welfare of the members are in a better position than any other organization to secure goods and services with the right quality, weight, and measurement.

In view of the monopolistic situation in many countries, more cooperatives should include in their operations the procurement and distribution of agricultural supplies to complement the credit provided to members. This will ensure the sound use of credit and at the same time secure quality inputs for farmers at the lowest possible costs.

Marketing of Farmer-Members' Products

Small rice farmers do not generally have good control over the marketing of their products. Middlemen have so entrenched themselves in the control of the marketing system that they can, and usually do, dictate their own price and manipulate the market. This control by the middlemen has meant that the farmers get relatively low prices for their produce and the consumers buy at relatively high prices.

Uniform standards of weights and measures for selling farm products are lacking, making it difficult to compare prices in the various markets and actually making the limited amount of available price information practically useless. Farmers usually sell their products individually and without regard to favourable market conditions as to when, where, and at what price they should sell.

As has happened in Japan, South Korea, and Taiwan, cooperatives may improve the discouraging marketing situation in the region by promoting orderly marketing and better merchandising of farm products. Cooperatives may make the supply of farm products for sale at the market equal to the demand of the buyers. When a rice farmer is acting for himself alone, he is often forced to sell most of his paddy at harvest time. This may be due to the perishability of his products, his need for cash, or his lack of storage facilities. Cooperative associations may avoid this problem if they can provide storage and credit facilities to their members.

In the Philippines, the government provided facility loans to paddy farmers' cooperative marketing associations to enable them to build their warehouses and operate their own rice mills. In 1967, of the 2712 warehouses in the country, 318 were owned by the rice farmers' cooperatives with a capacity of 7 290 800 cavans (Weitz Hettelsater Engineers 1968). This is approximately 18% of the total warehousing capacity in the Philippines. Many of these paddy farmer cooperative warehouses also operate rice mills.

Through large-scale procurement and distribution of paddy, marketing costs are reduced. Under a cooperative undertaking, distribution is done in large volumes and the cost of marketing is reduced. Cooperative marketing can also reduce, to one, the number of hands the farm products pass through; therefore, extra costs are eliminated.

In some countries, the pooling of farm products as a distinct cooperative practice is used by some cooperatives. Under the pooling system, the products are grouped into lots on the basis of grade, variety, or class and sold during a given period of time. The returns from the sale of the products are totaled and divided by the number of units sold to get the average sale price per unit. This is the price at which every unit of product in the pool is liquidated. Every farmer receives the same price for each unit of the product included in the pool.

Implementation of Government's Food Production Program

Cooperative associations could work with government agencies in the implementation of subsidy and price support programs to bring about the desired results. In Japan and Sri Lanka, cooperatives are the buying agents of the government in the purchase of rice or paddy. They are also used as the price stabilizing agency of the government. On a commission basis, some cooperatives provide to the government their warehouses, rice mills, and trucking facilities. In Taiwan, the farmers' associations are deputized by the government to collect fertilizer payment and land rent. They also undertake the warehousing and handling of paddy, and rationing of rice to the public, including the dependents of the Army.

Basic Requirements for a Cooperative to Succeed

Efficient Management

The failure of many cooperatives may be attributed to mismanagement. A newly organized cooperative very often cannot pay the salary of a qualified manager, but it is at this stage that the cooperative badly needs a competent manager; otherwise, it cannot expect to go far. Because of their inability to obtain the services of qualified management personnel, many cooperatives have died even before they could commence business operations. New and small cooperatives everywhere have particular difficulty in getting the services of capable managers. As beginning businesses, they cannot offer the salary, or the security, or sometimes even the potential of success that will attract the services of trained people. Salaries paid to managers tend to have a somewhat direct relationship to the size of the business. As it gets larger there are usually more employees to supervise and guide; there is an increase in capital; and there are more resources at stake. A mistake can be costly. As management decisions affect more people and capital, an increase in the compensation of the manager is justified.

Several measures have been used to solve the problem of inefficient management. One measure is to attract membership from the better educated and financially well-off members of the community so that they may lend not only their financial support but also their managerial abilities to the cooperative. But experience shows that combining the small and the large procedures in the same cooperative is not always possible. The government, therefore, more often than not, has to step in and provide opportunities for the training of managers and employees of cooperatives. The Agricultural Credit and Cooperatives Institute has been providing this function of training managers and employees of cooperatives for the last two years. National Cooperative Federations can eventually take over this training function and create a pool of trained managers who can be assigned to manage newly organized cooperatives or serve as trainers for newly recruited management personnel.

In the Philippines the new strategy for cooperative development includes the Management Training Program. This program will: (1) create a management training pool to be composed of top calibre cooperative managers who shall provide on-the-spot training to prospective cooperative managers; (2) develop suitable and practical management training materials and guides for the use of cooperative managers; (3) contract for and defray the cost of professional cooperative managers and/or firms that shall actually manage cooperatives as part of the training program. The Management Training Program shall be administered by an Advisory Board of five members that shall be appointed by the Secretary of the Department of Local Government and Community Development.

Another measure or method that provides a cooperative with the skills of management is a management service contract. Instead of the Board of Directors hiring a single general manager, as is usual, it contracts for the management function. This contract might be made with: (1) another cooperative; (2) a cooperative federation; or (3) a separate group of people who are organized specifically to provide the services of management to a cooperative or to a number of small cooperatives.

Adequate Volume of Business

A farmers' cooperative, like any other business enterprise, must be of a certain minimum size if the unit costs are to be reasonable.[11] In other words, a cooperative is a way of solving the very important problem of economies of scale for small farmers. In general, those cooperatives that are failing have a small volume of business. They do not have adequate income to finance the costs of a prospering agricultural business, and they are too small to hire competent managers and other staff, or to invest in warehouses, processing plants, and other facilities.

Satisfactory Membership Relations

A cooperative has to be operated or managed in the interest of, and in accordance with, the needs and wishes of the members. Unless this is the guiding principle in the operation of cooperatives, member participation, loyalty, and support cannot be sustained. The Board of Directors of a cooperative may serve as the connecting link between the association and the members. Being the policy-making body, the Board of Directors individually and collectively should constantly be in touch with the members to keep them informed of facts concerning their cooperatives as well as to hear their suggestions and complaints. Within the broad policies, the hired management should have wide latitude in planning and executing the day-to-day activities of the cooperative. In this way the policies and operations of the cooperative may continuously be geared to the members' requirements and desires. Prompt payment of dues, continuous patronage, good attendance at meetings, and efficient service to the cooperatives are all indicators of satisfactory membership relations.

Adequate Supervision and Guidance

Although the government regulatory authority may exercise guidance and restraints, it

[11]Owens E. L. and Antholt. Coops Can Help – If Government Is Willing. Small Farmer Credit Analytical Paper. 5 p.

should not interfere with the freedom of the members, the board, or the manager to determine their own problems and work out their own solutions (Report of the Philippine Delegation 1968). The government may also provide an auditing service that will analyze cooperative operations and point out mistakes or weaknesses. Although some kind of direction and guidance by the government is necessary to ensure that cooperatives are properly run, there should be a planned withdrawal of government interference as cooperatives demonstrate their ability to run their affairs. The provision of management counseling is essential for the sound development of cooperatives. However, this can best be done by nongovernmental cooperative institutions as, for example, the Central Cooperative Union in Japan and the National Agricultural Cooperative Federation of Korea.

Adequate Capital Contribution from Members

The need for member equity capital in cooperatives cannot be overemphasized. Although governments in the region recognize the need for providing sources of liberal financing for cooperatives, there can be no substitute for the members' contributed capital. The best indication of a member's faith and interest in an association is his readiness to put capital into the association. Members' capital is also the cheapest capital that can be used by a cooperative. Members' participation, loyalty, and attachment to a cooperative may be heightened through a systematic plan of capital formation from members' contributions.

Whatever the capital structure of a cooperative may be, the capital burden should be apportioned among the members in some way proportionate to the use that each one makes of the cooperative. Those who derive more benefit from, and do more business with, the association should be required to carry a correspondingly larger share of the financial load than those who make less use of the association. One way of doing this is to assess each member for a capital subscription in relation to farm area cultivated or per unit of pro-

duce delivered regularly to the cooperative. Another way is deduction of a preagreed percentage of sales or proceeds of crops sold to or through the cooperative. In the new strategy for cooperative development in the Philippines, forced savings of 5% of production loans for the purchase of shares of stocks of rural banks and 1 cavan of paddy per hectare per harvest to be contributed to the Barrio Guaranty Fund are the methods being adopted.

Continuous Cooperative Education and Training

Management training and member education play a vital role in the overall growth of the cooperative movement. Underscoring the importance of cooperative education, a noted Swedish cooperator once said, "If we had occasion to start our movement afresh and if we were given the choice betwen two possibilities, that of starting without capital but with enlightened membership and staff or, on the contrary, that of starting with a large capital and ill-informed members, our experience would incline us to choose the first course" (Quintane 1969).

"The success or failure of a cooperative institution is greatly dependent upon the employment of highly capable management officers. Of equal importance is the need for providing proper education and training for the members of the board of directors as well as the general public. It is simply not enough for the members to know what they can do for the cooperative to insure its success. Education is the process of moving from a stage of cocksure ignorance to one of thoughtful uncertainty" says Mr. E. Patterson (1968), Assistant Director for Agricultural Development, USOM, Thailand.

In the Philippines, the training of management employees and the board of directors has been the main responsibility of the Agricultural Credit and Cooperative Institute. Religious organizations, private agencies, and cooperative federations have been providing limited training programs to management employees; however, they have more member education activities. There are about 30 such

organizations doing membership education in varying degrees.

The national cooperative movements in advanced countries, such as Sweden, Denmark, Japan, Canada, and West Germany, have done a considerable amount of work in the field of member education that can provide us with experiences worth studying (Vir 1969).

In Sweden, the cooperative movement conducts large-scale education programs for its members mainly through study circles and correspondence courses. Member education classes are usually organized at the primary society level. Correspondence courses work very well in Sweden because of the high literacy among the rural people. Funding of the courses is the primary responsibility of the cooperative movement.

In Denmark, the high schools are the hub of general adult education activities including member education. As residential schools, they emphasize the importance of social attitudes and leadership qualities among the participants who learn and live together.

In Japan, cooperative member education is an important part of the extension classes organized by multi-purpose cooperatives for their members. The national organizations and the prefectural federations assist the primary societies in conducting member education programs. The government extension agencies assist Japanese farmers through their cooperative associations. Agricultural cooperatives, which are highly integrated and diversified, have been successful primarily because of the well-developed education programs prepared and implemented by voluntary as well as government sectors.

The Canadian experience in cooperative education through universities and colleges is relevant. Member education forms part of the adult education or extension programs conducted primarily for fishermen by Saint Francis Xavier University. This approach could be adopted in the Philippines if university and college authorities could be convinced to include member education in their general extension programs.

In India, a sophisticated program of cooperative member education is carried out through the National Cooperative Union, the

State Cooperative Unions, the District Co-
operative Union, and ad hoc committees. The
scheme, with about 750 cooperative education
instructors, is primarily designed for agricul-
tural cooperatives. These instructors are re-
sponsible for conducting training courses for
secretaries, committee members, and ordinary
members of cooperatives. The study circles are
usually organized by the cooperative in-
structors. The member education scheme in
Sri Lanka is substantially similar to that in
India.

Conclusion

Never in the history of the region have co-
operatives promised so much to promote social
justice and economic independence among the
impoverished masses of the people. However,
the momentum of development varies in dif-
ferent countries. Some countries like Japan,
South Korea, Taiwan, and Egypt have already
succeeded in developing potent and viable co-
operative organizations; some countries have
just recently identified the ingredients of suc-
cessful cooperative business enterprise; others
have but feeble beginnings. But in all instances
and in all countries in the region, there is
definitely a recognition of the possibilities of
cooperative strength, without which the coun-
tries will always remain backward and unable
to enjoy their fair share of the dignified and
decent life to which every human being aspires.

Cooperatives, if given favourable conditions
for development, can truly be an effective in-
strument for economic and social development.
They can alleviate the condition of the less
fortunate segments of our society that are in
need of social and economic amelioration, and
should have the right to enjoy the privilege of
self-development, social growth, and economic
independence under a truly just and demo-
cratic society. — VICENTE U. QUINTANA.
*Agricultural Credit and Cooperative Institute,
University of the Philippines at Los Baños,
College, Laguna, Philippines.*

India's Experience

This section discusses the developments in
the rice processing industry in India during
the past 9 years, and is restricted mainly to the
technical aspects of harvesting, threshing, dry-
ing, storage, parboiling, and milling. It pre-
sents a picture of the traditional practices,
the stages through which India moved to begin
modernization programs, some of the things
that were learned, the present situation, and
the starting organizations.

Traditional Practices

Before discussing the modernization pro-
gram in India, I will briefly discuss the tra-
ditional methods. This will give a clear indica-
tion of why we started modernization pro-
grams in India.

Harvesting and Threshing

Throughout India most paddy is harvested
and threshed by hand. The paddy stalk is
cut from the stubble and moved to the
threshing floor. Paddy is then threshed by hand
beating, trampling by bullocks, and some cases
"trampling by tractor." In some areas different
types of mechanical threshers have been used
on a very limited scale. Needless to say these
threshing practices incurred large losses in
terms of field losses, handling losses, and
threshing losses.

Drying

Until very recently most paddy harvested
in India was sun dried. This was accomplished
mainly by leaving the paddy standing in the
field until it was dried to approximately 14%

moisture. In some cases this was not possible and the paddy was harvested earlier, at a higher moisture level, and spread on sun drying yards and roads to permit drying to a sufficient level. Paddy that was parboiled was also sun dried on drying floors after parboiling.

Storage

Many farmers retained a large portion of the harvested paddy, which was usually stored in mud constructions in the village. Paddy that moved to market was procured and stored in "godowns" or warehouses. These warehouses ranged in capacity from a very few tonnes to several thousand tonnes. Very limited attention had been given to storage facilities and storage practices, and because of this, large losses were incurred during storage mainly due to rodents, birds, insects, and fungus growth. Very few stores had wooden dunnage, hardly any stores had fumigating facilities, and most stores were open to rodents and birds.

Parboiling

Practically one-third of India's paddy is parboiled. In small local rice mills the paddy is soaked in concrete soaking tanks and then steamed for a short time in metal steaming kettles. In some cases both the soaking and the steaming operations were done in used oil barrels. Very little attention was given to the quality of the rice, the parboiling was not uniform, and there were a number of admixtures.

Milling

India was blessed with about 50 000 registered huller rice mills and some 2000 disk-sheller rice mills. Very few mills had paddy cleaners, and hardly any mills had rice graders. Mills varied in size from a few hundred kilograms per hour to several tonnes per hour. Until this time there had been no effort to look at or solve the problems related to this industry.

Pilot Project Development

Study and Recommendations

During 1963 a study team consisting of representatives of the Government of India assisted by Ford consultants conducted a comprehensive study of the milling industry in India. In September 1963 they submitted the findings of their study and their recommendations: (1) the paddy received from the farmers is low in milling quality, and improved production practices and varieties would provide better paddy for milling; (2) traditional storage in India does not provide adequate protection, and an estimated 5% of the paddy can be saved by improved storage techniques and facilities; (3) milling machinery manufactured in India was designed 30–50 years ago. Most of this machinery consists of hullers that give a rice outturn of 64%, the rest are sheller-type mills that give an outturn of 68%. Many improvements have been made throughout the world and modern milling machinery is expected to produce a rice outturn of 71–72%; (4) the design of, and suggestions for, modern storage and rice milling facilities for several installations in India were included; (5) for each of the modern storage and milling facilities, the expected increase in outturn of rice would save 1600 t of rice per year. This traditional outturn would have an estimated value of 1 100 000 rupees; (6) the proposed modern storage and rice milling facilities would operate at a lower cost than mills currently in use; (7) India needs 1000 modern rice mill installations, which could make a major contribution to food supply and reduce the cost of storage and milling; and (8) additional research and evaluation, and a training program for rice mill operators on improved storage and milling techniques were proposed.

Project Planning

Following the above report, the Ministry of Food and Agriculture made the decision to begin a pilot project in modern paddy storage and processing. Their plans called for establishing seven pilot plants. Each one was to include mechanical handling equipment, silos for storage, mechanical driers, modern parboiling equipment, and modern rice milling machinery. With the exception of the seven imported rice mills, all the equipment was to be manufactured in India, and all silos were to

be of reinforced concrete and constructed in India.

Project Implementation

Construction began at the sites in 1965 and companies began to manufacture equipment. This equipment had not been built in India previously. All the industries faced many new problems, simple and complex: How fast do you operate the belt conveyor? What are the design pressures? What air velocities and air temperature? It may be worthwhile pointing out that by early 1966 progress had slowed to a standstill, mainly due to insufficient plans, detail, and coordination and it was necessary to go "back to the drawing board." Detailed plans and equipment specifications for driers, cleaners, parboiling equipment, and conveying equipment were brought from abroad and given to the manufacturing firms. With replanning, project coordination, and a full-time consultant, the project began to move forward. By the latter part of 1966, some of the mills, driers, and parboiling plants were in operation. Still later the silos were commissioned and were ready for operation.

Since this was the first time for manufacturing firms to build driers and cleaners, much time was spent in the factories on designs and construction. As the modern facilities were completed, operational problems arose.

Commissioning and Tryouts

Mill, drier, parboiling, and storage operators had to be trained on the job. For example, manufacturing firms had built a drier, according to plans, but had no idea of how it was operated. Foreign rice mill suppliers sent their technicians to supervise installation of their machinery and conduct on-the-job training in its operation. During the tryout period many practical problems arose, for example the drier feed-rolls did not function properly. After rebuilding these on site, the driers were put into operation. Many similar small problems had to be worked out with the cleaning and conveying equipment. During 1966–1968 most of the problems related to the new industry were

worked out, and the seven pilot plants were put into operation.

Supporting Industry

The success of the pilot project should be credited to many government and private industry personnel. Without their patience and initiative, the project may not have been completed. Consulting civil engineers assisted with the silo designs and the buildings and machinery foundations. The manufacturing industry did a magnificent job in turning out the new equipment. Contractors, working with all those concerned, coordinated the efforts and completed all construction without undue delays. As a result of this, India now has three major firms manufacturing modern rice mill machinery, in collaboration with foreign firms; several manufacturers with standard lines of mechanical driers, parboiling equipment, and conveying equipment; and a number of smaller manufacturing firms that offer various components for the rice processing industry, such as blowers, burners, gear drives, belting and even cleaners, rubber roller huskers, and paddy separators.

Some Things We Learned

Drying

Since the seven pilot projects were each considered a commercial rice mill (1, 2, and 4 t/h capacity) with supporting facilities, the LSU continuous flow drier was used in conjunction with tempering bins, storage bins, and the necessary conveying equipment.

The drier is much more efficient when paddy is precleaned. It averages 2% moisture reduction per 30-min pass (to dry paddy from 20 to 14%, three passes are required). Paddy is tempered between passes from 8 to sometimes 20 h. For drying field paddy, air temperatures ranging from 60 to 82 °C (140 to 180 °F) have been successfully used. Higher air temperatures dry paddy a little faster, but cause more paddy breakage during milling.

Parboiled paddy is recirculated in the drier, without tempering, at regular intervals. An air

temperature of 93 °C (200 °F) is used in the first part, and 82 °C (180 °F) for the remaining drying time. These higher air temperatures for parboiled paddy have not affected head yields. Furnace oil is being used, instead of kerosene, since it is cheaper. The drier is used as a direct fired unit, without heat exchangers. A steam heat exchanger has been used in a number of cases as the source of heat, and works most satisfactorily. Husk from the rice mill is burned in a husk-fired boiler, producing steam for the heat exchangers. This system has the lowest operating cost, even though its initial cost is higher.

Including depreciation, interest, maintenance, fuel, labour, and overhead cost, Mr. Bal from Kharagpur reports that the drying cost of parboiled paddy is 18.5 rupees/t of paddy, as compared to the sun drying cost of 12.5 rupees/t. It is assumed that if losses resulting from sun drying are considered, mechanical drying would be less expensive. Rao, from Kharagpur, reports that the drying cost of field paddy varies from 6 to 10.33 rupees/t.

Storage

The pilot project included reinforced concrete silos of different capacities, which had hopper bottoms for gravity flow unloading. Later a number of flat bottom silos were constructed, using labour and sweep augers for unloading. With the experience and particularly the economics of both types, it is recommended that large capacity silos for general storage, which are unloaded only a few times per year, be constructed as flat bottom silos. Silos used as receiving bins, working bins, or tempering bins should have a hopper bottom for easy unloading, with a minimum of conveying equipment and labour.

In several cases prefabricated metal silos were considered and even though their grain-keeping quality was good, they were more expensive than the reinforced concrete silos.

The first silo installations cost 380 rupees ($50.67) per tonne of storage capacity (260 rupees for civil works plus 120 rupees for the mechanical works). Today, new silo installations cost 210 rupees ($28) per tonne of capac-

ity (150 rupees for civil works and 60 rupees for the mechanical works).

Godown construction costs vary considerably from one part of India to another. Costs range from 150 to 225 rupees ($20 to 30) per tonne of storage capacity. In most cases construction cost is generally higher in the case of godowns. This is mainly due to the cost of gunny bags and the labour required to move the gunnies (see Table 49).

TABLE 49. Costs for grain storage in India (in rupees).

		Silos	Godowns[a]
(1)	Investment cost for 4000 t	880 000	680 000
(2)	Operation costs		
	(a) Staff salaries	7 200	7 200
	(b) Labour costs	—	8 000
	(c) Electricity	2 400	1 200
	(d) Maintenance	8 800	13 600
	(e) Depreciation	17 600	20 400
	(f) Interest on investment	66 000	51 000
	(g) Gunny bags	—	22 890
	Total	102 000	124 290
(3)	Storage cost/tonne/month	2.12 ($0.29	2.59 ($0.35)

[a]Note the high cost of maintenance and depreciation for locally built godowns.

