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Second Edition

EDITED BY

Bor S. Luh

University of California, Davis

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Persons interested in the production and utilization of rice cereal will find the new edition helpful and informative. Those in the rice-processing industries will find new ideas for developing rice products, convenience foods, breakfast cereals, baby foods, and new extrusion technology as applied to rice products. By-products from rice milling, such as rice bran, rice oil, and rice hulls, will bring greater returns to rice growers and processors. Chemical and physical properties of rice kernels, as well as their nutritive values, are presented in detail. These will be of great value to researchers, food and cereal scientists, and those in new product development.

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Davis, California B. S. Luh

CONTENTS

1

Introduction

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RICE IN RETROSPECT

Rice is considered a semiaquatic annual plant, although it could survive as a perennial in the tropics or subtropics. Cultivars of the two cultivated species, *Oryza sativa L.* and *O. glaberrima* Steud., can grow in a wide range of water-soil regimes, from a prolonged period of flooding in deep water to dry land on hilly slopes.

The crop has remarkable diversity because of its long history of cultivation and selection under diverse climatic and biotic environments, frequently in geographically separated areas. Today rice is grown in more than 100 countries, extending from 53°N latitude to 40°S and from sea level to an altitude over 3000 m. *O. glaberrima* is grown only in Africa on a limited scale. The production practices for rice in various countries vary from extremely primitive to highly mechanized operations.

Books on rice production have been published by De Datta (1981), Luh (1980), and Yoshida (1981). Pillaiyar (1988) published the "Rice Postproduction Manual," which deals largely with postharvest operations. Juliano (1990) reviewed the literature on rice grain quality, with emphasis on problems and challenges.

4

Parboiled Rice

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INTRODUCTION

The rice caryopsis varies widely among cultivars in shape and size. The Food and Agriculture Organization of the United Nations (FAO) classifies milled rice by length into sizes of extra long, more than 7 mm; long, 6.0–7.0 mm; medium or middling, 5.0–5.9 mm; and short, less than 5 mm (Chang and Bardenas 1965). The caryopsis of the Indica group is usually long, slender and rather flat. These varieties are used more often for parboiling because the operations of steeping and heating are quicker and easier as water and heat rapidly reach the center of the endosperm. Long-grain rice is quite distinct from medium- and short-grain rice in cooking and processing characteristics. Long-grain varieties usually cook dry and flaky, with a minimum of splitting, and the cooked grains tend to remain separate. Short- and medium-grain varieties, referred to as "soft-rice," are moister and firmer when cooked, and the grains tend to stick together. The long-grain varieties are characterized by a comparatively high amylose content and a medium-high gelatinizing temperature. Medium- and short-grain varieties have lower amylose content and lower gelatinizing temperature than long-grain varieties. Long-grain rices are used for canned soups and quick-cooking products. Medium- and short-grain varieties generally are used for making dry breakfast cereals and baby foods, and as an adjunct in brewing.

Parboiling is a hydrothermal process in which the crystalline form of starch present in the paddy rice (the rice grain from the field) is changed into an amorphous one as a result of the irreversible swelling and fusion of starch. This is accomplished by soaking, steaming, drying, and milling the rice. The parboiling process produces physical, chemical, and organoleptic modifications in the rice, with economic and nutritional advantages (Gariboldi 1972, 1974, 1984; Luh and Mickus 1980; Kasasian 1982; Bhattacharya 1985; Pillaiyar 1988, 1990). The major objectives of parboiling are to: (1) increase the total and head yield of the 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 (Ali and Ojha 1976). The changes occurring in the parboiling process are as follows:

1. The water-soluble vitamins and mineral salts are spread throughout the grain. The riboflavin and thiamin contents are four times higher in parboiled rice than in milled rice. The thiamin is more evenly distributed in the parboiled rice, and the niacin level in this rice is eight times greater (Kennedy et al. 1975).
2. The moisture content is reduced to 10–11% for better storage.
3. The starch grains embedded in a proteinaceous matrix are gelatinized and expanded until they fill up the surrounding air spaces.
4. The protein substances are separated and sink into the compact mass of gelatinized starch, becoming less liable to extraction. Dimopoulos and Muller (1972) reported that the parboiling process alters the solubility of rice protein in various solvents.
5. The enzymes present in the rice kernel are partially or entirely inactivated. Shaheen et al. (1975) found a reduction in the free fatty acid content of parboiled rice that has been stored for 10 months, presumably resulting from the inactivation of lipase. Anthoni and Singaravadivel (1982) found a decrease in free fatty acid in rice as a result of parboiling.
6. Proliferation of fungus spores and growth of eggs, larvae, or insects, etc., are prevented.
7. The solids leached into the cooking water and the extent of solubilization of the kernels on cooking are considerably reduced.

After rice is parboiled, the milling yield is higher (Filho 1986) because there are fewer broken grains. The grain structure becomes compact, translucent, and shiny. The milled parboiled rice keep longer and better than in the raw state since germination is no longer possible. The grains remain firmer during cooking and are less likely to become sticky. The nutritional value of parboiled rice is greater because of the higher content of vitamins and mineral salts that have spread into the endosperm. The

starchy endosperm of parboiled rice has a greater resistance to milling and, therefore, the bran and germ are more effectively separated.

Several workers have studied the improvement in rice kernel characteristics following parboiling. Rao and Juliano (1970) offer retrogradation as an explanation for the effect of parboiling on iodine staining, amylograph characteristics, resistance to breakdown during cooking, and reduced solubility of the starch. Studies of amylose solubility and hydration characteristics of parboiled rice have led Ali and Bhattacharya (1980a, b) to a similar conclusion.