Parboiling

The Central Food Technological Research Institute developed a parboiling process that has two simple steps: (1) soaking in hot water for 2–3 h; and (2) steaming for 15–30 min. A simple steel tank is constructed for soaking the paddy and hot water is recirculated during the soaking period.

Water temperature is kept at 60–70 °C. After soaking, the water is drained, and the paddy is steamed in the same tank. After steaming the paddy is unloaded, through the bottom of the tank, and moved on to either sun or mechanical drying. Husk-fired boilers supply the hot water and steam for the process, making the operation very economical. The size of the parboiling plants can vary, but they

usually are 24, 48, or 96 t/day to match the capacity of a 1, 2, or 4 t/h rice mill.

Milling

An analysis of milling studies is presented in "Comparative Performance" on pages 273–277.

Harvesting

Throughout India most of the paddy is harvested and threshed by hand. The paddy stalk is cut from the stubble and then moved to the threshing floor. The grain is then separated from the straw by hand beating or trampling by bullocks. Only in a few areas are simple mechanical threshers being used. Paddy moisture content at harvest varies with different practices. In most areas of India paddy is left standing in the field until it sun dries; in other areas, it is harvested at 20–25% moisture and stacked until dry before it is threshed; whereas, in other areas the paddy is harvested and threshed at a relatively high moisture content. Both the harvesting and threshing methods affect the quality and yield of paddy. Each variety of paddy has its individual properties known as "varietal characteristics," which means that varieties may differ from each other with respect to their requirements for harvesting, threshing, drying, and milling.

Several authors have reported results of harvesting and drying studies. The Rice Process Engineering Center at Kharagpur, India, reports that the optimum harvest moisture content of IR8 was found to be between 21 and 24%. The average field yield at this moisture level was 6740 kg/ha but it was reduced to 5550 kg/ha when the crop was harvested at 15% moisture level. During the sun drying process, the overmature paddy begins to shatter and fall and is lost in the muddy soil; some of the paddy is consumed by birds and rodents; and some is lost in cutting and transporting. These losses account for the 21.6% reduction in field yield during the field drying, harvesting, and threshing processes.

From this and other reports it may be summarized that paddy harvested at the optimum moisture level, following maturity, produces more yield per hectare than paddy allowed to remain in the field to sun dry. This provides a larger income to the paddy grower. Experience has also shown that paddy can be harvested and threshed by hand, at relatively high moisture levels, overcoming the traditional practices.

Expansion After the Pilot Project

Probably the most effective method of evaluating a pilot project is to observe the effects it has had on the industry. As the seven pilot rice mills went into production the industry immediately began to see the benefit of modern milling. Manufacturing firms then collaborated with foreign firms and began to manufacture modern rice milling machinery in India. From the seven pilot units, the first expansion was by the Food Corporation of India, which installed 24 modern rice mills. Today, approximately 4 years after the pilot plants were started, cooperative and private rice millers have built approximately 200 complete new modern rice mills and conducted several hundred modernization programs. A modernization program adds rubber roller shellers, paddy separators, and sometimes paddy cleaners and rice polishers to a miller's equipment. In many cases millers have also added modern parboiling tanks or mechanical driers.

Today there are also a number of smaller manufacturers that produce only rubber roll shellers, paddy cleaners, or other component machines for the industry.

Organization in India

A number of different organizations in India are supporting this modernization program in various ways. The Food Corporation of India has helped lead the way, both in milling and storage, and has also helped in quality control and in rice standards and grades. The Central Building Research Institute has studied problems of storage and designed a number of small, scientific, village storage facilities. They have also worked on the design and construction of larger silos, which has helped reduce

costs. FAO has a drying and storage project with the Storage Institute at Haipur. Here they are studying farm and village drying and storage problems. They also are assisting with extension education programs. The Ford Foundation has assisted the Government of India in establishing a Rice Process Engineering Center at Kharagpur. This is the first such institute in the world. Here they are engaged in research and development, teaching and training programs, and extension work in all aspects of paddy and rice storage and processing. The Central Food Technological Research Institute at Mysore has done work in parboiling, food technology, drying, and insect control.

These and other groups are assisting India in studying the problems, designing new equipment, implementing new programs, and generally expanding the concept of modern scientific storage and processing. — JAMES WIM-BERLY. *IRRI – Ford Foundation Sri Lanka, Rice Processing Project. Colombo. Sri Lanka.*

Case Studies

Borromeo Integrated Rice Case

The following two presentations are case studies on a proposal by Mr. Carlos Borromeo to establish an integrated rice operation. Although these discussions are not illustrative of either correct or incorrect presentation of a case analysis, they provide an insight into the reasoning that should be used in an analysis and provide a basis for discussion.

Mr. Borromeo purchased a modern drying and storage central with a mill and proposed to undertake the drying and storage needs of the area. Because he did not own any rice paddies he based his supply upon purchasing paddy from local farmers. He wanted to purchase, dry, and store the paddy when it was at a low

price and market a high quality rice at a premium price.

These case studies were able to forecast some of the troubles he would encounter.

Study 1

That the rice industry in the Philippines is extremely chaotic and in desperate need of rationalization is an observation that cannot be denied. The gross inefficiency of the whole system has adversely affected the well-being of both the producer and the consumer. Mr. Carlos Borromeo, a businessman, feels that this condition of the industry, coupled with dramatic technological breakthroughs, provides an excellent business opportunity. He envisions the development of an integrated rice operation that will overcome the credit, grading, storing, and retail problems of the rice industry.

Supply

Most of the rice produced in the country has substandard quality, and only a negligible portion would qualify for the world market. Because it is Mr. Borromeo's plan to deal with high quality rice, supply presents a formidable problem. It would be very difficult to get the farmers to produce quality rice even with the guaranteed price Mr. Borromeo is planning to offer. Besides planting, quality requires more fertilizer, knowledge of the modern methods of farming, better irrigation systems, and quality seeds, all of which result in higher expenses for the farmers. It would be difficult for the farmers to invest more, even with the prospects of increased earnings. To most of us the farmers' behaviour may be irrational, but for the farmers it is wise, and for some the only decision, because they have limited capital. Even if enough farmers agreed to produce quality rice, they might expect technological and financial assistance from Mr. Borromeo, which would increase the operating costs of the company.

Another problem would be the financial and personal commitments of the farmers. Many of them, because of hard-up conditions, borrow money from traders using their crops as

collateral; therefore, even before planting they have already sold their harvest. This relationship has existed for years, and is based not only on financial but on personal considerations. The traders are so entrenched in their position that it would be very difficult for Mr. Borromeo to dislodge them, especially if we consider that the projected requirement is 54 000 cavans of paddy. It is true that farmers can borrow from government institutions and rural banks, but experience has shown that it is much easier to borrow from traders.

Mr. Borromeo did not consider the risk from natural calamities. This is one reason why farmers would be reluctant to invest more. One strong typhoon and their investments would go down the drain, and Mr. Borromeo's supply would be gone. It would take time before a new crop was harvested, and meanwhile, his operating costs would be running continuously. It might be difficult for his company to look for quality rice in other areas, and transportation costs might be prohibitive. Furthermore, there is no assurance of the needed volume.

There are some factors in his favour, however. There are revolutionary developments in the rice industry that will result in higher and better production and credit is available from the Development Bank of the Philippines (DBP), Central Bank, rural banks, and other government institutions. Specifically, he may avail himself of the DBP's rice processing and storage program, the 100 000 peso CB–DBP Cereal Procurement Programme. It is doubtful, however, that these factors would be able to fully overcome the problems discussed. At best, he can meet his supply requirements after a few years, but not in his first year of operation.

Rice Processing

The government policy of encouraging the private sector in this area will help Mr. Borromeo; therefore, financing the equipment will not be much of a problem. We can assume that he will avail himself of modern facilities, e.g. warm air driers, bulk storage, and rubber roller mills; however, this area is not without problems. There is a scarcity of competent person-

nel who can run these facilities. Furthermore, only a few warehousemen invest in mechanical warm air driers because of their low returns. It does not necessarily mean that the company will have low returns on this, but this factor is worth considering. Problems in rice processing go hand in hand with supply. If there is insufficient supply, facilities will be underutilized, but the fixed costs will run at the normal level.

Finance

The financial projections of Mr. Borromeo are premised on highly questionable assumptions. (1) Adequate supply as early as the initial year of operations. As discussed earlier, this assumption is highly improbable. The breakeven point for the company is 40% assuming that his costs breakdown is correct. Mr. Borromeo should prepare to suffer initial losses, and his investment should give allowance for this. (2) All rice produced will be sold. Mr. Borromeo plans to sell quality rice in packages at a premium. Although this may sound like a novel approach to rice marketing, the probability of customers' rejection of the scheme is relatively high. Studies on consumer preference for packaged rice should have been conducted beforehand.

Furthermore, some costs were not considered. (1) Transportation expenses. Because he will sell his rice through retail outlets, Mr. Borromeo will have to deliver his rice to them. Transporting rice to retail outlets is expensive. It may even require acquisition of trucks. A modest provision for transportation expenses will raise his company's breakeven point to about 60–70% using 1825 t as the basis. (2) Working capital. Considering the volume of business, working capital is insufficient. For one thing, inventory alone requires a lot of money. To be able to supply on a continuous basis, Mr. Borromeo's company will have to store rice, particularly during the rainy season. He cannot expect the retailers to store rice for him. Considering that he is dealing with quality rice, the retail outlets he would be working with will be serving the middle and upper segments of society. These institutions normally expect some amount of credit to be

granted to them. Again accounts receivable would eat up a good portion of his working capital.

His financial projections undoubtedly have to be revised. Expenses are understated and sales projections are too optimistic. Furthermore, the income projections should be scaled to take into consideration the difficulties he will encounter in the initial years of operations.

Marketing

Mr Borromeo proposes to sell rice at 38.35 pesos a cavan[12] of rice to the retailers. Assuming a conservative retailer's margin of 10%, the cost to the consumer would be 42.20 pesos. The average retail value is approximately 30 pesos (figure used in the case); therefore, the premium is very high.

Mr. Borromeo's approach to marketing is novel. The rice would be packaged and sold through selected retail outlets although consumers are used to buying unpackaged rice. However, sugar packaged and sold at a premium gained acceptance. It may be argued that if it worked for sugar there is no reason why it will not work for rice. The difference lies in the amount of premium. In the case of sugar, the premium is very small, but from our computations, the premium for Mr. Borromeo's rice is very much higher. Besides, rice is our staple food; sugar is not. Even if it does gain acceptance, it may take some time. In revising the projections, this should be considered.

The government plays a very important role in the marketing of rice especially with its price control regulations. The price of rice is used conveniently by the people to gauge cost of living fluctuations. The government, knowing this, is doing its best to lower the price of rice as much as possible. If the government imposes a ceiling on the price of rice of all kinds, the profit picture of the company will be adversely affected. Mr. Borromeo can only hope that the government adopts the socialistic dual pricing system. It should be realized

that the government does, and will always, meddle with the law of supply and demand as far as rice is concerned.

Recommendations

We do not know the primary motivation of Mr. Borromeo in pioneering a new approach to the rice industry. It is clear that the problems he is facing are far more complicated than he has imagined. His financial projections are oversimplified. The success of his approach depends so much upon factors beyond his control. It is doubtful whether he can really cash in on the technological breakthroughs in the industry. For instance, the buildup given to the miracle rice or the IR8 variety as the solution to the problems, not only of the Philippines but of the world, proved to be nothing short of dramatic nonsense.[13] Then there is the government. It is a plus factor as far as supply is concerned, but a negative factor in marketing. As a businessman whose primary purpose is to make money, he should abandon his project. This is not to say that his project is not viable per se. It may succeed in the future when some of the constraints discussed above are eliminated.

If, however, Mr. Borromeo's primary purpose is to have the self-actualizing act of pioneering a seemingly novel approach, then he should go on. I recommend the following changes in his strategy: (1) the capital should be at least doubled to prepare for probable initial losses and to provide more flexibility in the operations; (2) all possible government aid should be availed of particularly in the field of financing, to minimize his financial exposure in the company; and (3) integration should be done stage by stage. The marketing of packaged quality rice at a premium should be tried. If it gains consumer acceptance, then he can start his backward integration.

It should be emphasized that even with the above changes in strategy the risks are still

---

[12]Computed as follows: 1 400 000 pesos ÷ 1825 × 50 cavants/t = 38.35 pesos per cavan of rice.

[13]Credit should be given, of course, to the International Rice Research Institute for this significant contribution. The disappointments of many should be blamed on the media for their gross exaggerations.

high and returns uncertain. — MANUEL B. VILLAR, JR. *University of the Philippines at Los Baños, College, Laguna, Philippines.*

Study 2

Assuming that Mr. Borromeo can come up with a system for his processing operations that would be technologically feasible, it appears that the bottleneck or critical point in the system would be the inputs.

Borromeo, in this case, is assuming the role of a change agent/initiator in an environment traditionally oriented in values, thoughts, and means. He wants to trade an economic idea, with its corresponding financial commitments, which must be accepted by the farmer, for the inputs for his operation. This is precisely where his problems and difficulties lie, he must assemble adequate inputs for his project to be economically viable.

Attitude of the Farmers

Farmers do not readily adopt and accept modern farm technology and new improved rice varieties because they have not had previous experience with them and "fear the unknown." This is understandable because they would naturally not want to risk their borrowed financial investments on something that is not guaranteed or proven. So, to their mind, they may as well stick to age-old techniques and methods with traditional varieties that produce proven measurable outputs and consumer acceptability. Furthermore, from the point of view of money, these changes and shifts would mean additional financial outlays, which the farmers are relatively short of. Again, we cannot expect the farmers to venture into these prospects which require more out of pocket investments, without some proven results.

Granting, however, that a considerable number of farmers are eventually convinced to change and shift to new varieties of quality grains, the absence of developed quality standards, price premiums, and assurances would only lead to further chaos in the industry and disillusionment on the part of the farmers, even if they eventually turn out high quality grains, because there are no bench marks or measures as a basis for equitable guaranteed reward. I believe that if this setback occurred, it would be very difficult to rectify since anomalies and frauds would become entrenched and the rice farmers would become unresponsive and disillusioned.

Experience

Already the farmers have had sad experiences in the past with the FACOMA's. For one thing, because of mismanagement and corruption within these entities and other related agencies, many of the farmers were cheated or simply robbed of their produce. This has left deep scars and with time these sad experiences have generalized into contempt and lack of trust for any agency that assumes functions and services similar to those the FACOMA's offered before.

This feeling is also aggravated by the fact that the farmers do not fully understand the biological nature of their produce. As we experienced, they would have their paddy stored fresh after harvesting. Naturally, the paddy would still have a high moisture content. When they claimed their paddy, it would have had time to lose some of its moisture content and its weight would be less than when brought in, and they blamed the FACOMA for stealing their produce. Another thing the farmer cannot accept is the fact that when he brings his produce to institutional processing operations, the grains are inevitably mixed and the farmer loses all means of identifying his own particular produce. This apprehension stems from the belief that his own particular grains are always better than those of the other farmers. When the time comes to draw out his grains, he is wary about not getting grains of equivalent quality. These factors intermesh with the problem of setting up or developing quality standards for the grains.

Financial and Personal Commitments

This appears to be the most critical aspect because, through time, the business relation-

ship between the farmer and his creditor has developed into a friendly and well established personal bond. The Filipino "utang-na-loob" comes into consideration here because when Borromeo asks a farmer to bring his produce to him, the farmer will think: "It was Pare Andong who provided for me during the planting season. He took care of the needs of my family and even the hospitalization of the Boy. I owe it to him, my crop and my gratitude. So why should I sell to Borromeo? What has he done for me – I don't even know him."

If only 50% of the farmers targeted by Borromeo to supply his inputs think like the farmer cited, all of Borromeo's projections for economical utilization of his system would be thrown off and he would be left with a very big plant lying idle. Therefore, if Borromeo hopes to compete in this aspect of ensuring assembly of inputs for his operations, he must not only assume the role of creditor and middleman, but he must also develop ties and bonds with the people in the community. He must blend into the social structure or organization of the environment he has targeted to tap.

Trading Practices

The farmers who are inevitably caught in a financial stranglehold by their creditors have no recourse but to sell their crops upon harvest directly to their creditors or dealers, usually on terms dictated to them to pay off their debts and commitments.

The dealers in turn concentrate mainly on the trading aspect of the business and are very reluctant to invest and participate in bulk storage. This is due to the fact that the government is in the industry and is controlling prices. The dealers are afraid to get caught with big bulks of rice at a government price ceiling lower than their acquisition cost. Because trading in the industry is brisk, active and fast dealers find it easier to realize larger profits by concentrating only on the trading function rather than tying up capital in inventory and storage facilities and assuming more risks.

We have been traditionally a rice importing country. Our production has always been well below our consumption requirements. From

the farmers, the assembly points, and the rice mill, therefore, the rice is directly marketed to the consumers to satisfy their immediate demand. Since theoretically there is no buildup of inventory or surpluses the need for facilities for long-term bulk storage has never been acutely felt. In fact, what we really often have are empty or under-utilized storage facilities.

Conclusion

I believe, that at this time, it was premature for Borromeo to set up his pilot project, which was beyond his capacity and capability.

With the monumental problems in the rice industry, which were recognized by Borromeo, it was foolhardy for him to have initiated the project without definite and adequate pledges from our decision makers and without having coordinating government agencies monitor his pilot project to give assistance and support and to institutionalize the project.

Recommendations

There are three oganizational levels working in the agribusiness system. In this context the following framework is recommended for formulating a working strategy and a method of implementation for Borromeo. It takes into account the involvement of both our decision-makers and government integrating and coordinating agencies.

Decision-Makers

(1) Determine and outline policy goals and objectives: (a) to provide government subsidy in the form of price assurances for grain crops, availability of cheap inputs like fertilizers, certified seeds, and insecticides; (b) to make available needed financing for production to farmers on low interest and easy payment terms; (c) to encourage formation of cooperatives to help farmers secure credit facilities, acquire equipment, and improve product marketing; (d) to implement infrastructure projects by the government, like irrigation systems and roads, to stimulate further growth in pro-

duction; and (e) to pursue the initial gains of increases in price production output brought about by land reform.

Integrators-Coordinators (DANR–NGA)

(1) Design a system for information gathering and feedback. (2) Allocate tasks to government implementing agencies for their respective participation: (a) NGA — determine pricing system to include assurances and support; promulgate policies on all activities related to processing, storage, transport, and marketing of grains; develop quality standards; determine priorities in setting up integrated facilities by physical location considering economical utilization of grain processing capacities and ensuring adequacy of supply at both ends of the system: encourage organized interrelationship among producers, warehouse millers, financiers, and farmer organizations; coordinate with other government agencies the program of extension service and infrastructural facilities; and encourage the adoption of proven systems in production processing and marketing phases to reduce costs and improve quality of grains; (b) Central Bank — formulate the credit policy and make available the needed financing for production, storage, processing, and marketing aspects; and (c) Bureau of Public Information — program public announcements to provide general information to the public at large about the rice industry; provide specific information about developments in the rice industry for people in the rice business; and educate the farmers and people concerned in the different functions of the industry. (3) Continually seek improvements and stimulate development of the rice industry.

Initiator

As the initiator in this case, Borromeo has the burden and responsibility of studying and analyzing the environmental factors that will affect the functional consideration of the integrated rice system he envisions.

From this system he should evolve his strategy that would be manifested in his ideas on how to compete, recognize opportunities, and allocate his resources. — JOSE C. LAPUS. *University of the Philippines at Los Baños, College, Laguna, Philippines.*

PROCESSING
METHODS

India

India is one of the major rice growing areas in the world, and rice is consumed by more than half of its population. The increase in rough rice production in the last few years is due mainly to the Green Revolution, the introduction of high-yielding varieties, along with increased manuring, improved irrigation systems, pesticides, and the help of international organizations.

Although our country has many different languages and regions and the people have entirely different living systems and food practices, paddy is still cultivated, in all regions, as it was in the past. However, postharvest operations vary widely from region to region. The people initially obtained rice by hand pounding, which is very laborious, so they switched over to processing operations in Chakkies; however, when hullers were introduced, these two processing systems became totally outdated. There are indications, however, that in some of the hilly areas in India, these systems are still in practice, although the quantity processed is negligible when compared with the total production.

It is not known how and when parboiling started in India. Undoubtedly, the parboiling of paddy was found healthy, apart from economic advantages like higher yield from soft varieties. When there was an acute shortage of food grains in India during the sixties, a delegation from the Ford Foundation studied the problems in the country and indicated that if existing outdated processing units like hullers were replaced by suitable modern equipment, a few hundred thousand tonnes of extra rice could be obtained and fed to the hungry population. Hence, seven imported modern rice milling units were installed in different regions in the country.

Of the roughly 67 000 processing machines in India about 60 000 are hullers. However, it has been found that modern rice mills are capable of yielding more marketable rice than hullers and under-runner disc shellers. The extra yield obtained by processing raw paddy by modern mills instead of hullers and shellers is 6.6 and 2.5%, respectively. For parboiled paddy the increase over hullers is 1.6%; over shellers it is 0.8%.

Parboiling is a method of processing that combines soaking with heating by external sources. It helps to strengthen the kernel (gelatinization of starch) and enables even weak soft grains to withstand milling without breakage. In fact, sun-cracked grains bind themselves remarkably well and mill like hard whole grains after they are parboiled. Compared with raw rice, parboiled rice is richer in vitamin B and has much less cooking loss if the gruel is drained.

Cold Soaking Method

In this method, the paddy is allowed to steep in cold water for 2–3 days. At the end of this period, the soaked paddy is open steamed, dried, and milled. To reduce the length of the soaking time the raw paddy can be steamed prior to steeping in cold water. Both of these methods are now being adopted all over the country because of their obvious advantages of low cost and convenience in operation.