Priestley (1976a, b) has suggested that the resistance of parboiled rice paste to swelling and solubilization may be attributed to the presence of associative bonding in the starch. To test whether this bonding is a result of retrogradation or the formation of an insoluble amylose complex, he studied the X-ray diffraction pattern of cereal starch with peaks at 3.84 Å (Angstrom) and 5.85 Å. Following parboiling, the A-type pattern is replaced by a V-type pattern with diffraction lines at 6.80 Å and 4.42 Å. These peaks confirm the presence of a helical amylose complex. There was no evidence of a B-type pattern characteristic of retrograded starch that would be expected to give peaks at 15.8 Å and 5.2Å.

The changes parboiling brings about in the rice are closely related to the techniques used. Lack of experience may nullify the advantages described, even reducing the food value of the cereal originally possessed. If the paddy is allowed to ferment during or after steeping, the sensory quality of the rice will be unacceptable for consumption. There are problems hindering the more extensive consumption of parboiled rice. Better technical knowledge in processing, packaging, and storage is needed to improve the quality of parboiled rice. Ohta et al. (1985) reported on the advantages of parboiling on the stability of the grain during storage.

CHARACTERISTICS OF PADDY RICE FOR PARBOILING

The rice varieties used for parboiling are those that are more brittle because of the soft structure of their endosperm. Long-grain paddy rice that gives a low output on milling is preferred for parboiling. The long and slender rice varieties are usually parboiled because they are fragile compared with the short or medium-length grains. Varieties that have good milling quality are generally not parboiled (Ali and Ojha 1976).

Some characteristics of paddy rice that affect the yield and quality of parboiled rice are:

1. Partially or fully shelled grains may be present.
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.

3. The pigments of the husk and pericarp may be dissolved during the soaking and steaming operations, causing discoloration of the endosperm.

4. Microbial infestation may cause a partial or total darkening of the endosperm.

5. Some injuries on the seed caused by mechanical impact or by insects may lead to partial discoloration of the parboiled rice.

Bhattacharya (1985) and Pillaiyar (1990) reviewed the literature on rice parboiling, including conventional home-style and modern processes. Biswas and Juliano (1988) studied properties of parboiled rice from varieties differing in starch properties. Differences in rate of water absorption during steeping and steaming of rough rice stemming from differences in starch gelatinization temperature (GT) may be minimized by soaking for 8 hr at 60°C and steaming for 10 min at 1.0 kg/cm^2 steam pressure (120°C) or 30 min at 100°C. The water content of parboiled rice was higher for low-GT rice than for intermediate-GT rices steamed at 100°C only.

Shelled Grains

The grains that are not protected by hulls absorb more water and heat, and this may alter their shape. They stand out in the milled product because of their darker color resulting from the greater quantity of heat absorbed. The grains that are not shelled, but with the hulls loosened or partly pulled off during threshing, are likely to deteriorate in shape and color.

Mold Infestations

Mold infestation leaves spots on the paddy, shelled, and milled rice. The grains become colored or stained. It may affect the outer surface of the hull, with spots visible on the paddy, or the outer layers of the caryopsis, with spots visible on the shelled rice. In severe cases, the mold may reach the starchy part of the endosperm.

The paddy must be shelled in order to see whether the surface of the caryopsis is stained or discolored. Polishing the grain will also reveal the presence of any caryopses with yellow or amber endosperms formed by enzymic amylolysis and lipasic action of the enzymes in the fungi on the grain. Parboiling can further accentuate the color change in the grains to form a dark or reddish shade.

Injuries Caused by Insects or Threshing

Infestation by insects, as well as threshing, may injure the caryopsis. The caryopsis will appear pitted, and stains will be seen after shelling or milling. The injury will lead to darkening of the grains during steaming.

Chalky, Green, and Red Grains

Chalky or green grains are caused by imperfect ripening for morphological reasons or by certain growth conditions. The chalky kernels present in a glassy- or waxy-textured variety of paddy assume importance in relation to parboiling operations. In order to gelatinize them completely, steeping and steaming conditions must be altered. Chalky or green grains are generally not immune to attacks by fungi, which can cause partial or complete darkening of the milled rice grains. Green or red grains turn dark in response to the parboiling process. After parboiling, those with a red pericarp and white endosperm show a deep or dark red pericarp with an endosperm that is slightly darker than normal. Thorough polishing is necessary to remove the colored pericarp completely.

Mechanical grading will remove the chalky or green grains and sometimes part of the red ones. When stored for some time, the unripe grains shrink considerably so that they can be easily sorted out by mechanical sizing according to thickness.

To make a qualitative examination of the paddy and the parboiled rice, a shelling and polishing machine must be available, together with sorting trays. The operations are as follows:

1. The raw paddy is visually examined to ascertain the amount of awn and empty glumes present, as well as the color and hairiness of the hulls. Notice should be taken of any spots that may denote fungal infections or damage. The percentage of shelled grains (whole or broken) and of partly cracked hulls can be determined by hand sorting.
2. After shelling part or all of the paddy, the shelled sample is examined to see whether fungi or lesions have damaged the caryopsis or the germ. If this has happened, the affected grains will be discolored after parboiling. When these grains have been picked out by hand or electronic sorting, the quantity by weight of shelled caryopses showing the characteristic colored spots can be determined.
3. Another unshelled sample is polished to see the texture of the caryopsis and to find discolored and chalky grains. Any defects in regard to texture and color due to fungal attack and deep-seated injuries are recorded.
4. The yield of milling, including total yield and percentage of broken grains, must be ascertained. This is important in calculations of the cost of the process.

CLEANING

The impurities present in paddy rice are varied; weeds, animals used for threshing, and natural drying all account for the extraneous materials found in the paddy. Impurities and seeds other than rice are usually removed during milling. Some are removed before shelling, and others after polishing along with the broken and damaged grains.

To ensure high grading, several machines are needed, with each one operating on a different principle.

Mechanical cleaning may be completed by washing and floating the paddy in water before it is put into the steeping tanks. This operation, called water flotation, is used to remove stones and sand. Straw and defective grains (chalky, empty, unripe, etc.) are light enough to float away in the process.

The equipment used for cleaning is similar to that employed in flour mills for separating stones from wheat and for dampening the wheat before grinding it. If paddy grains (kernels) have long awns, separation by water flotation may be impractical because even ripe grains will float on the surface of the water, together with the lighter impurities.

In some modern processes, separation by water flotation is preceded by mixing the rice with water and whirling it to free the surface of the paddy grain from air bubbles.

GRADING

The thickness of the grain is very important to the parboiling process, as the necessary period of steeping and steaming increases with grain thickness. If the grains are of different thickness, gelatinization of the starch will be uneven. If steeping and steaming times are prolonged and temperatures raised so as to gelatinize the thicker grains completely, the thinner ones will be gelatinized to a greater degree. The thinner grains will be darker, more compact, and harder. The resulting product will look uneven in color.

Sorting on the basis of kernel thickness is essential for good-quality parboiled rice. This is done by means of grading reels fitted with a steel sheet with rectangular slots or with wire netting. Further grading may complete the selection according to the length and bulk weight of the grain to obtain a final product of improved and uniform quality. Sorting by bulk weight, if necessary, is done by specific-gravity separators.

The paddy is divided into lots. Each lot with grains of similar size is parboiled separately, with different steeping and steaming times and temperatures. Drying and milling will thus be facilitated, and there will be fewer broken grains. The thinner grains obtained from sorting are usually those that are unripe or naturally misshapen. Sometimes, it may be best to use these thinner grains for the production of low-quality raw rice rather than to parboil them. If one lot is formed of mixed varieties, sorting is essential to separate them according to length, thickness, and bulk weight.

Sorting according to thickness also separates part of the shelled grains present in the mass of the paddy. It is, however, preferable to do this in "compartment separators," which are used to separate the shelled grains from the unshelled. The compartment separator utilizes the difference in the bulk weight between shelled and unshelled grains. To obtain the best results, it is advisable to feed the separator with lots of paddy that have been previously graded. The paddy should first be sorted and then passed in separate lots through the compartment separator. The specific-gravity separator, which occupies less space than the compartment separator but uses more electricity, can also be used for separating the shelled grains.

Extraction of shelled grains with the compartment separator also means sorting out stones. Because of their bulk weight, stones are extracted together with shelled grains. Thus, a high percentage of stones that must be removed on a densimetric table are removed here.

STEEPING

Different varieties of paddy rice have their own steeping characteristics. An efficient steeping process in medium-temperature water (65°C) should be used for the production of parboiled rice. The treatment must be done quickly to avoid fermentation, which would adversely affect the color, taste, and smell of the product. For effective and uniform results, the grain size must be uniform, and the caryopsis must be entirely covered by the hulls. If the caryopsis is exposed, the shape and color of the parboiled rice will be unsatisfactory.

The methods used to achieve steeping include: (1) the use of high- and medium-temperature water; (2) application of vacuum and/or hydrostatic pressure; and (3) the addition of wetting agents to the steeping water. These systems have been used either alone or in conjunction with one another to increase water penetration and to reduce steeping time. Steeping is needed to provide the starch with a sufficient amount of water for gelatinization. A moisture content of not less than 30% is required to fully gelatinize the starch in the caryopsis. Water absorption by the grain involves spreading the water-soluble substances evenly. Steeping also facilitates the transmission of heat from the surface of the hull to the middle of the endosperm.

In the United States, parboiling of rice has been fully mechanized. The facilities include 6–8 steeping vessels with built-in steam coils, hot-water tank, boiler, rotary-drum driers with steam-heat exchangers or husk-

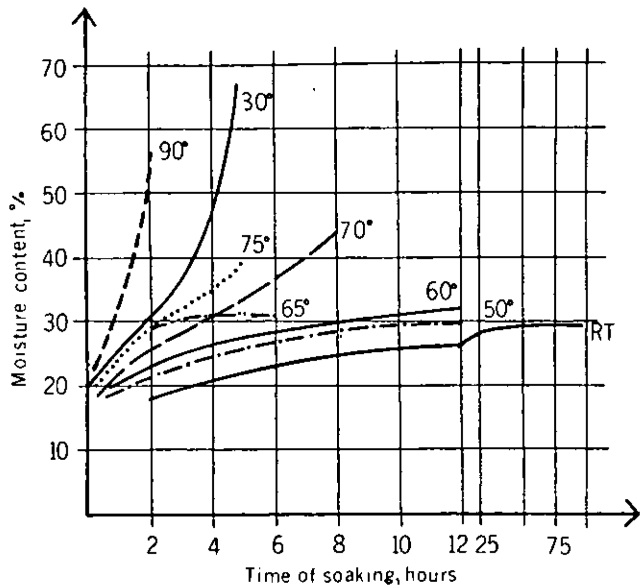

Figure 4-1. Water absorption by paddy rice in relation to temperature of steeping water (RT = room temperature). (From Bhattacharya et al. 1966.)

fired furnaces for drying paddy, mechanical handling equipment, rotary-hot-air drier, bin driers, milling equipment, and packaging machinery. The steeping vessels are fed with hot water at 80–85°C, and the raw paddy is transferred into them from an overhead surge bin. The water is circulated for 15 min and then maintained at 65°C for 4–5 hr, after which it is drained off. Steam is let into the built-in steam coils, and the paddy is steamed for 10–20 min and then moved to the driers through belt conveyors.

If steeping is prolonged, enzymatic action in the paddy is activated. Fermentation of the grain results in removal of the adhering organic impurities.