Hot Soaking Method

During the fifties, the Central Food Technological Research Institute (CFTRI) developed a method of hot soaking the paddy at 65–70 °C followed by open steaming. This method is, however, finding only limited application in the country partly because of the high cost of steam required for heating the water and, to a great extent, because of the difficulty of handling this paddy with the human labour that is used in most of the mills in the country.

Improved Method of Soaking Paddy

Recent studies conducted at the Paddy Processing Research Centre, Tiruvarur, have shown that during soaking, the paddy passes

from a resting to an active condition. It starts respiration, goes through changes that are preparatory to germination, and undergoes breakdown changes that result in part of the rice kernel passing into the surrounding aqueous medium. The soaking loss as a result of this averages 3.0% of the weight of the rice kernel, and increases with increased soaking time. It was observed that the unpleasant odour associated with parboiled paddy, which is caused by material passing from the kernel into the liquid medium, could be eliminated if an oxygen donating substance, for example a chromate, dichromate, permanganate, hypochlorite, ferric salt, or peroxide, was included in the medium. In the presence of such substances, there was also a 1.4–2.9% increase in the yield of brown rice (Table 50).

Parboiling in Modern Rice Mills

In the parboiling plants attached to modern mills, hot soaking is now being adopted to speed up the operations. But it has been reported that about 60% of the steam produced by the boilers is required to heat the water needed for parboiling. Removal of chaff and immature grains from hot soaked paddy is difficult; therefore, the resulting milled rice contains a high percentage of brown and dark residue from the immature grains, making it unattractive to consumers. The machinery that

was installed for the production of parboiled paddy was not compatible with the capacity of the mills and the cost of operations were found to be high. The quality of the parboiled rice was also not up to the expectation of the consumer. The chief advantage of the modern rice mill is the high quality of its bran, but the return from it cannot adequately compensate for the extra cost involved. The major portion of this cost goes towards the drying of the parboiled paddy.

Rinsing of Soaked Paddy with Brine

The TCMF Laboratory, Tiruvarur, has developed a method of rinsing the soaked paddy with brine (specific gravity 1080–1100) that closes the paddy husk during parboiling and reduces the absorption of water during steaming, thereby saving on the cost of drying to the extent of Rs. 4–6/t of paddy. The mill machinery needs periodic protective coating against possible corrosion.

Continuous Steaming Method

The Paddy Processing Research Centre, Tiruvarur, in collaboration with the TCMF engineers, has developed a method of steaming in which the soaked paddy gets uniformly parboiled while it moves along a slow conveyor. The advantage of this method is that uniformity of parboiling is achieved, which

TABLE 50. Effect of treatment of steep water on the yield of parboiled rice from paddy.

Name of mill and location	Variety of paddy	Experi-mental	Control (untreated)	Percentage increase in yield over control
Veeyar Rice Mill, Kuttalam	CO-25	SS + C	DS	2.8
Veeyar Rice Mill, Kuttalam	Ponni	SS + C	DS	1.9
West Rice Mill, Kuttalam	Nellore, Samba	SS + C	DS	1.7
Appachi Gounder & Co., Somanur	ADT-27	SS + C	DS	2.2
Veeyar Rice Mill, Kuttalam	IR8	SS + C	DS	2.3
Veeyar Rice Mill, Kuttalam	IR5	SS + C	SS	2.9
Buddha Rice Mill, Sulur, Coimbatore	ADT-27	DS + C	DS	2.3

[a]SS = single steaming, i.e. cold soaking of raw paddy followed by steaming; DS = double steaming, i.e. soaking of steamed paddy followed by steaming; and C = addition of chromate at 0.05–0.1% to steep water.

results in a better appearance of the parboiled rice and an increase in the oil content of the bran.

Pressure Parboiling

The data collected show that pressure parboiling ensures more uniform parboiling than open steaming. If the paddy is merely wetted or steamed before pressure parboiling, loss of kernel material during parboiling can be eliminated. The oil content of the bran obtained from polishing the brown rice is about 30%.

Maximizing the Oil Content of Rice Bran

To increase the oil content of paddy, which is normally 1.2–2.0% by weight, a regular breeding program has been initiated. Some of the varieties of paddy were found to contain up to 4% the weight of rough rice in oil (Table 51).

Recent studies undertaken by the Paddy Processing Research Centre, Tiruvarur, have

TABLE 51. Oil content of some varieties of paddy on a whole paddy basis (Paddy Processing Research Centre, M. R. Mills, Tiruvarur).

Variety	Oil content (%)
Cal rose/B₂b	1.15
B₂b Na HDA	1.41
B₂b HY 275/1	1.79
Black Pusher	1.8
AC-GGE	1.9
SLO-16	2.0
B₂b YPR-8	2.09
B₂b Assam-31	2.1
B₂b NORIN-1	2.22
B₂b NORIN-4i	2.37
B₂b TKM 6	2.45
B₂b Assam-34A	2.55
IR20	2.6
Karuna	2.65
B₂b W 94	2.95
B₂b Dawn	3.02
ARC-5902	3.1
B₂b Hamsa	3.15
B₂b Agomimontakag	3.4
B₂b CH-45	4.1
YPR-6	4.45

shown that the oil content of the rice bran can be increased up to 35% of its weight by manipulating the soaking and parboiling time. Prolonged soaking followed by steaming was found to increase the oil content to 25–30%; pressure parboiling increased the oil content of the bran to about 35%.

Postharvest Care of Rice

Most of the rice-growing area is in the humid regions. In certain parts, there are incessant rains during the harvest stage. The respiratory and other attendant changes are accelerated if the paddy that is harvested during humid weather is not attended to immediately. The FCI, the major procuring and processing agency in this country, realizing the gravity of the problem, established a series of mechanical driers at strategic points. In practice, the drying cost is found to be high as a result of using oil-fired burners in these driers. The IIT, Kharagpur, and other institutions in India are working on the replacement of the oil-fired burners with husk-fired ones. The FCI has designed and developed a mobile husk-fired drier to meet the requirements of the villagers. This drier has proved to be suitable for the northern regions of India.

Preservation of Wet Paddy with Chemicals

The research studies undertaken at the Paddy Processing Research Centre, Tiruvarur, have shown the possibilities of arresting the germ activity and other attendant changes that lead to the loss of dry matter from the paddy due to increased respiratory activities. In addition, heating, discoloration, and damage to paddy are prevented. Of the various chemicals tried, common salt at a level of 5–6% of the weight of the paddy was found to confer the necessary protection. The germ activity was suppressed without affecting the viability. Dry matter loss, which was found to be up to 12% after 10 days of storage of untreated paddy at a moisture content of about 23%, was considerably reduced when the paddy was treated with salt at a 5% level and

stored after the water was drained. The salt withdraws the water from the paddy by exosmosis, without more than a trace of it entering the paddy. The rate of reduction of the moisture content is given in Table 52.

TABLE 52. Rate of reduction in the moisture content of the rice kernel as a result of dry salt treatment.

	Percentage moisture content of kernel	
Time (h)	ADT-27	IR8
0 (initial)	25.0	27.0
12	20.9	16.2
24	19.7	16.6
36	19.3	16.0
48	18.5	16.6
60	17.8	15.0
72	16.9	15.0
84	15.6	14.5
96	13.6	13.2

Increasing the Oil Content of Bran in Hullers

Generally the bran produced in the huller mills contains about 6% oil. Because of this low level, extraction of oil commercially is found to be unprofitable. To increase the oil-bearing material in the bran produced in hullers, work has been initiated at the Paddy Processing Research Centre, Tiruvarur, that has resulted in the production of bran containing about 15% oil by modifying the hulling and blowing operations. The paddy is first shelled using a wide blade clearance on the huller. The shelled mixture is passed into a winnower for separation of the husk and is then polished. The polished bran gives an oil content of 15% with a low ash content.

In modern milling, the brown rice is polished in two or three polishing cones. After the superficial bran layer is removed from the rice by the first polishing cone, the sub-aleourone layer can be removed separately. After extraction of the oil, the bran has a whiter colour and can be added to any suitable flour material.

By-Product Utilization

The germ is the most valuable component of the rice kernel that is removed during milling; however, it could be recovered in a clean condition if a completely shelled (brown rice free from grit and stones) and cleaned rice was used. This germ gives 35–36% oil and the extracted material gives 33% high quality protein. The germ produces a white flour with a flavour reminiscent of almond, and is a very good source of vitamin B1.

The extraction of silicate from partially charred husk is comparatively easy and deserves attention because of a growing demand for silicate in various industries. A completely ignited white product containing 95% silica could serve as a base for organic chemical industries.

Preharvest Spray of Brine to Hasten Ripening and Reduce the Moisture Content

Recent studies carried out at the Paddy Processing Research Centre have opened up a new line of approach hastening the ripening phase of the paddy crop. Spraying brine on matured paddy even if it is under water stagnation makes the grain uniformly ripe and reduces its moisture content. In one trial, applying brine (specific gravity 1100–1150) resulted in uniform yellowing of the paddy so that no green colour remained and the crop could be harvested in 2–3 days time; however, the untreated control took about 10 days to attain uniform yellowing. An appreciable drop in the moisture content was also noticed when the ears were sprayed with brine (Table 53).

Using two sprayers with double boom discharge mechanisms, it is estimated that about 4 ha (10 acres) of paddy crop can be sprayed by two workers in an 8 h day. The economic utilization of this new technique is shown in Table 54.

Conclusions

This is only a portion of the problems solved and the practices adopted in India. No doubt,

when compared with the old era of hand pounding, we have achieved much more than we imagined possible in a comparatively short period, but we still must solve the practical problems involved in the processing of rice in a large country like ours. — R. CHANDRASE-KARAN AND P. PILLAIYAR. *Paddy Processing Research Centre, M. R. Mill, Tiruvarur, S. India.*

TABLE 53. Moisture drop after 4 days of salt spray treatment on standing matured paddy (variety CO-25).

Treatment	Paddy moisture (%)
Control	29.0
Salt solution (specific gravity 1.100)	14.5
Salt solution (specific gravity 1.200)	14.5

TABLE 54. Effect of preharvest spray of brine on paddy (variety IR20, Regional Research Station. Aduthurai)[a].

	Harvested Feb. 19, 1973		Harvested Feb. 24, 1973		Harvested March 9, 1973
	Control	Brine treatment Feb. 16, 1973	Control	Brine treatment Feb. 24, 1973	Control
Period from sowing (days)	140	140	145	145	158
Period from general flowering (days)	31	31	36	36	49
Yield on a wet basis (kg/acre)[b]	1704	1603	2004	2011	1743
Moisture content (%)	23.56	19.13	18.08	15.92	11.0
Yield on a dry basis (kg/acre)	1303	1280	1641	1692	1551

[a]Date of sowing October 2, 1972; date of planting November 16, 1972; and date of general flowering January 10, 1973.
[b]1 kg/acre = 2.47 kg/ha.

Indonesia

Indonesia, with 120 million people in 1972, is the fifth largest country in the world. The archipelago consists of over 3000 islands. The country is predominantly agricultural, with 85% of the total population living in rural areas.

Because rice is the staple food of the majority of the people, it is more generally preferred than any other crop. The soil and climate are suitable for the growth of rice and it is grown in all provinces of Indonesia. Rice is generally cultivated in "sawah" (irrigated land). Farmers also plant rice in the dry season if irrigation water is available.

Production

The country's average rice yield is about 11.4 million tonnes per year. While the consumption of rice increases rapidly as a consequence of the population growing at 23% per annum and the increase of per capita consumption, the production of rice is not keeping pace with the increasing consumption. To meet the local rice demand, the government, for the past several years, has resorted to importing rice, which has caused an annual drain on foreign exchange earnings of about 15%. In the last 13 years, Indonesia has been

importing rice amounting to over 10% of domestic production.

Starting in 1965, a promising program was initiated to induce rice farmers to increase their production at a profit both to themselves and the nation. This program is the so-called BIMAS (Mass Guidance).

The pattern of production is basically traditional, but it is in the process of changing. Many areas still use the traditional way of ploughing. Harvesting is done manually by hand with a sickle and "ani-ani." The moisture content of the paddy is 20–25%. The planting season in Indonesia varies from province to province, depending on the rainfall. The harvesting season also varies. One reason why harvesting and planting using machinery cannot be done is the small acreage owned by individual farmers. New varieties of paddy have been introduced, and they have to a certain extent given higher yields to the farmers. In fact, these varieties are considered to produce good rice and fetch a higher price.

Processing

At present, there are two types of rice processing facilities being used in Indonesia, namely, the traditional method (hand pounding) and the modern method (rice hullers and rice mills). More than 75% of rice processing is done by the traditional method. The whole paddy production of the country is milled and consumed locally.

A thresher is needed because a lot of the farmers store paddy on the stalk, which must be threshed before it can be processed. Some of the hullers are rubber-roller types and some are stone disc or steel types. Locally made hullers are usually stone or steel mills. Small rice mills and most imported rice mills are the rubber-roller type.

The distribution of hullers and small rice mills in the villages has resulted in about a 10% change in the method of processing rice for family consumption from hand pounding to milling. This is due to the increased recovery obtained from these machines (rice huller = 55% and rice mill = 65%). The huller owners do not purchase paddy because

they do not have enough financing for purchasing paddy; they just process the rice. The big mills usually have complete facilities and services for their operation. The majority of them are owned by "BULOG/DOLOG" (National Logistic Authority). BULOG introduced the mechanical drier and the success of BULOG in using the mechanical drier has led to other commercial rice mills installing and using them.

Problems

The present rice industry in Indonesia is moving toward modernization; however, the actual capacity of the available processing facilities is lower by about 50% than the potential capacity. The rice hullers only operate about 175 days in a year, and the rice mills only operate about 123 days in a year because of the lack of raw material to be processed.

Indonesian rice farmers are at the subsistence and semisubsistence level. They sell a low percentage of their rice and the size of their rice fields is, on the average, 0.5 ha. Farmers still use the traditional methods of processing rice by hand pounding, and usually use family labour. — SJUHINAR BUSTAMI. *Rice Mill "Sinar Kongsi," 58 Diponegoro, Padang, W. Sumatra, Indonesia.*

Khmer
Republic

Paddy is one of the main traditional crops in this agricultural country in which about 80% of the population is rural. Paddy has been grown for a long time, and growing methods vary with the soil type and the variety of the paddy. Upland rice is usually directly seeded in hills, grown without levees and inundation, and depends solely on natural rainfall. Lowland rice is grown in the whole

country on sandy, sandy-clay, or silty-clay soil. There are very early, mid-season, and late varieties. Floating rice is grown in the flooded zone of the Mekong, Tonle Sap, and Bassac Rivers and around the great lakes where the height of the water sometimes reaches 5 m when the flood is slow. Semi-floating rice has the same characteristics as floating rice except that it can only support a water level from 80 to 150 cm. Dry season rice is grown in the flooded zone after the water has receded.

In general, almost all the rice varieties grown in the Khmer Republic are photoperiodic. Wet season rice covers almost all the areas under rice cultivation. Varieties used are more or less late varieties (direct sowing: April, May, and June; harvest: December, January, and February of the following year). Rainfall is one of the main factors affecting paddy production.

Harvesting

Normally harvesting begins in December. Paddy is harvested when it reaches market maturity, i.e. when a third of the panicles are still green, because this produces a good quality paddy with a very low percentage of breakage. Physiological maturity is reserved for seed production, and in this case the percentage of breakage is high. Due to the lack of labour for harvesting, a lot of the paddy is harvested at physiological maturity, which is reached after the second half of January for late varieties.

Hand cutting, with a sickle, is generally practiced in the Khmer Republic. In some transplanting areas, farmers use a kind of sickle that has the handle curved in the opposite direction to the blade. This handle is used to gather the plants before cutting. In the direct sowing areas, especially in the province of Battambang, farmers use a curved sickle forming a semicircle with a short handle. The curved handle of the sickle gathers a number of plants in the left hand for cutting. The bunch of cut plants is then laid on higher ground to avoid wetting the panicles. When a certain amount of plants has been cut, they are tied together. In some cases the harvester

only cuts the plants and another group ties the bundles, which are scattered in the fields. When the farmers finish a plot, they gather and stack the reaped paddy in one place. This method of putting the bundles in stacks is good for maintaining the quality of the paddy because it reduces the breakage percentage during milling. The bundles are carried by oxcart to the threshing floor, which is prepared near the farmer's house or village.

The problem of harvesting paddy is becoming critical because labour force competition is reducing the amount of available labour. One can try to solve the labour problem by mechanization, but farm equipment is not manufactured in the country so spare parts are rare and difficult to find. In addition, fuel and lubricating oil are expensive. The following obstacles constitute the stumbling blocks to mechanization at present: (1) an inadequate system of irrigation and drainage; (2) local varieties lodge in the harvesting machines and cause high losses; and (3) selected varieties with short straw (IR8 for example) and a short cycle reach maturity in the rainy period; however, the sowing date cannot be delayed because the field would be flooded (rainy season) and would be impossible to sow.

Threshing

Hand threshing is done by one of two methods: (1) small bundles are beat by hand against an inclined wooden threshing table until all the grains fall, a team of four men can normally thresh about 200 kg of paddy in 1 h; or (2) five or six men trample a small stack; however, the yield obtained is very low.

Animal threshing consists of having from 4 to 8 oxen or buffalo trample the bundles on the threshing floor. The yield of the operation done by four oxen in a 3 h period is six sacks of paddy, or about 450 kg.

Mechanical threshing is done in the province of Battambang where there is partial mechanization. The sheaves are lined up on the threshing floor, and a tractor drives over them. When the tractor is stopped a few men shake the sheaves with long sticks. Driving is then resumed until most of the grains are separated

from the panicles. The tractor is stopped again; the straw is removed; and the operation is completed. Four to five operations can be done on the same threshing floor. After this operation the grains of paddy are winnowed.

Many foot-operated pedal threshers (Japanese type) have been introduced in certain rice areas, but it is difficult for the small-scale farmers to obtain many of them at once for the threshing operation. The capacity of the pedal thresher is low and the price is high.

Winnowing

Winnowing consists of separating the impurities from the grain. Farmers do it in three ways: (1) by the wind; (2) by a blower; and (3) by a hand-winnowing machine. For wind cleaning the grains are tossed into the air, and the chaff, straw, leaves, empty grains, and dust are carried away by the wind; whereas, the heavy grains fall onto the floor. Two or three operations of this kind are needed to obtain clean grain. For cleaning with a blower, the grains are dropped in front of a wind blower that blows away the dust and other impurities. In the hand-winnowing machine a draft is created by turning a handle that operates a fan. Paddy is fed into a hopper and falls through the draft, which removes the chaff. The clean grain is collected separately. One person manipulates the handle of the fan and adjusts the output of the grain from the hopper to synchronize it with the force of the wind. Two people feed the grain and another collects the clean grain and sacks it. The grain separated by the operation comes out through two channels; the grain from the second channel is considered uncleaned and must go through the operation one more time. The clean grain is dried and stored.

Drying

Drying is done immediately after winnowing. The grains are spread, under the sun, in a thin layer on the drying floor or on a mat. Normally drying takes 1 day. In certain areas the bundles are dried in the field, and in this case, after winnowing, the grain goes directly to the storehouse.

Storage

There are two ways of storing grains: (1) in bags; and (2) in bulk storage. Bag storage is the most widely used method even in rice mills with a high potential for transformation. The paddy is put in bags that are piled one on top of the other. This method facilitates handling, but the cost is high, it takes up a lot of space, and storage loss from rats can be high. Farmers use bulk storage of rice for family consumption. The storage room consists of an above-ground barn made of concrete, bamboo, or wood. This method reduces loss from rats.

Milling

Processing methods vary from simple hand pounding that uses a mortar and pestle to large scale processing in rice mill plants that use mechanized equipment and produce quality milled rice and by-products.

A mixture of varieties causes problems in milling because heterogeneous grain increases the percentage of breakage and reduces the amount of rice that is milled. Milling is done either by small scale dehuskers or, if the quantity is important, in large rice mill plants.

In rice plants, the paddy is stored first in a barn and then sent by elevator to a sieve that separates chaff and impurities from the grain. This cleaned paddy is transported to a hopper for discharge to a disc-huller that produces a mixture of husks, unhusked paddy, and brown rice. This mixture passes a fan that blows away the husks. The brown rice and unhusked paddy are separated on a table separator: the unhusked paddy returns to the huller, whereas the brown rice goes to the whitening cone.

In the first polishing cone some grains are broken, therefore, a mixture of white milled rice, large and small brokens, and rice polish is produced. The rice polish is removed by a fan and the unpolished grains go to a second cone. In this cone the rice is polished to the

desired norm and passes to a second separator that has three sieves. The first sieve retains head rice and first head, which are sent to a sieve that adjusts the percentage of head rice desired. The second sieve collects first head and the third collects second head. The processing of 2 piculs (120 kg) of paddy produces 100 kg of whole grain and heads, 12–13 kg of rice polish, and 6–7 kg of bran.

Marketing

Rice marketing can be done either by government agencies or by the private sector. Two government agencies are responsible for collecting and transforming paddy. Collecting paddy is under the control of the Ministry of Commerce and SATRAR; whereas, the service in charge of supply, transformation, and reconditioning is an autonomous enterprise of the OFFINACO, which is under the Ministry of Agriculture. The base price of paddy and the price of rice are fixed by the government. The private sector is made up of rice mill owners who perform the marketing operation. They buy paddy to run their mill and sell rice and by-products on the spot.

Special Problems and Actual Developments

To increase rice production, modern techniques are being disseminated by the agricultural service to the farmer. This is done by either extension work or demonstration plots. In addition, trials are being carried out by the agricultural service to find a formula for the combined use of fertilizers, high-yielding varieties, and crop protecting products.

Postharvest losses have not been solved because mechanization is not yet common. Losses can be reduced by harvesting at commercial maturity and stacking the bundles immediately afterwards; however, the loss problems can be solved only if harvesting is mechanized. There are cases where networks of irrigation and drainage are set up. A pioneer project is already being studied by the international agencies in three zones of the Khmer

Republic to set up an irrigation system where the harvest would be done by complete mechanization and losses would be reduced. Apart from the Agricultural Service, other state institutions can help farmers to increase production: The National Office of Cooperation (OFFINACO) can supply fertilizers and insecticides; the Farmer Agricultural Banks (Banque agricole paysanne) can give loans to farmers to enable them to buy fertilizers and insecticides; and the Department of Community Development can act as an extension agent.