The use of very hot water for steeping has been advocated as a means of reducing processing times. Within certain limits, the quantity of liquid absorbed in the time unit is in proportion to the temperature of the water. The use of water at a temperature slightly below that of starch gelatinization (typical for each variety, ranging from 60–70°C), increases the speed of water absorption. If the water temperature exceeds that of starch gelatinization, the absorption time is reduced, but more water is absorbed than is necessary for moistening the inner part of the kernel.

In Fig. 4-1, water absorption by paddy rice at different temperatures is presented. A moisture content of about 30% appears to be the very lowest for water to reach the core. This can be achieved without increasing the quantity of water absorbed with temperatures below 50°C and steeping times varying from 12–60 hr. If more water than necessary is absorbed, the caryopsis swells considerably, cracking open the hull and becoming exposed. Cracking of the hull is a serious drawback since many of the substances contained in the grains will diffuse into the steeping water.

Although hot water accelerates absorption, the milled product is more likely to be discolored by it. The discoloration of the parboiled milled rice increases with the duration of steeping and the temperature of the water, subsequent steaming being the same in both cases. The color becomes much deeper once the limit of 70°C is exceeded. It was shown that the maximum discoloration at 70°C appears about 5 hr after the paddy has been in water.

The time and temperature of steeping are related to the darkness of the parboiled milled rice. When the amylase in the rice is activated, sugars such as maltose and glucose are formed (Ali and Bhattacharya, 1980a). Research has shown that 60°C is the ideal temperature for amylase activity (Refai et al. 1967).

The color of the parboiled rice varies with the pH of the steeping water. If the pH is close to 5, coloring is at a minimum. The color deepens as the pH rises.

The smell and flavor of parboiled rice has been shown to be related to the condition of the steeping process. Steeping time and water temperature affect solubilization of the albuminoids contained in the outer layers of the caryopsis. By hydrolysis, the albuminoids are split up into amino acids.

Heating the sulfur-containing amino acids splits them to form hydrogen sulfide and organic sulfides of low molecular weights. These compounds combine with the alcohols produced by decomposition of the lignin in the paddy hull, producing odorous products such as thioalcohols and thioethers, which give some characteristic odor and flavor to the parboiled rice. If steeping at 65°C is beyond 8 hr, the steep water develops an off-odor that is passed on to the paddy and the finished parboiled rice. An association of this off-odor with rice parboiled by traditional methods is one of the factors that deters wide acceptance of parboiled rice by consumers (Pillaiyar 1990). Odor development is due mostly to the activities of bacteria present in the steep water.

Occasionally, both vacuum and hydrostatic pressure methods are used to reduce steeping time, keeping the temperature of the water within limits that do not adversely affect the quality of the final product. By removing interstitial air and by applying hydrostatic pressure to the steeping water, the steeping time can be reduced.

STEAMING

The purpose of steaming is to increase the milling yield and to improve storage characteristics and eating quality. Steaming improves the firmness after cooking and achieves better vitamin retention in the milled rice. These advantages are offset, however, by practical and economic disadvantages, which sometimes make it necessary to reach a compromise between the two tendencies. For example, whereas complete starch gelatinization results in a high milling yield, the color of the final product will be deeper.

Heating the steeped paddy with steam causes the following changes in the paddy:

1. The moisture content of the paddy rice increases because of the extra water formed by condensation.
2. Water-soluble substances spread inside the paddy grain.
3. The granular texture of the endosperm becomes pasty as a result of gelatinization of starch.
4. The cracks in the caryopsis become sealed and the texture of the endosperm becomes more compact.
5. The single parts making up the pericarp and the perisperm, the aleuronic cells of the endosperm, and part of the germ (scutellum) become partially softened and embedded in the amylaceous endosperm of the caryopsis.
6. Germination, fungus spores, insects with their eggs and larvae, and enzymes are annihilated or inactivated.

The fusion of the outer perisperm layers and the scutellum of the germ with the endosperm makes these parts difficult to remove during milling if it is desired to obtain a highly milled product that keeps well without becoming rancid during storage. Steam heating must, therefore, be applied uniformly to have an even exposure of the rice. The heating time and temperature must be controlled precisely in relation to the paddy variety being processed. In some plants, the steeped paddy is steamed under atmospheric pressure for 10 min or longer and then moved to a rotary drier through belt conveyors.

Steam heating may be done at atmospheric pressure by injecting steam onto the product contained in an open vessel or in an autoclave at a pressure higher than atmospheric. Continuous steam injection devices can be used.

When steam is injected on the rice in an open vessel, the excess water from steam condensation is easily taken off. When heating is done under pressure, the temperature can be varied easily, and heat distribution is more uniform. The equipment, however, is more expensive. There are more expenditures for mechanical installations to remove excess condensate and for loading and unloading the rice.

In order to gelatinize the starch, the paddy must absorb sufficient quantities of water and must reach the minimum gelatinizing temperature. Steam temperature at atmospheric pressure is always higher than that needed for gelatinization. To make sure that all starch in the rice grain is gelatinized, sufficient moisture and heat must be applied.

If the starch in the endosperm is not fully gelatinized, there will be white cores present in the parboiled product. The time exposed to steam must therefore be long enough to gelatinize the whole kernel completely.

The quantity of water to be absorbed, the time of exposure to steam, and the temperature or pressure of the steam itself provide the parameters that will decide the quality of the parboiled rice.

Through a variation of these factors, parboiled rice possessing particular characteristics and degrees of gelatinization can be obtained. "Fully parboiled rice" means that the starch has been gelatinized right through the middle of the grain and "partially" or "surface parboiled rice" means that gelatinization is only surface-deep, and the product has typical white cores. "Light parboiled rice" is obtained by steaming for a minimum time and at the lowest temperature needed. "Dark parboiled rice" is steamed for a long time at a high temperature.

Within defined limits of temperatures and pressure of the steam used, the milled parboiled rice shows differences in: (1) color, (2) volume after exposure to air heated to 121°C, and (3) soluble-starch content.