To increase rice production in the Khmer Republic, many technological inputs need to be organized. These include irrigation systems, mechanization, new cultivation techniques, high-yielding varieties of rice, fertilizers, rice processing methods, and pest controls. — KONG SAMOL AND CHHIEU NAM. *Agriculture Department, Phnom Pen, Khmer Republic.*

Laos

The economy of Laos is basically agricultural. Approximately 80% of the population lives in rural villages and is engaged in subsistence agriculture. The government of the Royal Kingdom of Laos (RLG) has undertaken an extensive program to accelerate agricultural development so that Laos can move towards economic self-sufficiency. To do this, the agricultural sector and rural development have been given top priority in the Laotian development program.

Since their settlement in the valley of the Mekong River, the Laotian people have been predominantly wet-rice farmers that live in small villages of anywhere from a few families to several hundred people. Each family farms an area just large enough to supply family needs. With the help of a buffalo, the farmer uses the few simple implements he has made for himself to plant, cultivate, and harvest his

crops by methods his ancestors followed centuries before.

The two major farming methods in Laos, which have remained relatively unchanged for centuries, relate to the cultivation of wet rice in irrigated fields and the cultivation of dry rice in forest clearings, which are called Rai in our native language.

The so-called wet rice is grown during the rainy season in paddy fields of two types: those utilizing irrigation canals and those where a system of dikes and terraces is designed to retain the rainwater. The regular paddy is planted in May or June and harvested in November or December. Not enough rice is grown locally to feed the urban population; therefore, some rice is imported into Laos, primarily from neighbouring Thailand.

The time of harvest depends on the type of rice, but the water in the paddy field has to be drained first. Harvesting involves the whole family and sometimes outside help as well. The rice plants are cut by sickle, tied together in small bunches, and then kept in the open air for a few weeks so that the grain moisture content is reduced.

Threshing is carried out by beating the plants either against boards or with sticks. No pedal or mechanical thresher is used at the present time.

In traditional rice milling, the rice is still milled in a wooden, foot-pedalled mortar and pestle device, but as a nation's agriculture develops, agriculture-related industries must also be developed. Though generally inadequate, the most important of these industries are the rice mills.

At this time, 407 rice mills of all sizes have been identified. The highest number of mills is found in Vientiane Province, which has 185 mills, the next highest number of mills is in Savannakhet Province, and the third highest in Borikane, which has 35. Of the 407 mills, only six have the capacity to produce an export-quality product. Most of the mills are rated 7.45 kW (10 hp) or less and are used primarily for custom milling of rice for local consumption. As the Agricultural Development Organization (ADO), created 8 years ago, became more involved in the marketing of rice, the need for greater milling capacity and

higher quality milling grew.

Throughout the country there are small, sometimes portable, mills with a daily capacity of up to 1 t that husk and polish the subsistence rice needs of rural villages. However, most subsistence farmers, distant from urban centres, still mill their own rice by hand in the traditional fashion.

Rice millers usually operate their mills for 6–8 months of the year. This is the time span they consider necessary to earn a reasonable profit. The quantity of rice milled depends on the mill size and the milling time per day. As an average, a mill with a capacity of 25 t per 12-h day will require about 625 t of paddy per month or a yearly average of 3750–5000 t of paddy per year. However, generalization is dangerous as milling fluctuate markedly from year to year in response to unpredictable swings in supply and demand. Moreover, market information is unreliable and inadequate, therefore, profit margins tend to vary from one year to the next.

The natural barriers to trade in Laos are so immense that without massive investments in roads and other forms of transportation certain sections of the country will never be economically integrated with the rest of the country. Without adequate roads within homogeneous geographical areas, an efficient rice marketing system cannot be developed. Given the current security situation, the country can be readily divided into ten well-defined marketing zones or marketing areas. A certain amount of rice normally moves within each marketing zone. Generally this trading is confined to the exchange between farmers or exchange at the local market, which is the case for the other locally grown agricultural commodities. As individual farmers began to produce a greater quantity of rice, it became obvious that almost no formal rice marketing structure existed that was capable of absorbing excess rice from the market. This often left the ADO as the only marketing agency in the area.

Traditionally farmers have been conditioned to the lack of markets and have reacted in the expected way by not producing more than a subsistence requirement. The government found that a totally production-oriented agri-

cultural program was workable only as long as there was a marketing structure capable of absorbing the increased production. The entry of the ADO into the marketing of rice has provided farmers with an outlet for their surplus rice at prices quoted in advance. Compared to Thailand, the price of milled rice in Laos is generally higher, which reflects among other things the difficulty of marketing rice in Laos.

As far as rice storage is concerned, it is estimated that about 30% of the rice production is lost annually in Laos because of inadequate storage facilities and insect and rodent damage. It is expected that a great increase in rice production would worsen the storage problem. Consequently, losses may increase unless the producers and the ADO improve their warehousing facilities.

Several major problems encountered in the agricultural sector, especially the rice production sector, from 1969 to the present have particularly hindered development in Laos: (1) the security and refugee problem; (2) the floods in 1969 and 1971; (3) an inadequate and expensive transportation and marketing system (no price support and stabilization program); (4) high middlemen charges; (5) an inadequate banking system; and (6) a shortage of trained personnel.

The Royal Laos Government still maintains a liberal policy on agricultural products. The import restrictions for Thai rice entering Laos are very limited; therefore, no direct control is operated at the present time to cut down some of the competition from Thai rice in the local market.

The new government program orients farmers towards growing more rice by introducing new improved rice varieties and better cultural methods to meet the country's needs. To meet these needs, the ADO has the following goals: (1) distribute the improved seeds to farmers; (2) encourage farmers to grow quantities of rice in excess of their subsistence needs; (3) make available new capital inputs (such as fertilizer, insecticide, tools, and sprayers) to farmers at low prices; (4) help farmers to obtain agricultural credit; and (5) improve the rice marketing system. To prevent postharvest losses, the ADO is trying to improve storage facilities.

The government has taken some measures to increase rice production by increasing the irrigated area to 14 990 ha in 1970 and to 22 577 ha in 1973. This increase has made a second dry-season rice cropping possible. However, no attention has been given to the technical approach to be used for future development or the improvement of technology for postharvest operations in the grain industry. — THAO SOMMAI AND LUANG BACCAM. *Department of Agriculture, Vientiane Province, Laos.*

Malaysia

The economy of Malaysia is basically agricultural, and rice forms the staple diet of the people. The climate and soil are suitable for the growth of rice, which is grown in three main areas. The first is in the northwestern coast in the states of Perlis, Kedah, and part of Perak; the second is in the northeastern part of West Malaysia, in the states of Kelantan and Trengganu; and the third is in the south-central area, in the states of Selangor and Malacca.

The pattern of production is basically traditional, but it is now in the process of change. Many areas still use the traditional way of ploughing, and harvesting is done manually. For ploughing, however, the industry is changing towards mechanization at a very fast rate. In many areas, tractors and pedestrian power tiller are being used in the preparation of land.

At one time, Malaysia produced rice on a single-crop basis, but in view of the need for self-sufficiency, every encouragement has been given to double cropping.

Production Aspect

As a result of double cropping, Malaysia is expected to achieve 90% self-sufficiency by 1975. For the purpose of double cropping the Muda Agricultural Irrigation Scheme has pro-

duced about 105 000 ha of land. In addition to this, the Kemubu, Lemal, and Besut schemes in the northeastern coast have made about 40 000 ha available for double cropped. Other irrigation schemes are in operation in the Tanjong Karang – Sabak Bernam area, in the state of Selangor, and in the Krian district in the state of Perak. In addition to these big double-cropping areas there are other states with their own minor double-cropping schemes. The estimated acreage of paddy for main-season and off-season crops as of 1971 was:

	Main-season	Off-season
Johore	10 900	4 650
Kedah	292 370	145 160
Kelantan	169 560	17 750
Malacca	29 390	3 830
Negeri Sembilan	24 960	10 490
Pahang	45 730	5 060
P. Pinang/S. Prai	38 690	37 340
Perak	119 040	82 360
Perlis	65 630	27 500
Selangor	50 600	49 210
Trengganu	24 970	10 420
Total:	871 840	393 770

The main-season and off-season plantings vary from state to state. For the state of Kelantan the main-season crop is planted in December and January, whereas harvesting is done in March or April. Off-season crops are planted soon after the harvest of the first season, i.e. in April or May. In Kedah, the planting for the main-season crop is in October or December and the harvest of the main-season and planting of the off-season crop is in February and March. Harvesting is still done by traditional methods despite the fact that experiments have been made with machinery. Two reasons why harvesting by machinery cannot be done are the small fields owned by individual farmers and the soft soil conditions.

With the implementation of double cropping in the major rice producing areas, new varieties of paddy have been introduced. These varieties are mostly short-term varieties locally known as Mahsuri, Rai, and Bahgia. These varieties, to an extent, have given high yields to the farmers and because they produce a

better quality rice they fetch a higher price. Despite the introduction of new varieties for short-term crops, many other local varieties, such as Taupek, are planted by the farmers. Although these varieties fetch a lower price, they should be planted when they are better suited to the land and soil conditions.

Milling Processes

The whole paddy production of the country is milled and consumed locally. Mills found in West Malaysia may be grouped into three main categories: small; medium; and large.

Small Mills

This sort of mill produces rice for home consumption and is found in most villages. It either belongs to an individual or to a small cooperative society in the village. The average milling capacity is about 3 piculs/h (180 kg/h). Some of the mills are licensed and others are not.

The small mills are the simplest and are usually powered by a diesel engine that is connected by belts to rotating shafts that move the major parts. The precleaner has a modern frame and uses a stone sheller.

Medium Mills

The medium-sized mills are those with a milling capacity between 1 and 2 t/h. They are usually located in the more urban areas and are owned by individuals or larger cooperative societies. The majority of the medium-sized mills provide rice for home consumption and for commercial sale. The medium-sized mills sell most of their rice to land schemes and low income groups; therefore, they try to achieve a 70% rice recovery. The quality of the rice produced by these mills is higher than that produced by the small mills because of commercial participation. Usually the medium-sized mills have ample facilities such as good weighing scales, drying yards, and transportation facilities.

The mode of operation of the medium-sized

FIG. 234. Conventional small mill operated by diesel engine: E = elevator; and G = gravity flow.

mills, especially those made locally, is almost the same as that of the small mills (Fig. 234). The paddy is poured from the sacks into a hopper. From here it is transferred by an elevator to the paddy cleaner. The cleaned paddy goes to a sheller and then to a husk separator. In the paddy separator the paddy is extracted from the shelled rice, and is sent to the polisher. After polishing the rice passes to a rotary sieve, which usually has a number seven sieve for high rice recovery.

In small rice mills there is usually only one sheller/huller and one polishing cone; however, in medium-sized mills a large capacity polisher, which has a wider diameter and two or three polishing cones, may be used.

Large Mills

These mills have an average milling capacity of between 2.5 and 10 t/h, and are generally owned by companies or by the National Padi and Rice Authority (NAPRA). These mills usually have complete facilities and services for their operation. There are still many large

mills that are using conventional machinery; however, the mills operated by NAPRA are mostly using up-to-date machinery. Despite the use of conventional machinery, a few of the large mills have been changing to improved parts, especially to the rubber-roll sheller from the old stone shellers.

Double-cropping means that the second crop must be harvested in the wet season. Therefore, the Padi and Rice Marketing Board (PRMB) under the FAMA[14] has introduced mechanical driers that have been so successful that other commercial mills are now using them. Aeroglide, Cimbria, and Satake driers are being used in different parts of the country.

[14]Before September 1971 all matters concerning paddy and its processing were under PRMB, a board formed under the Federal Agricultural Marketing Authority (FAMA). Later all PRMB assets were handed over to the National Padi and Rice Authority (NAPRA), which was formed to take over all the functions for paddy and rice. The NAPRA, which is a semi-governmental body, is the main force behind the modernization of the rice industry.

The Peringat Rice Mill

In 1971, a modern mill was built by improving the Sungai Besar mill built by the PRMB in Tanjong Karang. This integrated mill has a quoted capacity of 4.5 t paddy per hour (Fig. 235) and two mechanical driers with a combined capacity of 15 t of paddy per pass per hour. The mill is situated on the northeast coast of west Malaysia in the state of Kelantan, about 13 km (8 miles) south of Kota Bharu at a place named Peringat, and covers 6 ha (15 acres), of which about 1.2 ha (3 acres) are occupied by the mill buildings, godowns, and office.

The Mechanical Drier

The paddy is sent from the intake hopper to the precleaner by an elevator, which conveys three bags of paddy (4 piculs) per minute. Impurities, such as straw and immature grains, are removed in the precleaner and the paddy is sent at a continuous rate to the drying chamber of the Cimbria mechanical drier. During the 45 min pass through the drying chamber the moisture content of the paddy is reduced to 13–14%. The paddy is then transferred to tempering bins to be cooled. When the paddy is ready for milling, it is transferred to another storage bin in the mill. By having the storage bins attached to the mill a constant flow of paddy to the mill is assured.

Attaching a precleaner to the drier is helpful because it saves drying space since only paddy is dried, saves the trouble of frequent cleaning of the drying chamber, and reduces fire hazards in the chamber. If no precleaner, or an inefficient precleaner, is used, the flow of paddy in the drier may be slow. The precleaner should have a capacity that is larger than the intake capacity of the drier.

Rice Mill

The paddy, after being transferred from the drier into the rice mill bins, is passed on to the paddy cleaner where the dried clean paddy
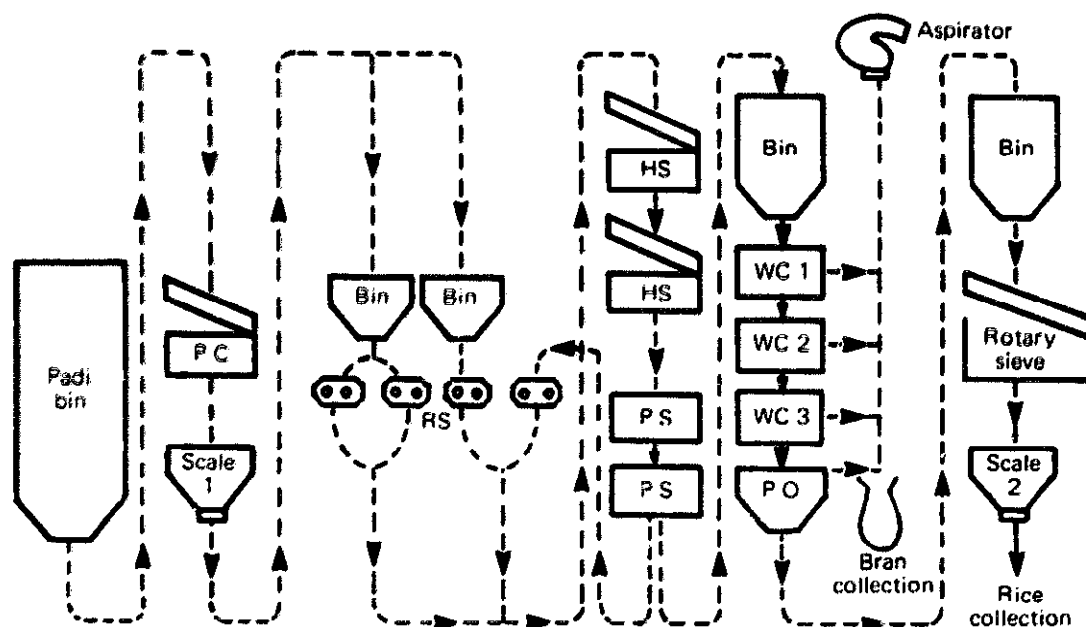
FIG. 235. Flowchart of NAPRA rice mill at Peringat, Kelantan, West Malaysia: (1) paddy bin used to give constant flow of paddy to the mill; (2) PC = paddy cleaner to remove impurities, stones, and metal (if it has a magnetic iron rod); (3) scale No. 1 to weigh net weight of dry paddy before going to the sheller, scale No. 2 to weigh rice output; (4) RS = rubber sheller (roller); (5) HS = husk separator; (6) PS = paddy separator; (7) WC = whitening cones 1, 2, and 3; (8) PO = leather polishing cone; and (9) S = rotary sieve.

is recleaned before being sent to the rubber roller. The cleaned paddy is weighed immediately after coming from the paddy cleaner, which gives the net weight of the dry clean paddy before milling. To ensure a constant supply of paddy to the rubber sheller, the paddy is first accumulated in a storage bin. The rubber roller lasts between 100–120 h before it has to be replaced.

One of the rubber shellers is reserved for paddy returned from the paddy separator. The shelled paddy is then passed to the husk separator, which leaves only the unshelled paddy and brown rice to be separated by the paddy separator. It was found that the husk separator performance was quite good in the sense that the grain is free from broken rice and splits.

The overall results obtained from the tests conducted on the rice mill machinery at Peringat showed that there was about 13% brokens. This brokens percentage is less than the 15% stated in the contract. The whole rice recovery is about 86% (grain above half-size is considered as whole grain). As mentioned earlier the quoted capacity of the mill is 4.5 t/h. From the test the rice produced per hour recorded at the automatic weighing scale is 3.8 t. Assuming a conversion rate of 65%, the quantity of paddy milled should be 5.8 t. However, as observed at the automatic weighing scale, the paddy weight was 5.7 t/h. Allowing for the fact that some of the paddy might have been stuck in the trunking of the scale, the quantity milled is estimated to be a little less than 5.7 t. Therefore, the actual capacity is more than the quoted capacity, probably because parts of the machinery installed at the mill had a larger than normal capacity. The total recovery of the mill was 77.7% (Table 55).

It should be noted that the mill and the drier form an integrated complex. Every part of the drier and the mill is run on the basis of one motor one machine. The mill and the drier are operated jointly by using a panel control in the control room. The panel, by means of electric eyes, can show the flow of paddy and rice at all points while the machine is in operation. It should be noted that this mill is comparatively quite free from dust.

TABLE 55. Mill returns for the Peringat Rice Mill.

	Net weight	Percentage
Dec. 31, 1972 – Jan. 31, 1973		
Paddy milled	27 745.20	
Rice produced	18 753.23	67.05
Brokens	478.74	1.72
Points	407.68	1.68
Bran No. I	1 270.20	4.93
Bran No. II	617.12	2.23
Total:		78.06
Paddy husks		21.94
Feb. 1, 1973 – Feb. 15, 1973		
Paddy milled	15 526.56	
Rice produced	10 603.12	68.29
Brokens	252.80	1.62
Points	186.44	1.02
Bran No. I	468.64	3.01
Bran No. II	528.96	3.04
Total:		77.52
Paddy husk		22.48
March 3, 1973 – March 7, 1973		
Paddy milled	4 551.12	
Rice produced	3 101.51	68.13
Brokens	60.04	1.31
Points	39.50	0.86
Bran No. I	237.84	5.22
Bran No. II	99.76	2.19
Total:		77.71
Paddy husks		22.29

Storage Capacity

The storage capacity of this mill is between 60 000 and 70 000 piculs of paddy. The storage availability, multiplied by the amount of paddy purchased every day, can just accommodate one season's operation at 22 h/day, leaving the other 2 h for service purposes. The godown is divided into these main sections; the large godown is for dry paddy, the godown adjacent to the drier accommodates wet paddy, and a rice godown was built adjacent to the mill.

Marketing System

A discussion of the processing industry would be incomplete without discussing mar-

keting. As the staple food for the people of Malaysia, rice is a controlled article. At one time a regulation was passed to control the purchase of paddy as well as rice; that regulation was under the food control ordinance. The urgency to coordinate production, processing, and marketing led to the formation of the National Padi and Rice Authority. This new organization has the powers to control everything that is concerned with paddy and rice.

NAPRA was formed to ensure fair prices of paddy to the farmers. The government has fixed a guaranteed minimum price of M$16.00/picul (100 katis) and NAPRA is to ensure the guaranteed price. To do this, NAPRA, with the aid of the government, has built many drying and milling complexes in major rice producing areas. So far considerable success has been achieved in this field.

Another function of the NAPRA is to ensure fair prices to the consumers. This has been done through licensing processes. The wholesalers and the retailers must apply for a license before they can sell any rice and there is a limit imposed on their storage capacity. Figure 236 shows the marketing channels for rice in Malaysia, and indicates that the paddy from the farmers is sold to licensed paddy dealers or purchasers who in turn sell it to

commercial or NAPRA mills. The licensed paddy dealers are usually farmer organizations or private commercial mills. The rice is then sold and stockpiled or sold directly on the open market where it is bought by dealers and distributed to retailers.

Conclusion

We can safely conclude that the rice processing industry in Malaysia is at the moment being influenced by the double-cropping process in the country. The new mills are mostly owned by NAPRA, and the private commercial mills are in the process of modernization and improvement. The rubber roller is increasing in use and has been replacing the stone husker. Some private mills have further improved their mills by using the rubber sheller for return paddy thus reducing the percentage of brokens. The mechanical drier has become a necessity and many private mills and all NAPRA mills have been installing this facility. Despite many improvements, however, very little has been done in the industry to solve the husk disposal problem. This factor has made the rice processing industry the centre of dust pollution.

Finally, we should caution ourselves that whatever improvement is made must reduce the production or processing cost in all fairness to the consumer. — AHMAD ANNUAR BIN MOHD. IBRAHIM, ABDUL RAHMAN BIN MOHD. DALIB, AND SALIM BIN ABDUL HAMID, *National Padi and Rice Board, Tingkat 20–21, Bangunan UMBC, 4 Jalan Sulaiman, Kuala Lumpur, Malaysia.*
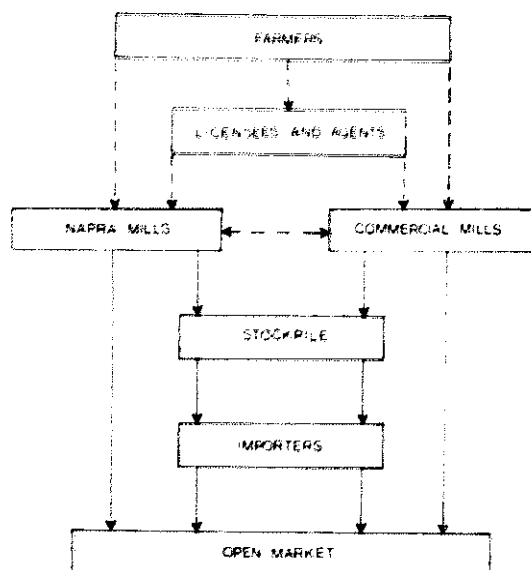
FIG. 236. Marketing channels for rice in Malaysia.

Nepal

Rice is our staple food. Our economic build-up can primarily be spoken of as an economy of rice because 90% of the population is involved in agriculture. The production of rice,

followed by efficient processing, can create further potential for large export, which, in fact, is a beacon light for our national economy. Therefore, special attention must be paid to making our products attractive in the international market.

The annual production of paddy in Nepal totals 2 321 600 t (1.981 t/ha), of which 78% is produced in the plain of Terai. The estimated milling loss per year, from hullers that give about 55% recovery is 464 320 t. Our total export of milled and parboiled rice amounts to 100 000 t/year.

Harvesting and threshing practices are primitive, and have an important bearing on the amount of milling breakage. The paddy plant is cut manually by sickle and threshed either by hand beating, by bullocks moving around the stack, or by means of pedal-operated mechanical threshers. In the major rice producing areas, the paddy is first bundled in the field to facilitate transport and then brought to the threshing point, but this practice does not equilibrate the average moisture level in the bundle. The paddy is then threshed by means of bullocks moving around the paddy stack. The process of threshing is time-consuming and is at the mercy of the weather. In good weather, paddy containing fairly uniform moisture is obtained; however, in rainy weather, nothing can be predicted.

Rice milling is a major industry in our country. More than 700 small 6-9 kW (8-12 hp) huller-type mills are situated in the plain of Terai, which is the major rice producing area. Their milling yield, on the average, is hardly 55%, which is nearly 15-20% below the average obtained in most modern rice mills, and in addition, these hullers yield a high percentage of brokens. Therefore, there is a great need to improve the quality of the rice. Some improvement in rice processing can be achieved by the addition of precleaners and mechanical sieves at different stages in the milling process. Unfortunately, rice millers are not likely to undertake any improvement in processing as long as they are able to sell their rice, irrespective of quality, in the Indian market. His Majesty's Government of Nepal is trying to revolutionize the industry by replacing the old hullers with modern mills that can

meet the requirements of the international market.

Both raw and parboiled paddy are processed in Nepal. Long, slender, and aromatic paddy varieties are milled as raw rice; whereas, inferior and mixed varieties are mostly parboiled. The parboiled rice is processed by cold soaking the paddy in cement tanks for 48-72 h, steaming, and sun drying. None of the millers use improved parboiling techniques, therefore, there is no control on steaming and drying. Because this process yields low quality products, quality control from harvesting to milling must be put into high gear.

More than 350 varieties of rice are planted and harvested year after year. One variety may have different names in different places, for instance, the variety called *kalonuniya* in Jhapa is known as *kalanamak* in Bhairawa. If a mixture of different paddy varieties is milled, the percentage of brokens is increased. The ability of grain to withstand the conditions of stress and the abrasive forces experienced during milling depends on the hardness of the grain; the harder the grain, the less the breakage. No milling equipment has been devised that can produce a high percentage of milled rice from a mixture of different varieties. Mixing leads to the undermilling of fine varieties and the overmilling of coarse varieties.

It is felt that a healthy foundation for the rice milling industry includes reducing the number of varieties of rice. The Agriculture Department is, therefore, launching extensive programs in paddy breeding and agricultural extension. Some of the high-yielding varieties that are recommended by the department for hilly areas are Chainan-2, Kausing-24, Taichung-176, Chainung-242, and Chainan-1, and for the Terai region IR8, BR-34, CH-45, and Taichung native-1.

There is no mechanization of storage in Nepal, and annual storage losses due to insects, rats, pests, moulds, and other factors is estimated to exceed 15% of the total paddy crop. Most of this loss is borne by the farmers at present.

The Agriculture Marketing Corporation is the semi-government organization dealing with rice trading in this country. This corporation is buying food grains to maintain proper buffer

stocks in areas where they are needed. These buffer stocks are maintained in different parts of the country to facilitate transportation to remote regions. The corporation is buying parboiled rice by employing two grades: Masino for fine and medium varieties, and Mota for coarse varieties. This grading is based entirely on an individual basis and no further specification has been laid down.

The millers in Nepal buy the paddy by employing their own grade, which is known as miller's grade. According to them, the paddy is classified into superfine, fine, medium, or coarse grade. Our test analysis indicates that this classification of paddy is based on: variety; shape; palatability; admixture of foreign grains; red grains; and translucence.

According to our study, the first consideration during the collection of paddy is the variety. Most of the fine quality varieties are very slender. The palatability characteristics (appearance, cohesiveness, tenderness, and aroma) have an important bearing on the existing quality grading, therefore, aromatic and slender varieties like Basmati and Kukurjali fetch a higher market price. Red and foreign grains are highly objectionable in the present grading system. Analysis shows that coarse varieties like Masara and Sathar may have up to 100% chalkiness.

All superfine and fine varieties of rice show a marked degree of translucency; therefore, it is an important factor in consumer preference. The yield of rice is higher for fine and superfine varieties; however, although the percentage of brokens produced from superfine grades is lower, the number of brokens produced by fine and medium grains is about the same. Our study indicates that the present grading system is based on: variety; general appearance; and grain size, colour, and brokens.

His Majesty's Government of Nepal has realized the problem, and the Department of Food and Agriculture Marketing Services is working on its effective solution. — T. B. KARKI. *Ministry of Food, Agriculture, and Irrigation, Department of Food, Agriculture, and Marketing Services, Shri Mahal, Kathmandu, Nepal.*

Philippines

Existing Postharvest Practices

Harvesting

Traditional manual harvesting of rice constitutes 22.1% of the total labour time. It is usually done by either of three popular instruments and methods: (1) a yatab that cuts the panicles without the leaves; (2) a lingkaw that is efficient for lodged varieties because it lifts and twists the stems together and makes them easier to cut; or (3) a sickle or scythe that cuts a number of stems at the same time. After the rice stalks are cut, they are bundled, piled, and left in the rice field for a few days before they are threshed.

Mechanical harvesters are hardly used in the Philippines because of the high cost of the machines, fragmentation of the farms, and the soil conditions.

Threshing

There are at least three methods widely used in this country, namely: the hampasan, trampling, and mechanical threshers. Of these the hampasan and trampling methods, either by man or animals, are more widely used although mechanical threshers are more popular in some areas. In the hampasan system the panicles are threshed by impact against a slotted board, pavement block, or piece of wood. The trampling method utilizes "rubbing action" for separating the grain from the panicle. The mechanical method of threshing utilizes impact and some stripping action to separate the grains from the panicle.

Cleaning

The prevalent grain cleaning method is winnowing. In this method, the removal of dockage such as straw, chaff, weed seeds, and other

foreign materials is accomplished by utilizing natural wind or manually operated blowers. In some instances, mechanical cleaning is integrated with threshing to fully utilize the power source, which is usually a 5–7 hp engine.

Mechanical cleaning is not very popular in the Philippines. Again, this is due to its high cost. A less expensive cleaner, which is locally manufactured, is the open double-layer oscillating sieve. It is directly driven through an eccentric drive from the main transmission shaft. The first sieve or perforated plate has large perforations. The overflow of this sieve is large impurities. The second sieve has small perforations, and its overflow is the precleaned paddy. The small impurities are discharged at the bottom. Other more expensive types of precleaners. use an aspirator combined with the oscillating sieve or perforated rotating cylinders.

Drying

The most common grain drying method practiced in the Philippines is sun drying. Planting is usually timed so that the paddy will mature after the rainy season to permit sun drying.

Filipinos are accustomed to sun drying and possess ample skills in using it to the best advantage. Grains are spread on a flat dry surface, either on cement pavements or on bamboo mats, and occasionally stirred or raked so that the grain will dry uniformly. Some paddy is dried in shocks in the field.

There is, however, a great need for mechanical driers in the country today because of the introduction of new high-yielding, early maturing, and nonseasonal varieties. At present, there are no accurate figures on the number of driers and their capacity. The available statistics reveal that existing NGA driers and those leased to the private sector total only 66 units with a drying capacity of 526 t/day, which is very much below the required drying capacity.

Storing

The prevailing grain storage practice in the Philippines makes use of warehouses where the grain is stored in jute or plastic sacks. This method lends itself to segregation of different varieties but offers very little protection against storage pests. The sacks are susceptible to pest and rodent depredation and relatively fast container deterioration.

Two systems of piling stocks are utilized. One is the conventional stacking in which the bags are piled side by side and one on top of the other until the desired pile height is attained. In this system of piling there is no provision for ventilation space between bags. The other system, called the Japanese style, provides ventilation space between bags. This system of stacking the bags allows for the circulation of convective air currents that provide a medium for heat dissipation.

On a commercial scale, but to a lesser extent, bulk or open storage is practiced in the Philippines. In this storage practice, the grain is poured on the floor of the warehouse or into metal containers called silos. The former method of open storage is readily susceptible to attacks by storage pests and the latter storage structure cannot handle different varieties of grains.

Where the grain production and landholdings of the farmers are small, the method of storage uses bamboo mats. The bamboo mats are rolled into convenient sizes and are used as temporary or permanent storage receptacles. Other receptacles such as cans, barrels, boxes, woven bags, and earthenware are also used for temporary or permanent storage.

As a result of these antiquated and inadequate storage facilities in the country, we suffer from physical losses and deterioration of grain.

Milling

The rice milling equipment used in the Philippines can be classified loosely into: hand pounding equipment; Engleberg mills; cono mills; and rubber-roller mills. The first is still used in some parts of the Philippines. In this technique rough rice is dried and hand pounded in bundles (pongos) without passing through threshers.

A significant feature of the grain industry

in the Philippines is the use of a large number of Engleberg mills with capacities ranging from 15 to 50 cavans/day. The rice milling industry consists of far too many of these units, which are obsolete, poorly organized, and inefficient. It is estimated that the Engleberg mills process about 40% of the total annual paddy production. The majority of these Engleberg mills are widely distributed in rice producing and consuming areas, close to the source of raw materials and in close contact with the farmers. These mills are very wasteful. The milling recovery is very low (59% or less) and the value of the by-products is even lower. However, these mills require only a small capital outlay and are accessible in barrios, which justifies their popularity in the rural areas.

A more efficient under-runner disk huller rice mill coupled with whitening cones is popularly known in this country as a cono mill and is popular for commercial milling because of its capacity. Close to 3000 cono-type rice mills are in operation in the Philippines. Generally, most of these mills are produced locally. The capacity of these installations ranges from less than 100 to over 1000 cavans of rough rice per 12 h of operation. The distribution of these machines is still limited, but its performance is quite an improvement over the Engleberg type. Cono mills have a milling recovery of 65% or more by weight at second class milling degree.

The rubber-roller mill is already distributed in some parts of the country and has a milling recovery of over 69%. However, the problems with this type of mill are: (1) some units were installed in areas where the supply of paddy cannot meet the capacity; and (2) the cost of imported spare parts is high.

Marketing

Marketing of rice is open to any Filipino citizen who wishes to engage in the rice business. An individual may buy paddy, dry, mill, and sell the products at government regulated prices. The government establishes a floor price for paddy. If the price falls below the floor price the government, through the National Grains Authority, will procure paddy directly from the farmers to ensure a safe return of their investment. It is also a general rule that the NGA purchases 5–10% of the production to serve as a buffer stock for lean months. The ceiling price is designed to protect the consumers and at the same time give an incentive to the processors.

Price Stabilization Program

The NGA is geared to stabilize the price of grain both at the farmer's level and at the consumer's level. The government support price for paddy is 1.00 peso/kg, and the government ceiling price for milled rice is 1.90 peso/kg. The NGA has formulated a program of activities as follows: (1) massive procurement at the government support price; (2) distribution of buffer stocks at the regulated consumer's price; (3) utilization of the quedan system to facilitate the financing of more purchases and exchanges of grain inventories; and (4) establishment of a Grains Centre to serve both as a convenient clearing house for processing and distribution of grains and as a training centre.

Procurement Program

Every year there is a tremendous dollar drain out of the country for the procurement of foreign rice and corn to fill up production shortages and stabilize the consumer's price. It is for this reason that the government has set up a program to provide government funds for the massive procurement of paddy and corn at support prices to encourage farmers to produce more.

The procurement methods of the NGA are as follows: (1) direct procurement – NGA personnel will execute direct procurement operations; (2) procurement via Facomas and other Farmer Producers' Cooperatives — NGA will implement procurement operations by means of an agency tie-up with Facomas and other cooperatives, which can meet some qualifying requirements with respect to facilities, competence, and uprightness; (3) procurement through private warehousemen-millers — NGA will appoint private warehousemen-millers as agents to whom sufficient procure-

ment funds will be allocated without interest; and (4) procurement by means of quedans — establishment of a quedan system is among the main programs of the NGA.

Distribution Program

The distribution program requires careful planning because the Philippines is an archipelago of 7100 islands and there is a lack of transportation facilities. This is a major activity of the NGA that is vital in stabilizing the consumer's price for rice, especially during the lean months, July to September, when prices traditionally tend to increase beyond the reach of the great mass of the people. With these problems at hand, the NGA has set up a program of both short range and medium range activities.

Short Range

(1) Plan and implement the dispersal and distribution program prepared by the Directorate for Grains Economics.

(2) NGA shall move the stocks from unloading points to different warehouses in various provinces as soon as they are unloaded from vessels.

(3) Agency, branch, and regional offices shall conduct public biddings and/or scaled canvasses for the purpose of contracting integrated services.

(4) Screening committees shall be formed to carefully screen retailer-applicants and cooperatives wishing to retail NGA rice.

(5) Initiate supervision of the unloading and distribution of grains imported by the private sector.

Medium Range

(1) Study and promote a system of marketing utilizing the pattern of barrio councils (Samahang Nayon) and Area Marketing Cooperatives.

(2) Coordinate with the procurement division on the use of the quedan or warehouse receipt as a tool for grain distribution.

To ensure the success of the quedan program, the NGA has formulated new imple-

menting policies: (1) to promote maximum participation and cooperation among all sectors involved in the grain industry, more specifically the financing; (2) to adopt rigid screening procedures in licensing bonded warehouses; and (3) to institute strict measures to control and supervise the system.

In addition to the above implementation policies the NGA has listed a program of activities: (1) to establish a rigid set of rules and regulations to govern the quedan system by April, 1973; (2) to prepare a uniform accounting system and record-keeping system in bonded warehouses, as prescribed by law, by March, 1973; (3) to furnish bonded warehouses with printed quedans in denominations prescribed by law, by July 1973; (4) to launch an information drive among all sectors involved in the grain industry stating the advantages and benefits of the quedan system starting April, 1973; and (5) to encourage the banking sector to engage in bonded warehousing.

Special Country Problems

The most important problems encountered by the Philippines in relation to rice production are related to infrastructure facilities required by the grain industry for self-sufficiency in food and feed grains.

Of utmost importance is the construction and maintenance of adequate irrigation facilities as a means of increasing the total effective area devoted to the production of lowland rice. Of the 3 200 000 ha cultivated in rice, only about 800 000 ha are irrigated during the rainy season and about 200 000 ha during the dry season. Considering that high production is possible only in' irrigated areas, it is understandable that an increase in yield can only be attained where irrigation is sufficient. It can be assumed that all other modern inputs in production can be dispensed with and appreciable yields can still be obtained as long as there is irrigation. On the other hand, application of all other important inputs will be useless if there is insufficient irrigation.

The second problem is distribution of the produce from the rice field to the marketing centres. Out of 35 000 barrios in the Philip-

pines only 50% are accessible by feeder roads. This transportation problem results in a very low selling price in the production areas not easily accessible by land transportation. This acts as a disincentive to production in the rural areas.

What may be considered as a third major problem is lack of farm machinery suitable to the fragmented farms, a condition that prevents effective utilization of large and efficient farm machinery. Most of the small hand tractors marketed at present still require further improvements to be at par with the efficiency of dryland machinery.

The fourth problem is a lack of infrastructure facilities for drying and storage. Sun drying is still the most common method in practice, despite its unpredictability, because it is more economical. Mechanical driers are still too costly for the average Filipino farmer who has only 2.5–3 ha of riceland. This condition results in appreciable losses due to handling and storage and in low milling recovery and quality because of improper drying.

To rectify the adverse effects of these conditions, the Philippine government has embarked on a more aggressive program of infrastructure development. Irrigation systems, either by gravity or by pumps, are being built in cooperation with the private sector. Construction of new roads and improvement and repair of existing ones are pursued continuously. The manufacture of machinery suitable for small farms is being encouraged to improve grain facilities in strategic areas in the country. Continuous technical training to upgrade the quality of personnel involved in the grain industry has been included in the over-all program towards self-sufficiency in food and feed grains.

A National Grain Industries Development Authority has been created. This move is expected to promote efficiency in all sectors of the industry, which will lead towards self-sufficiency in food and feed grains and eventual participation in a grain export trade.

Current Developments

The creation of the National Grains Authority by virtue of Presidential Decree No. 4,

which incorporated into one organization the functions of the defunct Rice and Corn Administration and the former Rice and Corn Board, is expected to strengthen and safeguard the stability of the grain industry in the Philippines.

Periodic evaluation of grain stocks is conducted to monitor and stabilize the relationship between supply and demand as a means of keeping grain prices above the cost of production but within reasonable reach of the ordinary consumers. Grain facilities are evaluated and monitored to promote better efficiency in grain handling and processing as a means of reducing losses in milled grain. Filipino inventions involving tractors and other farm implements, rice and corn mills, and driers and storage facilities adapted to unique Philippine conditions are being encouraged not only to improve both production and processing of grain products but also to generate more employment in manufacturing industries.

A study is underway to phase out the inefficient machines used for rice milling. This involves development, fabrication, evaluation, and production of more efficient types of rice mills for Philippine farms. A program for progressive conversion of conventional warehouses to bulk-storage facilities is contemplated, and feasibility studies are in preparation. A grain exchange scheme to prevent unnecessary movement of stocks as a means of ensuring sufficient supply in all areas during the lean months is being prepared to reduce losses resulting from transportation.

The present programs of the National Grains Authority for grain industry development are as follows: (1) construction of 45 provincial grain centres, nine regional centres, and one national centre that will have a complete line of postproduction machinery and facilities; (2) the construction of 10 conventional warehouses throughout the country; and (3) the rehabilitation, renovation, and/or transfer of the existing warehouses installed in different parts of the country. — ERNESTO TUBON AND JAVIER LOZADA, JR. *Technical Research and Services Division, National Grains Authority, Quezon Boulevard Extension, Quezon City, Philippines.*

Sri Lanka

According to the rainfall pattern of Sri Lanka, the cultivation year can be divided into two distinct seasons, namely, Maha and Yala. Cultivation during the Maha season takes place between October and March; whereas, the Yala cultivation is done between April and September. In Maha 460 000 ha are cultivated and in Yala 260 000 ha, therefore the yearly hectarage is 720 000. Harvesting of the Maha crop extends from January to April with a peak collection in March and April. Yala cultivation, which is done only with the help of supplementary irrigation, is harvested in July, August, and September. Although the bulk of the crop is harvested in August–September, there is no congestion in any place because the crop is not that large. But in the case of the Maha crop, a very large crop is obtained and to deal with the peak period of harvesting, a large storage space is required. Although the harvesting of paddy is concentrated in a very few months, the consumption of rice remains constant and, as a result, a large storage space is necessary to store the paddy until it is milled and marketed as rice.

The purchasing and milling of paddy in Sri Lanka is vested in a government organization known as the Paddy Marketing Board. The Paddy Marketing Board is the monopoly buyer of paddy as well as the sole authority in the milling and marketing of rice. There is a vast organization to execute the Board's functions, and in this the cooperative societies and private millers play a very important role. Paddy offered for sale is purchased by the various purchasing centres operated by the cooperative societies that act as agents of the Paddy Marketing Board. The stock of paddy thus purchased is kept in their godowns temporarily before it is delivered to the large stores owned by the Paddy Marketing Board. From these stores, quotas of paddy are issued to the Paddy Marketing Board mills and other private mills, which do the milling for the Board on a contract basis. From the private mills, rice is handed over to rice stores for storage prior to distribution to consumers.

There are about 4500 paddy purchasing centres scattered throughout the country, and these centres, which are managed by cooperative societies and a few cultivation committees, perform the important function of purchasing paddy from the farmers. The Government of Sri Lanka offers a guaranteed price for paddy, and this money is paid to the farmers at the time of acceptance of the paddy. For this purpose the Paddy Marketing Board has arranged the issue of loans to all authorized agents from a State Bank.

Certain conditions have been laid down by the Paddy Marketing Board for the procurement of paddy. All authorized agents who operate the paddy purchasing centres grade the paddy at the time it is purchased from the farmers. Dry paddy containing 1% or less extraneous matter is purchased according to the refraction. In areas where paddy is purchased by volume, a sliding scale of prices operates on the basis of percentage refraction such as 6, 7, 8, 9, 10, 11, and 12%. The highest price is payable to paddy having a refraction up to 6%. In areas where purchasing by weight is practiced, the paddy is divided into two groups according to refraction. Refraction of 1–6% receives the highest price, whereas the 7–12% refraction paddy receives a slightly lower price. Paddy is further graded according to the length and colour of the rice grain. "Madi" paddy includes paddy that gets damaged at harvesting as a result of heavy showers etc. Depending on the grading, varieties are further classified as unmixed and mixed. Pure or unmixed with a refraction of 6%, irrespective of the length of grain (whether long or short) and the colour of the rice grain (red or white), receives the highest price of 39 Sri Lanka cents per pound or US $134/t.