A graph showing the increase in volume (as an ascertainable ratio) of milled parboiled rice made at different steam temperatures is presented in Fig. 4-2. An increase in expanded volume is observed when the steam temperature during parboiling is increased from 100 to 120°C. The soluble-starch content of milled parboiled rice after steaming at temperatures of 65–135°C was studied by Roberts et al. (1954). It increased rapidly from 4 mg/g at 65°C to 15 mg/g at 121°C and to 28 mg/g at 135°C. This indicates that some solubilization of starch occurs at higher steaming temperatures.

The relationship between the color of milled parboiled rice and steaming parameters has been given by Bhattacharya et al. (1966). Color changes are caused by chemical and physical transformations induced by heat. The absorbed water can dissolve the coloring pigments in the hulls, and the parboiling process drives them inward to the endosperm. Through the parboiling process, the starch assumes a different refraction to light, which alters the appearance and color of the product. During steeping, activation of various enzyme actions leads to the formation of reducing sugars, which

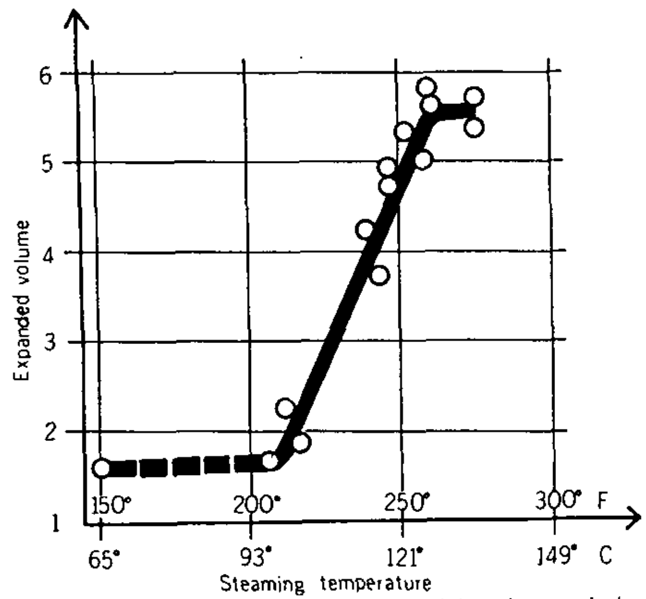

Figure 4-2. Increase in volume of milled parboiled rice steamed at various temperatures and after exposure to a stream of air heated to 121°C (249.8°F). (From Roberts et al. 1954.)

are responsible for maillard-type browning reactions with amino acids and protein when heat is applied during drying. Activation of the enzyme during steeping was shown to occur at about 60°C.

DRYING

Objectives and Methods

The objectives of drying parboiled rice are to reduce the moisture content to an optimum level for milling and subsequent storage and to obtain the maximum milling yield.

The conditions required for drying parboiled rice differ considerably from the processes normally used on threshed paddy direct from the field because the moisture content of parboiled paddy is higher than that of harvested paddy. The grain texture is also different because the starch has been gelatinized to form a compact grain. At the beginning of the drying process, the temperature of the parboiled paddy approaches 100°C, whereas that of the threshed paddy is at ambient temperature. In many cases, the hulls of parboiled paddy are cracked open to some extent. Thus, the drying of parboiled rice requires a different process. Threshed rice must be dried slowly at air temperatures slightly above that of the environment. Milling yield is not affected by drying temperatures when the moisture content is reduced to 16–18%. More attention is given to the temperature used in reducing the moisture content to 14% or lower, which is considered optimum for storage.

To prevent cracking, the drying process is stopped for a while when the moisture content reaches 16% and then drying is resumed using the appropriate temperature and drying time. This interval is called "conditioning," which varies somewhat with the variety of rice and the severity of the process. The optimum temperature and time needed for final drying are related to the temperature of the paddy after conditioning. Generally, slow and prolonged drying is essential in the final stage to ensure a maximum yield of whole grains. The cracks which develop during the final stage are due to increased brittleness of the caryopsis when the moisture content falls below 16%. Below this moisture level, a hardening stage sets in which may lead to cracking or else set up tensions causing the grain to break during milling.

The percentage of rice kernel breakage is related to the moisture content and the condition period between the first and second drying stages. After steeping and steaming, the sample was dried to the critical moisture content of 16%. A part of it was then given a further drying while the rest was put aside and the second stage begun after periods varying from 2–48 hr. The percentage of broken grains after milling decreased with the increase of tempering time and with a reduction in moisture content.

Drying in the shade with the rice spread out on roofed over floors would yield excellent results, but the long time and large space requirements have made this system rather unpopular. In some parts of Asia before the rice is spread to dry naturally, while still hot from the steaming process, it is heaped up and left for several hours. In this way the gelatinizing action is prolonged, making the milled product harder and darker in color.

DRIERS

Various types of vertical-column driers and horizontal, continuous-flow, rotating-cylindrical hot-air driers have been developed in modern plants (Gariboldi 1974). The vertical-cylindrical driers are preferred where low-temperature drying air is used and the rice is exposed to the drying air for a long time. Horizontal-rotating, continuous-flow, cylindrical driers are normally used when rapid drying at high temperatures is required (Fig. 4-3).

In rotary-cylindrical driers, hot air is used, and heat is also applied to

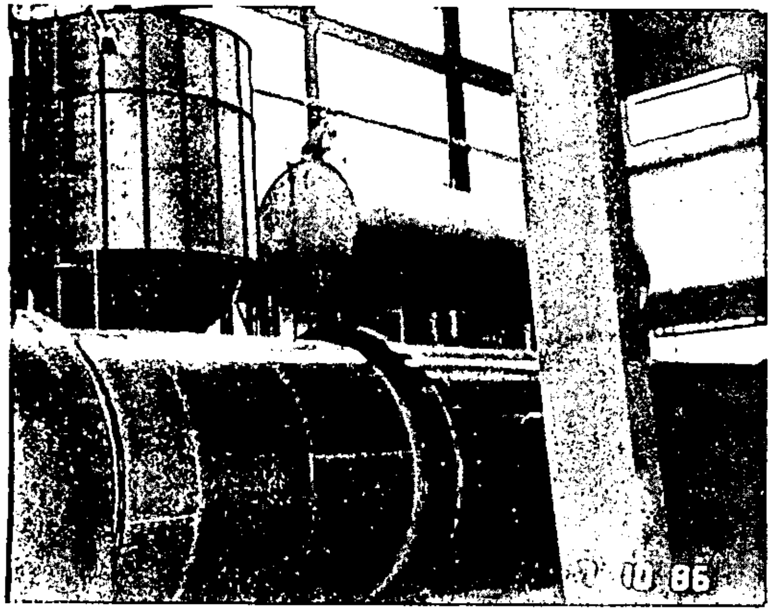

Figure 4-3. A modern rotary drier for parboiled paddy rice. (Courtesy of B. S. Luh 1986.)

the cereal by fitting an external steam jacket to the drier and a tube nest inside it. High-temperature drying (80–100°C) with a horizontal-cylindrical drier is used for reducing the moisture content to 16–18%. It is followed by further drying at lower temperatures in a conventional column drier.

The vacuum drier offers savings in fuel and removal of unpleasant smelling substances formed when the rice is steeped and steamed. Vacuum drying is usually done inside the container in which the rice was steamed.

In the hot-air drier, the drying time is determined by the temperature and the amount of air. In the vacuum type, the determining factors are the temperature, the surface-heating area of the rice in contact, and the attainable vacuum. For more detailed information, the papers by Bhattacharya (1985), Kunze and Calderwood (1985), Pillaiyar (1988), as well as Chap. 9 of *Rice Vol I: Production* (Luh 1991), will be helpful to the readers.

TEMPERING

After drying, the parboiled paddy must be allowed to rest for a time before milling. This time interval is called the *tempering period*. A tempering period of about 48 hr is needed for the product to dissipate the heat it

received during drying. Also, the moisture content inside each grain must become uniform throughout.

Tempering must be done to ensure dissipation of heat without speeding up the cooling by artificial means. If the rice is arranged in small heaps or spread out in a closed but well-ventilated storage space, 20–30 cm thick, it will consolidate perfectly. When placed in tall, narrow silos with natural ventilation or mechanically stirred several times, the highest milling yield will be obtained. Milling is done only when the rice has become stabilized at an ambient level and the grains have hardened and become glassy in texture. During tempering or cooling the rice may lose some moisture owing to evaporation caused by the residual heat. The amount of moisture lost is proportional to the temperature of the rice when it leaves the drier. If the rice is to be stored for a long time before milling, it must not be left in large stacks or stored in large silos until tempering has been completed since the cereal might be damaged by the heat in the stack.

Parboiling can reduce or raise the moisture content of raw paddy to levels that are most appropriate for milling and storage. The moisture content of parboiled milled rice may be brought up to 12–14%, even if that of the raw paddy used for the process is below these percentages.

MILLING

Parboiled rice, when properly prepared and milled, gives the maximum yield of edible rice with a minimum amount of broken grains. Parboiling gives hardness and seals any cracks in the caryopsis. Any breakages are caused only by mechanical action of the milling machines. Good results from the treatment depend to a great extent on the drying process.

Before it is parboiled, the paddy must be properly cleaned and graded according to thickness, length, and weight. Milling will be easier, and the chance of breakage in the machines is minimized, if the machine is correctly adjusted.

The part of the germ known as scutellum contains oil and protein. It is partly combined with the caryopsis so that the embryo is held in place and is usually not detached during shelling.

It is necessary to pass the product through a cone-type whitening machine abrasive or a horizontal cylinder covered with abrasive material in order to remove the pericarp, the perisperm, and the layer of aleuronic cells. Polishing is done in a fraction machine.

In many cases, parboiled rice is undermilled and still carries most of the aleuronic cells and traces of the perisperm, as well as the germ at one end.

When raw milled rice is compared with another lot of an identical

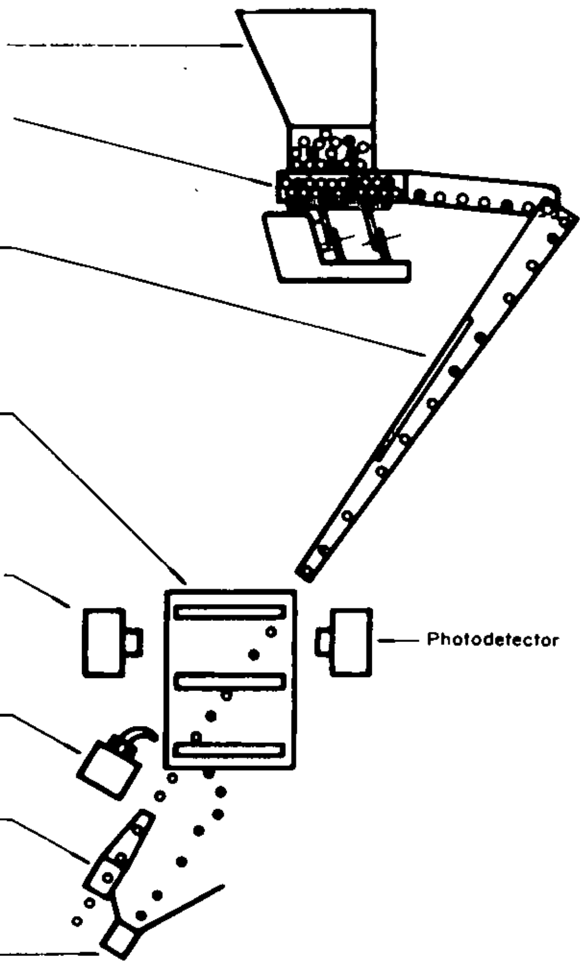

Figure 4-4. Sorting device of a solid-state electronic rice sorter. (From Gariboldi 1974.)