Paddy was purchased in all parts of Sri Lanka until 1971 by measuring with the bushel, which is approximately 20 kg of paddy. Purchasing by weight was introduced in eight districts in the latter part of 1972; in the remaining 14 districts purchasing by volume continues. The delay in the introduction of

the weight system is caused by the difficulty involved in supplying such a large consignment of weighing machines and the large expenditure that is involved.

Paddy produced in the country is stored in warehouses in gunny bags and, as a result, a large number of gunnies are required. The warehouses have not been constructed scientifically and as a result there is a wastage of grain. Grain is subject to damage by insects, rodents, and birds as well as to spoilage due to leaking roofs and seepage of water through the floor. Along with the establishment of the Paddy Marketing Board, due consideration has been given to this wastage and steps are being taken to correct the deficiencies. All this time, stacking has been done according to primitive practices, which do not provide adequate ventilation for the grain. Better methods of stacking are being introduced gradually so that the employees who are used to very old methods will not be confused as a result of the changes.

No dunnage has been provided to any of the stores, and this results in the spoilage of gunnies through the seepage of water from the floor. Storage of these bags for long periods results in the damage of grains as well. As the gunnies used for packing paddy are not produced locally, importation of gunnies is a drain on the country's foreign exchange. In this context, steps are being taken to provide wooden dunnage for the paddy stores to prevent this dual wastage. The high cost of supplying wooden dunnage has acted as an impediment to the provision of dunnage to the affected stores. Efforts are made to use local material such as cadjans, palmyrah leaves, and polyethylene sheets until wooden dunnage is provided.

The current storage capacity is around 16 million bushels, and as a result of the Green Revolution, the country faces an acute storage problem. As paddy offered for sale has to be stored somehow, the Paddy Marketing Board is using a system called "open storage" as a temporary measure during peak periods. This involves the storage of paddy in open air under polyethylene covers, which protect the grain from the weather. Under this system, the bags of paddy are subject to good ventilation when the polyethylene covers on the sides of the stacks are removed during favourable weather.

Although the purchasing of dry paddy at 14% moisture is anticipated, this would not happen at all times of the year. A crop of paddy that is to be harvested, if exposed to a series of showers, will not be at the ideal condition at the time of selling. Farmers do not have driers nor sufficient space to store the wet paddy and the moisture content will be very much more than 14% at the time of disposal. This happens very often in the case of the Yala crop as a result of late sowing of slow maturing paddy varieties. Even the Paddy Marketing Board store does not have any driers to dry paddy.

Milling of paddy is done by about 950 mills, most of which have a low capacity. The Paddy Marketing Board owns 19 large mills, which are larger than the other mills. The rest of the mills are privately owned but possess licenses issued by the Paddy Marketing Board. Some of the privately owned mills do milling exclusively for the Paddy Marketing Board. In such cases, paddy is issued to mills for milling on a hire basis. The transportation costs of paddy from the store to the mill and of rice from the mill to the rice store are borne by the Paddy Marketing Board.

The Paddy Marketing Board has fixed the quantity of rice required from the various grades of paddy. The highest outturn of 71% with 30% brokens and 3% bran removal is recovered from the grade one paddy that is issued for raw milling. The outturn fixed for grade two paddy is 70.5% for raw milling with the same degree of polish and brokens. In the case of parboiled rice a 71% outturn with 12% brokens and 4% bran removal is required for grade one paddy. For grade two paddy the outturn fixed by the Paddy Marketing Board is 70.5%.

The Paddy Marketing Board owns 19 rice mills: seven steel huller mills; four disc sheller mills; and eight rubber roll sheller mills. There are only three disc sheller mills owned by private millers. Mills that process parboiled rice possess steel hullers; whereas, mills that do raw milling usually possess rubber roll sheller mills. Milling of paddy in Sri Lanka is done in two ways. Paddy is either milled raw or

after parboiling. In the latter process paddy is soaked in water, steamed, and dried in the sun before milling. There is a consumer preference for raw milled rice in the southern part of the country, whereas the rest of the country prefers parboiled rice.

Parboiling is a cumbersome process but it has several advantages. Parboiling is done either by cold water soaking or hot water soaking. In the cold water soaking system, paddy is soaked in water for 3 days in large soaking tanks and subsequently steamed for about 30 min. The paddy is dried in the sun for a few days before it is milled. In the case of the hot water soaking system, the paddy is added to a tank of hot water having a temperature of about 70 °C, soaked for 2–3 h, and steamed for 20–30 min. The paddy is then dried in the sun for a few days, before milling. During cold water soaking, paddy tends to ferment and as a result a disagreeable odour is usually produced. Although this could be avoided by changing the water regularly, in areas where water is scarce the water is hardly changed, which increases bacterial fermentation. As a result of this, the processed parboiled rice often has a bad odour. However, the parboiling process has its use in salvaging much of the sun-cracked and Madi (or water-damaged) paddy that would otherwise produce a very high quantity of brokens.

The heat necessary for producing steam for the parboiling process is supplied by either burning firewood or husk. Most of the mills owned by the Paddy Marketing Board possess husk burners to produce the necessary heat for the parboiling process.

The current milling practice in Sri Lanka is largely centered around the Engleberg-type steel hullers. These work at a lower efficiency and require a large power input. A 0.75 t/h mill will need at least 33 kW (45 hp) to operate, while a modern mill of 2-t capacity would require only about 45 kW (60 hp). Most of the huller mills are locally manufactured and have a ravenous appetite for imported bearings. From these steel huller mills poor quality bran is obtained because of the mixing of husk and bran. Very often, the recovery of head rice is low as a result of the large number of brokens.

Although the country's paddy production has increased very rapidly in the past decade, no corresponding increase has been made in the storage and milling capacities. If the production of paddy is to reach 2 million tonnes in the future, rapid expansion of the storage and milling facilities is necessary. The milling capacity is just sufficient to meet the milling requirements during most parts of the year. During the peak period of March–April it is insufficient mainly due to poor distribution of the mills. A large number of the large privately owned mills are located in non-paddy-growing areas, which prevents the rapid milling of the existing stocks of paddy because of the need to transport the paddy from the producing area.

The Paddy Marketing Board is using bulk storage of paddy, and already the construction work for four storage-milling complexes has begun. Each complex will have a storage capacity of 9000 t, and to meet the future storage requirements more of these complexes may be erected. Bulk storage of paddy entails less operational cost, as compared to warehouse storage. The new mills that are to be installed in the complexes will be able to give a higher outturn of good quality rice. — B. D. E. M. PEREIRA AND F. S. Y. SAMUEL. *Paddy Marketing Board, P.O. Box 205, Colombo 5, Sri Lanka.*

Thailand

Harvesting

Riceland in Thailand can be divided into four main parts: the Central Plain; the South; the North; and the Northeast. In the Central Plain, as well as in the North and the Northeast, farmers use similar harvesting techniques. They use a sickle to cut the rice stems, then tie the stems into bundles, which will yield about 10 kg of paddy grains each when promptly threshed. These bundles are normally lined up in the fields for a few days

before being moved to the threshing ground, so as to allow the moisture in the grains to evaporate a little before threshing.

The harvesting season in Thailand begins around late November or early December. When freshly harvested, paddy has a moisture content of approximately 20%. At threshing time it is preferable to have the moisture content at about 13–14%. In the Central area, the North, and the Northeast, threshing begins almost immediately after harvesting and before storing. However, farmers in the South employ a different technique. They cut the rice stem with a half-circle shaped knife that is locally called "kae." By using the knife instead of the sickle, farmers in the South have to cut the rice stems one by one. Obviously the sickle can do a much quicker job, but rice stems cut with "kae" are more even and are easier to store. Therefore, the Southern farmers tie the branched paddy into small bunches and store it unthreshed.

Threshing

In the North and South, a necessity in the threshing area is a huge, flat, round container made of bamboo sticks, which is widely known as "kra dong." In the North the paddy bundle to be threshed is placed securely between two pieces of wood that serve as a handle. The bundle is beaten against the "kra dong" so that the grains will come off the panicles. In the South, the branched paddy cut with a knife is too short to be threshed this way. Therefore, the Southern farmers place the bunches of paddy in the "kra dong" and thresh them with their feet. In the Central Plain and in the Northeast, farmers thresh their paddy on the ground. A dry, hard, and smooth area is chosen for the purpose. It is carefully cleared to get rid of every piece of sand, gravel, or stone. The farmers then coat the surface of the area with a mixture of buffalo dung and mud. This mixture cements the cracks in the ground and prevents the loss of paddy grains into these cracks. When the coated area is dry, the paddy bundles are beat against the ground. Some farmers let the buffaloes do the threshing by walking them over the paddy

bundles. Small pickup trucks and tractors can also be used in a similar way. However, threshing with buffaloes, trucks, and tractors usually results in a greater loss of paddy grains because of grain cracking and dehusking. Therefore, threshing by human hands is still preferable to animal or mechanical threshing.

Cleaning

The most popular method is to put the paddy grains into a big deep container, toss the grains in the container up into the air, and let them fall on the prepared ground. The breeze will blow dirt and small foreign particles away from the rice grains. A big bamboo fan can be used to create air movement.

Another method widely used among farmers owning large quantities of paddy is cleaning with a locally made mechanical wind blower. The frame is made of teak wood, the blade is made of plywood, and the rotor as well as the other important parts are made of cast iron. An entire unit costs about US$30.

Drying

No special method has ever been used for drying paddy. Moist paddy is generally left to dry in the sun. In Thailand, where there is always strong sunshine during the postharvest season, farmers usually have no problem in getting the moisture of the paddy down to that of the air level. Unexpected rainfall during this season can be very dangerous. Paddy grains that are badly damaged by the rain are not stored but are sold to rice millers as quickly as possible because they have better equipment and facilities for drying paddy. Farmers, on the other hand, depend largely on the sun and the wind.

Storing

Most farmers sell their paddy before they have to store it. Usually in late September there is a great demand for new crops because

the crops of the previous year are running short. Middlemen travel with small trucks to the threshing grounds in different areas and buy paddy from the farmers right after threshing and cleaning. Of course there are some farmers who have a great deal of paddy and who are well-to-do enough to build good and safe storage facilities for their paddy. An average storage bin is made of wood, with a wooden floor raised a few feet from the ground and wooden walls, and has a galvanized iron roof. The storage capacity of each bin differs according to the economic status of the farmer and depending on the amount of paddy to be stored. An average bin can store approximately 7–10 kwiens (7–10 t).

Milling

In each village there usually is one small rice mill that mills only for local consumption. This kind of mill employs a very simple technique of dehusking and polishing using a very basic grinding stone without sifters or separators. Therefore, the milled rice is rough and broken, and a large number of husks are mixed with the bran. A medium sized mill employs a much better technique because the quality of the milled rice is emphasized, especially when the rice is sold to rice exporters. There are as many as twelve milling stones in this kind of mill for the purpose of dehusking and polishing alone. Big rice mills are also equipped with modern devices for sifting and separating. However, rice mills in Thailand still lack modern equipment and techniques. None of them is big or modern enough to accommodate a bran oil extractor. Bran released from all the mills is usually sold for animal feed or to oil extracting plants. According to a survey made by the Ministry of Industry, at the end of 1972 there were 38 494 rice mills in the kingdom. Only 125 mills have a daily milling capacity of 40 t or more; the rest are small and substandard.

Marketing

After milling, part of the rice is sold to wholesalers for distribution in the nearby markets and a small portion is sold directly to local consumers. A large portion of the rice is transported by barges and trucks to metropolitan areas.

Middlemen play a very important part in the rice market. There are hoarders who buy paddy from farmers in the early season and stock it until late in the season when rice supplies are decreasing and demands in foreign markets are increasing. Wholesalers buy rice from millers through the brokers. In the early season they buy a great amount and gradually distribute this to retailers as well as exporters. Retailers exist everywhere in the country. Small shops, big grocery stores, big cooperative stores, or even vendors of miscellaneous household goods and groceries can be rice retailers. Brokers also have an important part in rice marketing. They manage to quickly acquire the latest information on the current movements of price, both in the domestic markets and the world markets, and by advising millers, wholesalers, and exporters they have their own way of influencing, if not controlling, the price of the rice in the domestic market.

The amount of rice exported yearly from Thailand is about 1.2–1.6 million tonnes. Rice, therefore, has been and will remain the greatest source of income in Thailand.

Rice Breeding

The Thailand rice breeding program had its inception in 1950, under the late Dr H. H. Love. It primarily involved selection within indigenous varieties. In 1960, intensive work began on breeding for resistance to blast and in 1966 a formulation of breeding objectives and a vigorous hybridization program were begun. During the past 10 years, breeding for increased resistance to local diseases and insects has been emphasized. More recently, deep water rice, improved grain quality, and protein have been added to the breeding objectives.

The breeding program has resulted in the recent release of three dwarf, high-yielding varieties; a tall, stiff-strawed disease-resistant variety; and a semi-dwarf type capable of withstanding water depths of as much as 130 cm.

The breeding program has emphasized those objectives concerned with good grain quality, disease resistance, responsiveness to fertilizer, and wide adaption. This has been accelerated by the addition of grain quality laboratories for analysis of physical and chemical characteristics of the breeding lines and detailed cataloging of indigenous genetic stocks. Presently, 21 rice experiment stations participate in yield trials in addition to their own breeding work, which provides ample data for rapid evaluation of new breeding material.

The mutation work has shifted emphasis from treatment of tall, indigenous types that showed several defects to promising hybrid experimental lines that required improvement in only one or two major characteristics. Gamma rays, fast neurons, and chemical mutagens are being utilized to obtain the desired mutation.

Attacks by the tungro virus (known as yellow leaf in Thailand) from 1965 to 1966 and the concept of plant types fostered by the International Rice Research Institute caused a great change in the breeding program. New semi-dwarf types were used extensively in crosses with the tall, photoperiod sensitive, recommended Thai varieties in an effort to combine virus resistance and stiff straw with greater responsiveness to fertilizers.

Development of RD-1, RD-2, and RD-3

RD-1 and RD-3 were officially named and released in 1969. They were selected from the cross Leuang Tawng × IR8 by the pedigree method at Bangkhen Rice Experiment near Bangkok. Leuang Tawng, then the only non-photoperiod sensitive variety recommended by the Rice Department, had hard, long, clear grains, but it was susceptible to lodging and diseases, such as blast and tungro virus. It was crossed with IR8 mainly to obtain lines similar to IR8 in plant type but with the long, slender, clear grain of Leuang Tawng. RD-1 and RD-3 are photoperiod insensitive, nonglutinous, resistant to tungro, have stiff straw, translucent grain, and mature in about 120–130 days. In yield trials conducted extensively throughout the country they consistently produced yields

similar to those of IR8 at all levels of soil fertility.

RD-2 originated from a cross of Gam Pai-15 × Taichung Native-1 back-crossed to Gam Pai-15. Gam Pai-15 is a glutinous variety recommended for northeastern Thailand. The cross and initial selections were made at IRRI, but reselection within segregating F_4 and F_5 pedigree lines was made in Thailand and resulted in the identification of RD-2.

The performance of RD-1, RD-2, and RD-3 in yield trials under conditions of reasonably good soil fertility and water control suggests that, depending upon the cultural conditions, they can yield from 15 to 100% more than the conventional varieties.

Mechanization

Mechanized rice cultivation was initiated by the Engineering Division of the Rice Department 15 years ago. In 1957, the total tractor population for the cultivation of rice and other crops in Thailand was only 234, the majority being government owned. Since the Engineering Division implementation of the tractor contractor system in 1957 the purchase and use of tractors in Thailand has been increasing at a significant rate. From a total number of 234 tractors in 1957, there are now more than 80 000 units.

Development of the local farm equipment industry is also progressing at a significant rate. Besides imported agricultural machinery and implements, there are several types of farm machinery and implements that have been locally developed and produced for distribution by small workshops and large plants. This equipment is modified from imported materials and then redesigned for suitability to both the conditions and environment of each particular area in Thailand and the purchasing ability of the farmers with low financial standing.

Locally designed and manufactured farm machinery and implements are: (1) Different low-lift propeller pumps, driven by low horsepower engines and used for paddy field irrigation. The present annual production is 30 000 units. This type of pump was designed by the

Engineering Division 10 years ago; (2) Various sizes of puddling machines. These machines are of 7.5–11.2 kW (10–15 hp) and are used for soil preparation under wet field conditions. The present annual production is 2000 units; (3) Hand tractors (Iron Buffalo type) driven by 3.4–6.7 kW (4.5–9 hp) gasoline or diesel engines used for wet paddy soil preparation. Approximately 3000 units are manufactured annually; (4) A rice thresher designed by the Engineering Division as a mobile trailer unit, capable of threshing at a rate of 700 kg of cleaned paddy per hour; and (5) A centrifugal rice mill designed by the Engineering Division. Because the milling recovery is from 74 to 80%, pilot mills are being set up in farmers' cooperatives so that the farmers will receive higher returns of milled rice than what they now receive from local rice mills (45% recovery). Local manufacturers are now beginning to produce this new type of rice mill.

The current research and development activities in the Engineering Division are aimed at reducing the cost of rice to the minimum through complete use of machinery in all steps of rice production from irrigation, cultivation, harvesting, to milling.

Current Developments

Since the airplane has become an essential farm machine, it has made possible many of the cultural practices now used in the production of rice. The Engineering Division is now implementing a project by grouping together small farm holders into a single farm unit. For complete rice mechanization, heavy machinery, consisting of bulldozers, graders, and ditchers, has been bought and is now being used to implement the first stage of the project, land consolidation. For aerial seeding and fertilizing, airplanes from the Ministry of Agriculture are being used. The Government of New Zealand has given two Fletchers to this project. From Australia, a new type of airplane known as the Aritruck has been purchased, and is being used in this project for making artificial rain during the dry season.

This project is designed to assist the rice farmers in earning a higher annual income from rice as well as other crops. Therefore, this pilot project will be used for the various research programs designed to: (1) find the cost of remaking original farmers' land into productive irrigable land; (2) arrange crop diversification programs by the use of modern farm machinery and equipment, aerial seeding, fertilizing, and crop spraying to bring about the most efficient use of the land, resulting in the highest income for the farmers; (3) compare the cost of crop production and the income earned from such a project for the feasibility of expanding this program to other farming regions of Thailand; and (4) find out whether such a far-reaching project would be acceptable to the farmers as compared with their present method of farming.

This program is solely undertaken on the Ministry of Agriculture's own budget. The Engineering Division of the Rice Department is responsible for the implementation of this pilot project. Work is now being carried out following the various steps laid out and it is expected that this program will advance sufficiently so that enough facts and data will be available for the final evaluation. — CHAW SUVANSATIT AND PRAYOON SAWANGSAK. *516/19 Larnluang Road, Bangkok, Thailand, and College of Agriculture, Kasetsart University, Bangkok 9, Thailand, respectively.*

APPENDIX

Test Results

These results are from drying and milling tests conducted by the participants of a training course on postharvest technology. Because the conditions during the tests were not controlled or described, and the tests were not replicated and, therefore, give no measure of experimental error, the results must be used as presented and cannot be generalized. — D. B. DE PADUA. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

TABLE A1. Comparison of field losses (grains/m²) during combining and handcutting of paddy. The loss per square metre is the amount of grain collected from random metre-square areas of the rice field after harvesting (April 12, 1973, moisture content = 21%, yield = 6300 kg/ha).

	Harvest method	
	Handcutting	Combining
Group 1	157	1023
2	65	811
3	97	2192
4	78	679
5	82	1263
Mean	95.8	1194
Weight of 100 grains (g)	2.55	2.55
Loss per square metre (g)	2.45	30.50
Loss per hectare (kg)	24.5	305
Percentage loss	0.39	4.84

TABLE A2. Threshing evaluation using averages of the five class groups (April 11, 1973).

Type of threshing	Percentage of rice that is threshed	Head rice (%)	Large brokens (%)	Small brokens (%)	Moisture content (%)
Control	69.5	98.9	0.4	—	12.6
Hampasan[a]	67.1	97.9	1.7	0.3	12.3
Project thresher[b]	67.6	98.3	1.5	0.2	12.7
IRRI thresher[c]	69.3	97.7	1.5	0.2	12.8
Combine[d]	67.8	94.2	4.8	0.8	12.9

[a] The native hampasan, which is hand fed against the bamboo grid.
[b] The project thresher, which is a drum-type wire loop thresher.
[c] International Rice Research Institute table thresher.
[d] A Japanese manufactured harvesting and threshing combine.

TABLE A3. Evaluation of flat-bed grain drying by means of sample milling (April 12, 1973).

Sample type		Amount of paddy (g)	Amount of rice (g)	Head rice (%)	Large brokens (%)	Small brokens (%)	Average moisture content (%)	Average grain temperature during drying (°F)
Sun dried controls	1. 200		137.0	95.5	2.3	2.0		
	2. 200		139.7	96.5	3.5	—		
	3. 200		130.8	97.4	0.1	0.8	13.39	Room temperature
	4. 200		133.8	96.3	3.7.	—		
	5. 200		130.2	97.0	2.7	0.2		
	Avg. 200		134.3	96.5	2.5	0.6		
Top of the grain layer	1. 200		135.1	96.8	1.5	1.7		
	2. 200		135.0	96.7	3.3	—		
	3. 200		135.2	96.6	2.8	—	14.86	91
	4. 200		132.7	97.4	2.6	—		
	5. 200		133.5	97.6	1.6	0.4		
	Avg. 200		134.3	97.2	2.8	0.4		
Centre of the grain layer	1. 200		139.0	96.3	0.9	2.2		
	2. 200		142.4	97.3	2.7	—		
	3. 200		133.8	97.2	2.5	—	12.32	99
	4. 200		135.3	97.5	2.0	0.5		
	5. 200		135.7	96.5	2.5	1.1		
	Avg. 200		137.2	96.6	2.1	0.7		
Bottom of the grain layer	1. 200		137.1	96.6	1.2	1.8		
	2. 200		140.4	97.1	2.9	—		
	3. 200		132.3	97.1	0.7	2.0	11.73	106
	4. 200		132.4	97.5	2.5	—		
	5. 200		139.1	96.6	2.3	1.0		
	Avg. 200		136.4	96.9	1.9	1.0		

TABLE A4. Drying gradient produced in a flat-bed drier for a 45.7-cm (18-inch) bed of grain dried at 43 °C (110 °F) for 2.5 h (April 11, 1973).