variety that has gone through parboiling, the respective milling degrees must first be defined in terms of the quantity of bran removed during whitening. Milling parboiled paddy becomes a difficult operation not only because the process has hardened and merged the outer layers with the endosperm but also because the fatty substances, especially those contained in the germ, have been dissolved and distributed throughout the caryopsis. These substances make the grains slippery during the process of mechanical erosion and tend to cause the bran to cake. To avoid this, the whitening machines must be thoroughly air-cooled by means of a

central aspiration system. Between one whitening operation and the next, the rice is allowed to stand for some time in feeding bins. When parboiled rice is pearled, the cones are usually made to turn at 10% higher rpm than for raw paddy. At least four whitening machines are used to get parboiled rice completely polished.

When the paddy is put directly into the huller without prior shelling, the hull, which came off the caryopsis during the first stage, acts as an abrasive and, at the same time, absorbs some of the fatty substances, thus facilitating polishing.

The bran and polish are darker in color and contain more fatty substances compared to those obtained after milling raw paddy rice as a result of the spread of the fats in the germ toward the perispermic layers and the aleuronic cells. The bran from parboiled rice has prolonged resistance to the formation of free fatty acids. This makes it better and easier to use for the extraction of edible oil. The bran obtained from raw paddy has a fat content of 12–14%, and the bran from parboiled rice may contain 16–22%. The bran obtained from processing raw paddy may show an increase in fatty acids of about 1%/hr during the first 12 hr after milling. In modern milling plants, the bran from milled rice is immediately passed through an extruder under 2.8–7.0-kg/cm pressure at 138°C for 5–15 sec to inactivate the lipase activity, thus preventing the formation of free fatty acid due to enzymic hydrolysis of the rice oil present in the rice bran. The bran so treated is more stable during storage. The lipase was inactivated by heat energy formed during extrusion of the rice bran.

In bran from parboiled rice, there is hardly any increase of free fatty acids during the first 15–20 days following milling. The latter can therefore be easily collected, transported, and stored for subsequent extraction of its oil content. The action of heat during the parboiling process has a stabilizing effect and inhibits lipasic action, which causes the fats to hydrolyze.

Color Sorting

The parboiled rice must be sorted to remove discolored grains. A flat conveyor belt about 0.9 m wide is used. The speed of the belt is adjustable as desired by the operator. The rice is spread on the belt in a thin layer and inspected as it moves along by sorters who pick out the discolored grains by suction, using a plastic or rubber tube connected to a centrifugal air pump. The grains thus sucked up are deposited inside a cyclone separator through which the flow of air passes before reaching the pump. The cost of sorting depends largely on the percentage of discolored grains present.

Automatic machines based on photoelectric devices have been used to sort the rice by color. The existence of such machines enables rapid sorting of parboiled rice.

The automatic sorting machines have the following advantages over the manual sorting belts: (1) the speed is faster and the rice passes through the machine at the same speed, irrespective of its content of discolored grains, and (2) sorting is more efficient as the grains are checked from all angles.

The photoelectrical cell consists of a metal plate covered by a layer of oxidized selenium. Its electrical conductivity varies according to the amount of light striking its surface. The principles on which these machines work are essentially as follows. The grains of rice are fed into a uniformly lit chamber so that they can be scanned simultaneously on two sides by two photocells. The light reflected by the grain passes through a filter and, by means of a system of lenses, its intensity is metered by the photocell. The color is electronically compared by reference to a standard background. Sorting is based on the ability of the photocells to determine if the light of a certain hue reflected from a given object is more or less than that reflected from the background selected. Any minute change in light intensity reaching the photocells causes an electrical change within them. This change, which is due to the photoelectric effect, causes an output voltage to swing above or below the constant background signal level. Whenever the output signal level for the grain being viewed is equal to or above the background standard signal level, the grain is acceptable. An ejection circuit is activated whenever the output signal level for the grain in view swings below the background level.

In modern sorting machines, the rice presented for scanning is made to slide in line down a straight slope from which it reaches the scanning area at a previously calculated speed and curve (Fig. 4-4). The scanning unit, the photodetectors, and the impulse amplifier are the essential components of the machine. Transistors have completely replaced electron tubes, and plug-in circuit boards are now commonly used. Many improvements have been made in extracting the discolored grains so that the selection between rejected and acceptable grains has become quicker and more accurate.

Newer machines use a stream of pressurized air that knocks the grain aside from its path. Improvements made on these machines have brought about a continuous rise in sorting speeds and output. Running costs of both power consumption and maintenance are low.

STABILITY OF MILLED RICE

Parboiled paddy can be shelled where it is produced, and then stored and carried to other destinations, where it is whitened and consumed.

After milling, the smell and flavor of the rice may undergo changes if

the fatty substances in it become rancid. The reason why parboiled rice turns rancid is that the antioxidants, especially the tocopherols (vitamin E), are inactivated by the hydrothermic treatment. This is especially true when it is packaged in paper, cardboard, or transparent materials. Antioxidants such as BHA (butylated hydroxyanisole) and BHT (butylated hydroxytoluene) may be used to prevent deterioration in smell and flavor after milling.

A factor of great importance to the keeping quality of rice is the moisture content. The moisture content of parboiled rice both before and after milling is not easy to determine as the texture of the grain differs considerably from that of raw rice. Most moisture-measuring instruments used for raw grains do not give a correct indication of the moisture content of parboiled rice. To avoid any possibility of error, the classic method of drying the rice in an oven for a few hours has proved to be the most reliable.