Group	Initial moisture content (%)	Moisture content after sun drying (%)	Moisture content after flat-bed drying (%)		
			Top	Centre	Bottom
1	16.73	13.56	15.38	12.54	12.00
2	16.97	13.08	14.76	12.00	11.46
3	15.96	12.75	14.91	12.00	11.46
4	16.48	14.18	14.44	12.83	12.29
5	16.78	13.37	14.81	12.21	11.46
Avg.	16.66	13.38	14.86	12.32	11.73

TABLE A5. The comparative test results of two commercial-scale milling operations.

	Locally made rice mill with one disc huller, and two whitening cones (very old)[a]	Satake rice mill with rubber roll huller, two abrasive and one friction type whitener (new)[b]
Weight of paddy (kg)	1000	1000
Weight of samples, etc. (kg)	6.36	16.59
Weight of paddy milled (kg)	993.64	983.41
Weight of milled rice (kg)	670.23	689.77
Weight of samples (kg)	10.63	14.44
Total weight of milled rice (kg)	680.86	704.21
Rice mill recovery (%)	68.52	71.6
Weight brewers' rice (kg), (% of paddy milled)	6.64, 0.67	6.41, 0.65
Weight coarse bran (kg), (% of paddy milled)	53.27, 5.36	20.5, 2.09
Weight fine bran (kg), (% of paddy milled)	40.09, 4.04	17.32, 1.76
Total weight bran (kg), (% of paddy milled)	93.36, 9.40	37.82, 3.85
Total milling time (min)	85	34
Capacity of rice mill (kg/h)	701	1735

[a]The rice mill was properly set for immediate production of semi-milled rice.
[b]The mill was not used for more than 1 year. It took about 20 min to adjust the mill, during which time a large quantity of under-milled rice was produced, which explains the too high recovery and too low bran production. The amount of paddy in the milled rice was too high.

Labour

and

Power

Labour and power requirements for rice harvesting and processing operations and the corresponding capital investment under Philippine conditions, 1975. Because the values are only approximations, the data must only be used for general comparisons. More detailed economic costing is required for specific case studies. — C. L. INTONG, JR. *Department of Agricultural Engineering, College of Agriculture, University of the Philippines at Los Baños, College, Laguna, Philippines.*

Operation	Labour requirement or capacity[a]	Equipment rated-horsepower	Cost
I. Harvesting and Handling			
A. Manual			
1. Scythe reaping	34 man-h/ha		P3000–5000/1000 knives[b]
2. Cutting with sickle or knife	60–80 man-h/ha		
3. Ethiopian sickle	100–120 man-h/ha		
4. Hand harvesting with small knife	240 man-h/ha		
5. Cut, transport, and stack	80–160 man-h/ha		
6. Bundling	24 man-h/ha		
7. Handling	39 man-h/ha		
8. Carrying and stacking	25–45 man-h/ha		
9. Animal-drawn reaper	0.15–0.25 ha/h		
10. Reaper: 2-m cutter bar, 2 horses	0.6 ha/h		
B. Mechanical			
1. Windrower (cut and lay on ground)—1 man	5.4–10 man-h/ha	4–6 hp	
2. Tractor and binder		40–60 hp	P150 000
(a) Bind (2 men)	4 man-h/ha		
(b) Check (2 men)	8 man-h/ha		
(c) Haul (2 men)	2 man-h/ha		

(continued)

Labour and Power (*continued*)

Operation	Labour requirement or capacity[a]	Equipment rated-horsepower	Cost
3. Combine: Japanese, small			
(a) Single row—1.5-m wide cutter (1 man)	0.18 t/h		P5000–10 000
(b) Hand thresher (reaper) (2 men)	0.19 t/h		
(c) Regular type (miniaturized)	0.37 t/h		P10 000–20 000
4. Combine: USA and European	4–20 ha/h	50–200 hp	P150 000–400 000
(a) In the tropics (3–4 men)	3.2–21.5 man-h/ha		
(b) In the USA (2 men)	2.2–7.5 man-h/ha		
II. Threshing			
A. Manual			
1. Threshing flail	20–30 man-h/t		
2. Beating on bamboo frame	30–60 man-h/t		
3. Threshing with hand sticks	36 man-h/t		
4. Foot threshing by man	40 man-h/t		
5. Pedal thresher	80–100 man-h/t		
6. Trampling by ox	12–18 man-h/ha		
7. Treading by 2 bullocks	140 kg/h		
8. Treading: 3 animals and 3 men	490 kg/h		
B. Mechanical			
1. Treading with standard tractor	80 man-h/ha	40–80 hp	P40 000–100 000
(a) 2 threshing floors	620 kg/h		
(b) 3 threshing floors	960 kg/h		
(c) 4 threshing floors	1258 kg/h		
2. Japanese power thresher	48–197 kg/h	0.5–3 hp	P3000–10 000
3. National Institute of Agric. Eng. (England) thresher (5 men)	512 kg/h		
4. IRRI drum thresher	250 kg/h		
5. IRRI table thresher	350–400 kg/h		
6. IRRI axial flow thresher	1000 kg/h	7 hp	
7. IRRI PTO-thresher	2200 kg/h		
8. Large stationary thresher (McCormick type)	20–30 t/day		
III. Cleaning and Transporting			
A. Manual			
1. Winnowing basket	45 kg/h		P10 000–20 000 per 1000 baskets
2. Tossing in air	40 kg/h		
3. Chaff sieve	175–200 kg/h		
4. Winnowing sieve plus breeze	900 kg/h		
5. Hand fan in field	150 kg/h		
6. Hand-driven winnower	200–1700 kg/h		P500–1000
7. Carrying and stacking	25–45 man-h/ha		

(*continued*)

Labour and Power (*continued*)

Operation	Labour requirement or capacity[a]	Equipment rated-horsepower	Cost
8. Cut, transport, and stack	80–160 man-h/ha		
9. Loads on shoulders (40 kg)	120 loads/ha		
10. Loads on sledges (80 kg)	60 loads/ha		P100–200
11. Loads on ox carts (400 kg)	12 loads/ha		P300–500
12. Loads on hand-drawn carts —bicycle mounted (200 kg)	24 loads/ha		P200–300
B. Mechanical			
1. Cleaning fan mill	1.5–7 man-h/t		
2. Electric powered seed cleaner	600–700 kg/h	0.5–1 hp	P3000–5000
3. Electric powered precleaner	2–20 t/h	1–3 hp	P10 000–20 000
4. Electric powered aspirator	2–20 t/h	2–5 hp	P30 000–55 000
5. Electric powered belt conveyor (10 m)	2–20 t/h	1–5 hp	P5000–10 000
6. Electric powered bucket conveyor (10 m)	2–20 t/h	2–6 hp	P10 000–20 000
7. Electric powered screw conveyor (10 m)	2–20 t/h	3–9 hp	P15 000–30 000
8. Winch crane (1 man)	5–10 t capacity	2–5 hp	P3000–5000
9. Lift truck (1 man)	2–5 t capacity	30–60 hp	P30 000–60 000
10. Grain trucks (2 men)	5–10 t capacity	100–200 hp	P100 000–200 000
11. Tractor trailer (2 men)	3–7 t capacity	50–100 hp	P50 000–100 000
IV. Drying and Storage			
A. Manual (sun/sack)			
1. Sun drying on pavement	26.5 man-h/ha		
2. Sun drying on floor mats	35 man-h/ha		
3. Sack storage			
(a) Sacks (50 kg bag)	100 bags/ha		P2000–3000/1000 bags
(b) Building protection	1.5 m²/t		P750–1000/ft² of building
B. Mechanical			
1. Manually loaded batch-type drier (2 t/8 h)	12–18 man-h/capacity	3–6 hp	P6000–10 000
2. Mechanically loaded batch-type drier (40 t/16 h)	6–9 man-h/capacity	10–25 hp	P200 000–750 000[c]
3. Columnar-type drier (2 t/h)	3–6 man-h/capacity	25–50 hp	P400 000–1 000 000[c]
4. Continuous flow drier (2 t/h)	3–6 man-h/capacity	30–75 hp	P500 000–1 500 000[c]
5. Bulk storage			
(a) Structure (silo and building)	500–3000 t/silo		Cost for 1300–6000 t silo P15 000–100 000
(b) Aeration equipment	1 or 2 men	10–30 hp	P30 000–150 000
(c) Fumigation requirement (usually part of aeration)	1 or 2 men	5–10 hp	
V. Milling and Storage			
A. Manual			
1. Asian treadle mortar	12–18 kg brown rice to 10–15 kg white rice/h		

(*concluded*)

Labour and Power (*concluded*).

Operation	Labour requirement or capacity[a]	Equipment rated-horsepower	Cost
2. African mortar and pestle	1 kg brown rice to 1 kg white rice in 4 h		
3. Sack storage			
(a) Sacks (50 kg)	67 sacks/ha		P2000–3000/1000 bags
(b) Building	1 m³/t		P750–1000/ft³ of building
B. Mechanical			
1. Kiskisan—complete mill	0.15–0.90 t/h	5–20 hp	P10 000–20 000
2. Cone-type mill—complete	0.25–1 t/h	15–140 hp	P40 000–250 000
3. Large cone-type mill—complete	2–10 t/h	150–1000 hp	P2 000 000–7 500 000
4. Rubber roll mill—complete	0.25–15 t/h	10–500 hp	P15 000
5. Bulk storage of brown rice			
(a) Structure	400–5000 t		
6. Parboiling			
(a) Conventional	4 t/h		Rs. 6.74/t (total cost of mill Rs. 610 000[d])
(b) Modern	4 t/h		Rs. 4.79/t (total cost of mill Rs. 740 000[d])

[a] 1 ha = 1000 m² and yields approximately 5 t of paddy.
[b] 7 pesos ≃ $1 (Canadian).
[c] Less conveyors and tempering bins.
[d] 8 rupees ≃ $1 (Canadian).

Characteristics

Some Rice Varieties and Their Basic Characteristics

ADT-27. 1965. An *indica* × *japonica* hybrid of early maturity and height released by Madras State of India. Moderately responsive to nitrogen.

Apostol. A tall traditional variety of the Philippines that is sensitive to photoperiod.

Bahagia. 1968. A sister selection of IR5 released by West Malaysia. Intermediate in plant type and maturity.

BAM 3. A selection from a tall traditional variety. Released by the Orissa State of India.

Basmati 370. 1933. A selection from the Basmati variety of old India. Known for its aroma and kernel-elongation character. Late in maturity and low yielding. It commands a high market price in South Asia and East Africa.

Bengawan. 1941. Released by the Central Research Institute of Agriculture, Indonesia. It is a tall variety that is weakly sensitive to photoperiod and is noted for its good eating quality.

BPI-76. 1960. An intermediate variety developed by the Philippines Bureau of Plant Industry. It is strongly sensitive to photoperiod.

C4-137. 1969. An intermediately tall variety released by the University of the Philippines College of Agriculture. It is weakly sensitive to photoperiod.

C4-63. 1967. An intermediately tall variety developed by the University of the Philippines College of Agriculture. It is weakly sensitive to photoperiod and is noted for its good eating quality.

C4-63G. *ca.* 1968. A pure line selected from C4-63 having green basal leaf-sheath (green base).

C0-29. *ca.* 1960. A hybrid variety of Madras State (India) having early maturity and blast resistance. Moderately tall in stature.

C0-33. *ca.* 1970. A semidwarf variety of Madras State (India) originating from IR8 × ADT-27. Also known as Karuma. Early maturing and responsive to nitrogen.

Dara. 1960. A tall variety released by the Central Research Institute of Agriculture, Indonesia. It is relatively insensitive to photoperiod.

Dee-geo-woo-gen. A semidwarf variety of Taiwan. Insensitive to photoperiod. Taichung Native 1, IR8, and many semidwarf lines were derived from Dee-geo-woo-gen.

GEB-24. *ca.* 1930. A spontaneous mutant selected from a traditional variety of Madras State. It has good grain quality and became the parent of many Indian varieties. 150 day maturity.

Intan. 1940. A tall variety released by the Central Research Institute of Agriculture, Indonesia, but is also known in the Philippines. It is weakly sensitive to photoperiod.

IR8. 1966. A semidwarf variety. It is the first variety named by the International Rice Research Institute (IRRI). It is relatively insensitive to photoperiod; outstanding in nitrogen response. It has poor grain type.

IR5. 1967. Developed at IRRI. It is intermediate in height and weakly sensitive to photoperiod. It has poor grain type.

IR20. 1969. A semidwarf named by IRRI. It is weakly sensitive to photoperiod.

IR22. 1969. A semidwarf named by IRRI. It is weakly sensitive to photoperiod.

IR6. 1970. The name given to IR6-156-2 before it was named as Mehran 69 in Pakistan.

IR24. 1971. A semidwarf name by IRRI. It is relatively insensitive to photoperiod.

Jaya. 1968. A semidwarf variety released by the All-India Coordinated Rice Improvement Project. It is relatively insensitive to photoperiod. It has poor grain type.

Jhona 349. 1933. A selection from Jhona, a traditional variety of the Punjab area (India and Pakistan). It has a higher yielding ability than other local varieties but is poor in grain quality.

Karuma. see C0-33.

Kullakar. A 130 day traditional variety from which ADT-27 was isolated. Native to Madras State of India.

Malinja. 1964. A moderately tall and relatively early maturing (though sensitive to photoperiod) hybrid developed in Malaysia.

Mashuri. 1966. An intermediate variety released by the Rice Department of Malaysia. It is relatively insensitive to photoperiod and is prized for its fine grains.

Mayang Ebos. A tall and late traditional variety of Malaysia that has very strong grain dormancy. Sensitive to photoperiod.

Mehran 69. 1970. A semidwarf, long-grain selection from IR6-156-2 released in Pakistan.

Palman 246. 1939. A selection from Palman, a traditional variety of the Punjab area (India and Pakistan). It has good-looking grains but poor cooking quality.

PB5 (Peta Baru 5). Indonesian name for IR5.

PB8 (Peta Baru 8). Indonesian name for IR8.

Pebifun. A relatively early, moderately tall, *indica* variety of Taiwan. A major variety grown in the double-cropping area of West Malaysia during 1942–1964.

Pelita. 1971. Released by the Central Research Institute of Agriculture, Indonesia. It is weakly sensitive to photoperiod.

Peta. 1941. A tall variety released by the Central Research Institute of Agriculture, Indonesia, but is also grown in the Philippines. It is weakly sensitive to photoperiod.

Ratna. 1970. A semidwarf variety released by the Central Rice Research Institute, India. It is weakly sensitive to photoperiod and is noted for its high grain quality.

RD-1. 1969. A Thai semidwarf variety. It was the first hybrid variety named by the Rice Department (now Rice Division).

RD-3. 1969. A Thai semidwarf variety. Similar to RD-1, it is also nonglutinous.

RD-5. 1973. A moderately tall Thai hybrid variety having a plant type intermediate

between the tall traditional type and the semidwarf. Weakly sensitive to photoperiod.

Ramadja. 1954. A tall variety released by the Central Research Institute of Agriculture, Indonesia. It is weakly sensitive to photoperiod.

Ria. 1966. IR8 under a Malaysian name.

Rojolele. A tall traditional variety of the bulu type; purified from a farmer's variety. It is relatively insensitive to photoperiod.

Siam 29. A tall traditional variety that is sensitive to photoperiod. Both Malaysian and Thai strains have the same name.

Sigadis. 1954. A tall variety developed by the Central Research Institute of Agriculture, Indonesia. It is relatively insensitive to photoperiod.

SLO-13. *ca.* 1950. An intermediately tall strain selected from a traditional variety. Developed in Andhra Pradesh, India.

Syntha. 1963. A tall variety developed by the Central Research Institute of Agriculture, Indonesia. It is weakly sensitive to photoperiod.

Taichung 65. 1927. A *ponlai* (*japonica*) variety of Taiwan that is well adapted to double cropping in the subtropics and tropics.

Taichung Native 1. 1960. The first semidwarf variety released by the Taiwan Provincial Department of Agriculture. It is relatively insensitive to photoperiod.

Tangkai Rota. A traditional variety of Malaysia having relatively erect leaves, intermediate height and maturity. A parent of IR5.

Tjeremas. *ca.* 1940. A tall variety developed in Indonesia that has the same parents as Peta. It is also grown in the Philippines. It is weakly sensitive to photoperiod.

TKM-6. *ca.* 1950. A relatively early and tall hybrid derived from GEB-24 × CO-18. It has slender grains and moderate resistance to stemborers. Developed in Madras State, India.

Characteristics of present Philippine Seedboard recommended lowland rice varieties

Characteristics	BPI-76(NS)	C4-63G	C4-137	IR8	IR5	IR20	FK-178A	IR22
Plant								
Maturity (days)	125–135	125–135	130–140	125–135	140–150	120–130	120–150	115–130
Photoperiod reaction	nonsensitive	nonsensitive	nonsensitive	nonsensitive	nonsensitive	weakly sensitive	sensitive	weakly sensitive
Height	medium	medium	medium	short	medium	short	tall	short
Lodging	moderately resistant	resistant	resistant	highly resistant	resistant	moderately resistant	moderately resistant	resistant
Tillering ability	medium high	medium high	medium high	high	high	high	medium low	high
Position of leaves at harvest	slightly drooping	semierect	semierect	erect	semierect	erect	drooping	erect
Blast disease	moderately resistant	moderately resistant	moderately resistant	resistant	intermediate	resistant	resistant	resistant
Bacterial leaf blight	intermediate	intermediate	moderately susceptible	intermediate	intermediate	intermediate	moderately resistant	moderately resistant
Tungro virus	intermediate	resistant	resistant	susceptible	intermediate	resistant	intermediate	susceptible
Grain								
Threshing characteristic	medium	easy	easy	easy	easy	medium	medium	medium
Head rice recovery	intermediate	high	high	high	low	high	high	high
Grain dormancy (weeks)	4	4	4	3	4	4	—	3
Grain type	medium, bold	long, slender	long, slender	long, bold	long, bold	medium, bold	long, bold	long, slender
Amylose content	intermediate	intermediate	high	high	high	high	—	high
Gelatinization temperature	intermediate	intermediate	intermediate	low	intermediate	intermediate	—	low
Eating quality	very good	excellent	very good	fair	good	good	very good	good

Characteristics	IR24	BPI 121-407	C12	BPI 3-2	PARC 2	C168	IR26	IR29
Plant								
Maturity (days)	125–130	125–130	125–135	125–129	123–128	126–131	116–125	115
Photoperiod reaction	nonsensitive	nonsensitive	nonsensitive	nonsensitive	nonsensitive	nonsensitive	nonsensitive	nonsensitive
Height	short	short	medium	medium	short	medium	short	short
Lodging	resistant	resistant	moderately resistant	resistant	resistant	resistant	resistant	moderately resistant
Tillering ability	high	high	medium high	medium high	medium high	medium high	medium high	high
Position of leaves at harvest	erect	erect	slightly drooping	drooping	erect	erect	erect	—
Blast disease	resistant	moderately resistant	moderately resistant	intermediate	intermediately resistant	intermediately resistant	—	resistant
Bacterial leaf blight	intermediate	moderately resistant	intermediate	intermediately resistant	intermediately susceptible	intermediately susceptible	intermediately susceptible	resistant
Tungro virus	intermediate	intermediate						resistant
Grain								
Threshing characteristic	medium	medium	medium	medium	—	medium	medium	—
Head rice recovery	high	high	high	high	intermediate	high	high	high
Grain dormancy (weeks)	4	4	4	4	—	4	4	4
Grain type	long, slender	long, slender	long, bold	medium, slender	—	long, slender	—	medium, slender
Amylose content	low	intermediate	intermediate	intermediate	intermediately high	intermediate	low	—
Gelatinization temperature	—	—	intermediate	—	—	—	—	low
Eating quality	very good	very good	very good	very good	—	very good	good	—

Equilibrium moisture content of rough rice

The hygroscopic equilibrium moisture content of rough rice at various temperatures and moisture contents. These values can be superimposed on a psychrometric chart to show the approximate variation of the equilibrium moisture content of the grain corresponding to the specific temperature and relative humidity of the atmosphere (from Huston 1972).[a]

% moisture (wb)	Equilibrium relative humidity (%) at the following temperatures, °F																							
	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150
1	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.7	0.8	1.1	1.3	1.7	2.0	2.5	3.1	3.8	4.6	5.6	6.8	8.2	9.8	11.7	14.0
2	0.3	0.4	0.5	0.6	0.7	0.9	1.1	1.3	1.6	1.9	2.3	2.8	3.3	4.0	4.7	5.6	6.6	7.7	9.0	10.5	12.2	14.2	16.4	18.9
3	0.9	1.1	1.3	1.5	1.8	2.1	2.5	2.9	3.4	3.9	4.5	5.3	6.1	7.0	8.0	9.2	10.4	11.9	13.5	15.3	17.2	19.4	21.9	24.5
4	2.1	2.5	2.8	3.3	3.7	4.3	4.8	5.5	6.2	7.0	7.9	8.9	10.0	11.2	12.5	13.9	15.5	17.2	19.0	21.0	23.2	25.5	28.0	30.7
5	4.4	5.0	5.5	6.2	6.9	7.7	8.5	9.4	10.4	11.5	12.6	13.9	15.2	16.6	18.2	19.8	21.6	23.4	25.4	27.5	29.8	32.1	34.6	37.3
6	8.1	8.8	9.7	10.6	11.5	12.5	13.6	14.8	16.0	17.3	18.6	20.1	21.6	23.2	24.9	26.6	28.5	30.4	32.4	34.6	36.8	39.1	41.5	44.0
7	13.2	14.2	15.3	16.4	17.5	18.7	20.0	21.3	22.7	24.2	25.7	27.2	28.8	30.5	32.2	34.0	35.9	37.8	39.8	41.9	44.0	46.1	48.4	50.7
8	19.8	21.0	22.2	23.5	24.8	26.1	27.5	28.9	30.4	31.9	33.4	35.0	36.6	38.3	40.0	41.8	43.5	45.4	47.2	49.1	51.1	53.1	55.1	57.1
9	27.6	28.8	30.1	31.5	32.8	34.2	35.6	37.1	38.5	40.0	41.5	43.1	44.6	46.2	47.8	49.4	51.1	52.8	54.5	56.2	57.9	59.6	61.4	63.2
10	36.0	37.3	38.6	40.0	41.3	42.6	44.0	45.4	46.8	48.2	49.6	51.0	52.4	53.9	55.3	56.8	58.3	59.8	61.2	62.7	64.2	65.8	67.3	68.8
11	44.7	46.0	47.2	48.5	49.7	51.0	52.2	53.5	54.8	56.0	57.3	58.6	59.8	61.1	62.4	63.7	64.9	66.2	67.5	68.8	70.0	71.3	72.6	73.8
12	53.2	54.4	55.5	56.6	57.7	58.9	60.0	61.1	62.2	63.3	64.4	65.5	66.6	67.7	68.8	69.8	70.9	72.0	73.1	74.1	75.2	76.2	77.3	78.3
13	61.2	62.2	63.1	64.1	65.1	66.0	67.0	68.0	68.9	69.8	70.8	71.7	72.6	73.5	74.4	75.3	76.2	77.1	77.9	78.8	79.7	80.5	81.3	82.2
14	68.3	69.1	70.0	70.8	71.6	72.4	73.2	74.0	74.8	75.6	76.3	77.1	77.8	78.6	79.3	80.0	80.7	81.4	82.1	82.8	83.5	84.2	84.9	85.5
15	74.5	75.2	75.9	76.6	77.2	77.9	78.6	79.2	79.8	80.4	81.1	81.7	82.3	82.9	83.4	84.0	84.6	85.1	85.7	86.2	86.8	87.3	87.8	88.3
16	79.8	80.4	80.9	81.5	82.0	82.5	83.0	83.5	84.0	84.5	85.0	85.5	86.0	86.4	86.9	87.3	87.8	88.2	88.6	89.1	89.5	89.9	90.3	90.7
17	84.2	84.7	85.1	85.5	85.9	86.3	86.7	87.1	87.5	87.9	88.3	88.7	89.0	89.4	89.7	90.1	90.4	90.8	91.1	91.4	91.7	92.0	92.3	92.7
18	87.8	88.2	88.5	88.8	89.1	89.4	89.8	90.1	90.4	90.6	90.9	91.2	91.5	91.8	92.0	92.3	92.6	92.8	93.1	93.3	93.5	93.8	94.0	94.2
19	90.7	91.0	91.2	91.5	91.7	91.9	92.2	92.4	92.6	92.8	93.1	93.3	93.5	93.7	93.9	94.1	94.3	94.5	94.6	94.8	95.0	95.2	95.4	95.5
20	93.0	93.2	93.3	93.5	93.7	93.9	94.1	94.2	94.4	94.6	94.7	94.9	95.0	95.2	95.3	95.5	95.6	95.8	95.9	96.0	96.2	96.3	96.4	96.6
21	94.7	94.9	95.0	95.2	95.3	95.4	95.5	95.7	95.8	95.9	96.0	96.1	96.3	96.4	96.5	96.6	96.7	96.8	96.9	97.0	97.1	97.2	97.3	97.4
22	96.1	96.2	96.3	96.4	96.5	96.6	96.7	96.8	96.9	97.0	97.0	97.1	97.2	97.3	97.4	97.4	97.5	97.6	97.7	97.7	97.8	97.9	97.9	98.0
23	97.1	97.2	97.3	97.4	97.4	97.5	97.6	97.6	97.7	97.7	97.8	97.9	97.9	98.0	98.0	98.1	98.2	98.2	98.3	98.3	98.4	98.4	98.5	98.5
24	97.9	98.0	98.0	98.1	98.1	98.2	98.2	98.3	98.3	98.4	98.4	98.4	98.5	98.5	98.6	98.6	98.6	98.7	98.7	98.7	98.8	98.8	98.9	98.9
25	98.5	98.5	98.6	98.6	98.6	98.7	98.7	98.7	98.8	98.8	98.8	98.9	98.9	98.9	99.0	99.0	99.0	99.0	99.1	99.1	99.1	99.1	99.2	99.2

[a]Courtesy of Wratten and Kendrick (1970). Extrapolated data by Hogan and Karon (1955), and Karon and Adams (1949). Equation by Strohman and Yoeger (1967). Accuracy of extrapolated data beyond the range of 77 to 111 °F has not been verified experimentally.

Physical characteristics of the rice grain[a]

Bulk density	576 kg/m³	Dielectric constant	
	(36 lb/ft³)	(frequency, 10–40 mc/s)	
Air velocity for conveying seed	15–25 m/s	10% moisture	3.8
	(3000–5000 fpm)[b]	16% moisture	3.8
Voids, air space	48%	19% moisture	4.3
Kernel specific gravity	1.11	Specific heat	
Angle of repose	36 degrees	15% moisture	0.42 g-cal/g-deg C
Coefficient of friction			(0.42 BTU/lb-deg F)
Smooth steel	0.41	22% moisture	0.52 g-cal/g-deg C
Finished concrete	0.52		(0.52 BTU/lb-deg F)
Smooth wood	0.44		

[a] Taken in part from Hall 1957.
[b] Salisbury 1950.

References

AGRAWALA, N. S. 1963. Parboiling of rice in India. Bull. Grain Technology, 1(3): 55–60.

ALI, N., and T. P. OJHA. 1975a. Soaking characteristics of paddy. J. Agric. Eng. Res. *In press.*

—— 1975b. A new concept in parboiling technology. I. Agric. Eng. Res. *In press.*

ALI, N., and A. C. PANDYA. 1974. Basic concept of parboiling of paddy. J. Agric. Eng. Res. 19(2): 111.

ARBOLEDA, J. R., and D. B. DE PADUA. 1965. Performance studies of small capacity rice mills. Paper presented at the Rice and Corn Seminar, Univ. Philippines, College of Agriculture, Los Baños, Laguna, Philippines.

BAL, S., N. ALI, and T. P. OJHA. 1974. Parboiling of paddy. RPEC Publication No. 745. Indian Institute of Technology, Kharagpur, India.

BANDOPADHYAY, B., and T. K. Ghose. 1965. Studies on the hydration of Indian paddy. I. A rate equation of the soaking equation. Indian J. Technology, 3(11):360.

BARKER, R., and G. DOZINA, JR. 1970. Second generation problems in the rice industry in the Philippines. Paper presented at the Seminar-Workshop in Grain Processing, University of the Philippines, College of Agriculture, Los Baños, Laguna, Philippines.

BECKER, H. A. 1960. On the absorption of liquid water by the wheat kernel. Cereal Chem. 1(2): 309–323.

BHATTACHARYA, K. R. 1969. Breakage of rice during milling and the effect of parboiling. Cereal Chem. 37: 478–485.

BHATTACHARYA, K. R., and S. Z. ALI. 1970. Improvements in commercial sun drying of parboiled paddy for better milling quality. Rice. J. 73(9): 3–4, 9–15.

BHATTACHARYA, K. R., and Y. M. INDUDHARA-SWAMY 1967. Conditions of drying parboiled paddy for optimum milling quality. Cereal Chem. 44(6): 592–600.

BHATTACHARYA, K. R., and V. P. SUBBA RAO. 1966a. Processing conditions and milling yield in parboiling of rice. J. Agric. Food Chem. 14(5): 473.

—— 1966b. Effect of processing conditions on quality of parboiled rice. J. Agric. Food Chem. 14(5): 476.

BHOLE, N. G., S. BAL, and V. R. RAO. 1970. Paddy harvesting and drying studies. Rice Process Engineering Centre, Indian Institute of Technology, Kharagpur, India.

BORASIO, L., and F. GARIBOLDI. 1965a. Parboiled rice – production and use; Part I, Production. Rice J. 68(5): 32–35, 41.

—— 1965b. Parboiled rice – production and use; Part II, Use. Rice J. 68(8): 23–27.

CENTRAL FOOD TECHNOLOGICAL RESEARCH INSTITUTE. 1969. Parboiling of paddy. Project Circular No. 7 (revised), Mysore, India.

CHILDERS, E., and M. VAJRATHON. 1969. Social communication components in development programs. Paper presented at the 11th World Conference of the Society for International Development. New Delhi, India. November 14–17.

DESIKACHER, H. S. R., M. K. BHASHYAM, and H. A. B. PARIPA. 1967. Relative yields of total and head rice from raw and parboiled paddy. J. Food Sci. Technology, 4: 156.

DESIKACHAR, H. S. R., C. M. SOWBHAGYA, C. S. VIRAKTAMATCH, Y. M. INDUDHARASWAMY, and M. K. BHASHYAM. 1969. Steaming of paddy for improved culinary, milling, and storage properties. J. Food Sci. Technology. 6(2): 117–121.

DESIKACHAR, H. S. R., and V. SUBRAHMANYAN, 1959. Expansion of new and old rice during cooking. Cereal Chem. 36: 385–391.

EZAKI, H. 1963. Harvesting rice in Japan. Paper presented at Agric. Eng. Conf. on Aspects of Rice Production. IRRI, Los Baños, Laguna, Philippines.

—— 1969. Rice harvesting machines in Japan. Japanese Agric. Res. Chart. 4(1): 13.

FALCON, W. P. 1970. The green revolution: second generation problems. Am. J. Agric. Economics, 52(5): 698–710.

FOOD AND AGRICULTURE ORGANIZATION. 1954. Rice and rice diets — a nutritional survey (revised). FAO, Rome, Italy.

—— 1967–1968. Pilot study on paddy losses in Thailand during harvesting, drying, and threshing. FAO, Rome, Italy.

FRASER, C. W., and W. L. HOLEY. 1932. Factors that influence the rate of absorption of water by heat. Cereal Chem. 9: 45.

GARIBOLDI, F. 1972. Parboiled rice. Chapter 12. *In* Rice chemistry and technology. *Edited by* Houston, D. F. American Association of Cereal Chemists, Inc., St. Paul, Minnesota.

—— 1973. Rice testing methods and equipment. Food and Agriculture Industries Service, Agri-

cultural Services Division. Agriculture Department. FAO, Rome, Italy.

GHOSE, T. K. 1963. Development of an improved and fully mechanized method for the production of parboiled rice. Jadavpur University, Calcutta, India.

GHOSE, R. L. M., M. B. GHATGE, and V. SUBRAHMANYAN. 1960. Rice in India (revised). ICAR, New Delhi, India.

GRABE, D. F. 1968. Quality control in seed production. Short Course Proceedings. Mississippi State Univ., State College, Miss.

GREGG, B. R., A. G. LAW, S. S. VERDI, and J. S. BALIS. 1970. Seed processing. New Delhi, India.

GUPTA, C. P. 1963. Rice engineering research. Department of Agricultural Engineering, Indian Institute of Technology, Kharagpur, India.

HALL, C. W. 1957. Drying farm crops. Agricultural Consulting Associates Inc., Distributed by the Avi Publishing Co., Inc., Wesport, Connecticut.

HARINGTON, R. E. 1970. Thresher principles confirmed with a multi-crop thresher. J. Agric. Eng. 6(2): 49–61.

HOGAN, J. T., and M. L. KARON. 1955. Hygroscopic equilibria of rough rice at elevated temperatures. J. Agric. Food Chem. 3(10): 855.

HOUSTON, D. F. (ed.). 1972. Rice chemistry and technology. American Association of Cereal Chemists, Inc., St. Paul, Minnesota.

HOUSTON, D. F., and G. O. KOHLER. 1970. Nutritional properties of rice. National Academy of Science, Washington, D.C.

HOUSTON, D. F., I. R. HUNTER, and E. B. KESTER. 1956. Storage changes in parboiled rice. J. Agric. Food Chem. 4(11): 964.

HOUSTON, D. F., I. R. HUNTER, E. A. McCOMB, and E. B. KESTER. 1954. Deteriorative changes in the oil fraction of stored parboiled rice. J. Agric. Food Chem. 2(23): 1185.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1969. Annual Report. Los Baños, Laguna, Philippines. pp. 27–43.

—— 1971. Annual Report for 1970. Los Baños, Laguna, Philippines.

JAYANARAYANA, E. K. Influence of processing conditions on the browning of parboiled rice. Rice J. 68 (12): 16–17.

JOHNSON, L. 1963. Power requirements in rice production. Paper presented at Agric. Eng. Conf. on Aspects of Rice Production. IRRI. Los Baños, Laguna, Philippines.

JOHNSON, S. 1968. Terminal report. General engineering and economic research portion of contract number AID/CSD-834. IRRI. Los Baños, Laguna, Philippines.

JONES, J. W., and J. W. TAYLOR. 1933. Effect of parboiling rough rice on milling quality. U.S. Department of Agriculture, Circular No. 340.

JONES, J. W., L. ZELENY, and J. W. TAYLOR. 1946. Effect of parboiling and related treatments on the milling, nutritional, and cooking quality of rice. U.S. Department of Agriculture, Circular No. 752.

KARON, M. L., and M. E. ADAMS. 1949. Hygroscopic equilibrium of rice and rice fractions. Cereal Chem. 26:1.

KHAN, A. U. 1969. Agricultural Engineering Semi-annual Substantive Report No. 8. IRRI, Los Baños, Laguna, Philippines.

KISAN KRISHI YANTRA UDYOG, KANPUR. 1972. Automatic parboiling and drying of paddy, prospect and promises — a performance study. Government of India.

KUPPUSWAMY, M. A. 1972. Mathematical model for a continuous system of paddy parboiling. J. Agric. Eng. Res. 9(3): 53.

KURIEN, P. P., R. RADHAKRISHNAMURTHY, H. S. R. DESIKACHAR, and V. SUBRAHAMANYAN. 1964. Effect of parboiling on the swelling quality of rice. Cereal Chem. 41(1): 16–22.

LAWRENCE, R. 1970. Some economic aspects of farm mechanization in Pakistan. USAID, Lahore, West Pakistan.

LELE, U. G. 1970. An analysis of modernization of the rice milling industry in India. Dep. Agric. Economics, Cornell Univ., USAID Res. Project. Occasional Paper No. 37.

MAHADEVAPPA, M., and H. S. R. DESIKACHAR. 1968a. Expansion and swelling of raw and parboiled rice during cooking. J. Food Sci. Technology, 5(2): 59–62.

—— 1968b. Some observations on the histology of raw and parboiled rice. J. Food Sci. Technology, 5(2): 72–73.

MATZ, S. A. 1959. The chemistry and technology of cereals as food and feed. The AVI Publishing Co., Inc., West Port, Conn.

MEARS, L., and R. MARQUEZ. 1972. Rice storage and milling. Univ. Philippines, IEDR, Discussion Paper No. 72-11, 51 pp.

MOZUMDAR, A. C., A. N. BOSE, N. C. GANGULI, and B. C. GUHA. 1960. I – Soaking and gelatinization; II – Dehydration; III – Effect of hot soaking and mechanical drying on the nutritive value of parboiled rice. J. Biochem. Microbiol. Technol. Eng. 2(4): 431.

MECHAM, D. K., E. B. KESTER, and J. W. PENCE. 1961. Parboiling characteristics of California medium-grain rice. Food Technology, 15(11): 475–479.

MOHSENIN, N. N. 1968. Physical properties of

plant and animal materials: Part I. Department
of Agric. Eng., Penn. State Univ., University
Park, Penn.

PATTERSON, E. 1968. Good leaders and sound
management. Official Proc. 6th. Far East Work-
shop on Agric. Credit and Coop. Bangkok.
Thailand, March 10–22, pp. 164–166.

QUINTANA, V. U. 1969. Patterns of cooperative
management training, and member education.
Paper presented at Second Nat. Conf. of the
Agric. Coop. League of the Philippines. Agric.
Credit Cooperative Institute, Los Baños, La-
guna, Philippines, July 22–25.

RADHEY, L., and J. E. WIMBERLY. 1970. Notes
on modern parboiling plants. Rice Process Eng.
Centre, Indian Institute of Technology, Kharag-
pur, India.

RAGHAVENDRA RAO, S. N., and B. O. JULIANO.
1970. Effect of parboiling on some physio-
chemical properties of rice. Food Chem. 18(2):
289.

RAGHAVENDRA RAO, S. N., M. N. NARAYANA, and
H. S. R. DESIKACHAR. 1967. Studies on some
comparative milling properties of raw and par-
boiled rice. J. Food Sci. Technology. 4(4):
150–155.

RAMA RAO, V. V., and S. BAL. 1973. Design and
layout of a modern parboiling and drying plant.
Unpublished report. Rice Process Eng. Centre,
Indian Institute of Technology. Kharagpur,
India.

REPORT OF THE PHILIPPINE DELEGATION. 1968.
Presented at Sixth Far East Workshop on Agric.
Credit and Cooperatives, Bangkok, Thailand,
March 10–22.

REVIER, P. R., and A. W. YOUNG. Field inspection
techniques in seed production. Seed Technology
Laboratory, Mississippi State Univ., State Col-
lege, Miss,

ROBERTS, R. L., A. L. POTTER, E. B. KESTER, and
K. K. KENEASTER. 1954. Effect of processing
conditions on the expanded volume, colour,
and soluble starch of parboiled rice. Cereal
Chem. 31(2): 121–129.

RUIZ, E. 1965. Harvest losses of palay grains of
BPI-121 lowland rice variety at different levels
of moisture content. Central Luzon State Univ.
Sci. J. 1(2).

SALISBURY, J. K. (ed.) 1950. Kent's mechanical
engineers handbook. Design and production
volume. 12th edition. John Wiley and Sons,
Inc., New York, N.Y.

SEED PROCESSING, STORAGE, AND DISTRIBUTION
MANUAL. 1967. Produced cooperatively by Na-
tional Seeds Corporation (India) and the
Rockefeller Foundation.

SHIVANNA, C. S. 1971. Traditional and modern
methods of parboiling and drying paddy. Food
Industries J. 4(5): 1–12, 24–25.

SINGH, B. P. N. 1972. Kinetics of water sorption
and swelling by grain. Lecture. Agric. Eng.
Dep., Indian Institute of Technology, Kharag-
pur, India.

STEVENSON, J. H. 1970. Chapter 1. Introduction.
Symposium on Food Grain Marketing in Asia.
Asian Productivity Organization, Tokyo, Japan.
pp. 1–9.

STROHMAN, R. D., and R. R. YOEGER. 1967. A
new equilibrium moisture content equation.
Trans. Am. Soc. Agric. Eng. 10(5): 675.

STROHMAN, R. E., H. F. MCCOLLY, and B. A.
STOUT. 1965. Agricultural Engineering Depart-
ment, Michigan State University, A.S.A.E.
Paper No. 65–169.

STOUT, B.A. 1966. Equipment for rice production.
FAO Agric. Dev. Paper No. 84, pp. 116–117.

SUBRAHMANYAN, V. 1972. Utilization of donatable
oxygen as a means of controlling putrefactive
changes during the cold soaking of paddy –
successful application in association with tra-
ditional and modern mills needs more intensive
study of the associated phenomena leading to
wider application. Unpublished report. Paddy
Processing Research Centre, Triuvarur, India.

TANEJA, M. L. 1963. Harvesting of rice in India.
Paper presented at Agric. Eng. Conf. on Aspects
of Rice Production, IRRI. Los Baños, Laguna,
Philippines.

TIMMER, C. P. 1972. Employment aspects of mar-
keting change in Indonesia. Food Research
Institute, Stanford Univ., California, USA,
Discussion Paper No. 72–3.

UNITED NATIONS. 1960. Agricultural mechaniza-
tion. Mechanization of loading, unloading, and
transport operations in agriculture. United Na-
tions, Rome, Italy.

VAN RUITEN, H. 1971a. Quality control of paddy
and milled rice. Philippines: United Nations
Development Program.

—— 1971b. Recent developments in the rice
milling industry of the Philippines. UPCA/
UNDP Project: Training of technicians for the
grain industries. SF PHI 34.

VAUGHAN, C. E., B. R. GREGG, and J. C.
DELOUCHE (ed.). 1968. Seed processing and
handling. Seed Technology Laboratory, Mis-
sissippi State Univ., State College, Miss.

VIR. 1969. Adult education and cooperatives.
Paper presented at 16th Nat. Seminar on Adult
Education for Democracy. Jointly arranged by

the Ind. Adult Education Assoc., New Delhi and the Government of Pandichori, Dec. 26–29.

WEITZ HETTELSATER ENGINEERS. 1968. Economic and engineering feasibility study. Storage, handling, and marketing of selected crops in the Republic of the Philippines. Produced under contract with USAID. p. 203.

WIMBERLY, J. E. 1971. Development of rice drying and processing in India and Pakistan. Paper presented at the International Rice Research Conference, IRRI, Los Baños, Laguna, Philippines.

—— 1971. Modern versus traditional rice mills — a performance study. Ministry of Agriculture, Government of India.

WRATTEN, F. T., and J. H. KENDRICK. 1970. A further treatment of hygroscopic equilibrium of rough rice and soybeans at elevated temperature. Proc. Thirteenth Rice Technical Working Group, Beaumont, Texas, February 24–26.

Index