When the solvent-extraction milling method is used, the rice keeps much better than that given ordinary mechanical milling. The organic solvents dissolve most of the fatty substances contained in the endosperm, thus reducing the rancidity problem.

THE PARBOILING PROCESSES

Water or steam is required to gelatinize the starch in the rice grain during parboiling. The water used in washing, floating and steeping must be of potable quality. The amount of water needed for washing and floating the paddy varies from two to three times the weight of the cleaned paddy. Some of the washing water may be regenerated.

About 600 kg of water are needed to steep 1000 kg of rice paddy. During steeping, 20% of the water is absorbed by the paddy. The steeping water left behind contains the impurities in suspension and is either thrown away or regenerated for further use.

The amount of steam needed to heat 1 metric ton of paddy varies with the degree to which the starch in the caryopsis must be gelatinized and with the method of heating. In a modern plant, about 80 kg of steam are required for heating 1000 kg of paddy. If steaming is done in open containers by injection at ambient pressure, the quantity used will be considerably larger.

The quantity of steam needed to parboil paddy rice is a mere fraction of that required for the whole process because steam is also needed for heating the steeping water and the air where the paddy is artificially dried. The steam required to produce parboiled rice in modern plants is supplied by high-pressure boilers sent to the various points at which steam is needed at a low pressure. In some plants, steam is produced at high pressure for power in turbines or engines before it enters the heating system of the parboiling plant at a low pressure.

The parboiling process includes cleaning and grading the paddy, parboiling, steam production, drying, milling, color sorting, and packaging. Between stages, bins are used for storing the products or by-products so that the various operations are kept flexible.

There have been developments in industrial production of parboiled rice. Numerous technological improvements have been accomplished to *increase the yield, improve the* quality of edible rice, and save labor costs.

The plants may operate under continuous or batch processes. Some use a long steeping and steaming cycle with low temperatures, and others use short cycles with high temperatures and pressures.

The technique to be used depends *on the variety and quality of the* paddy to be treated and the quality of the final product desired. The various operations may be automated to reduce running costs.

When a parboiling plant is built, the continuous production system is preferable if the paddy consists of only a few varieties grown *on a large* scale. A batch production system is more suitable where the paddy is of many different varieties and characteristics. The steeped rice should be moved from the soaking tanks to the steaming autoclave and from there to the driers by gravity.

Steeping the paddy in water at certain temperatures, with or without the vacuum or pressure, is an essential step. The steeping water must be kept at an even temperature, and the whole lot must be steeped for the same length of time. The same principle applies to the steaming process. *It is important* that saturated steam be used to avoid too high a temperature. Care must be taken to prevent the rice from absorbing impure condensate, which would adversely affect the flavor and color of the product.

Different techniques may be used to provide the best possible milling yield *and a moisture level that will* ensure good steeping qualities. The use of driers constructed for drying threshed paddy should be avoided unless their design and materials have been suitably altered.

A highly mechanized plant with automated processes may be suitable in a country where labor costs are high but *unsuitable for countries where* labor costs are cheap and maintenance facilities for sophisticated equipment are not available.

EXAMPLES OF PARBOILING SYSTEMS

Schule Process

The Schule process (Fig. 4-5) was originated by a German rice-machinery manufacturer. *In* this system, steam is not applied directly to the paddy but is used to heat the water. The paddy is put into a pressure tank and is

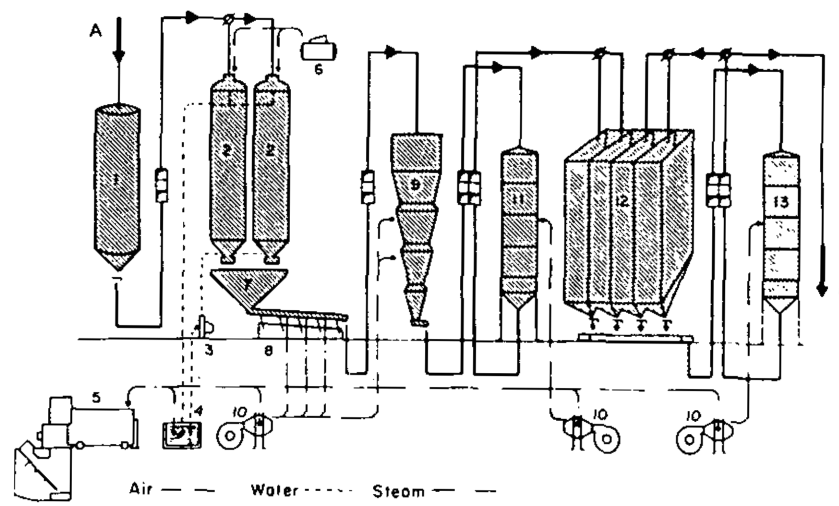

Figure 4-5. The Schule process: (A) Raw paddy, (B) Processed paddy: (1) Feeding bin, (2) parboiling pressure tanks, (3) preheated water circulation pump, (4) water heater, (5) steam boiler utilizing husk as fuel, (6) air compressor, (7) wet parboiled rice–receiving hopper, (8) vibratory conveyor, (9) predrier, (10) drying air heater and blower, (11) column drier, (12) tempering bins, (13) column drier. (From Gariboldi 1974; FAO; Luh and Mickus 1980.)

first soaked for about 120–160 min in water at medium temperature while the water is kept in circulation. When the rice has reached the temperature of the soaking water, the water supply is turned off, and hydrostatic pressure (4–6 kg/cm^2) is applied by admitting compressed air. The second cooking period starts by lowering pressure and readmitting the water, which has been heated to a very high temperature to ensure that the starch gelatinizes completely. The water is then drained away, and the paddy, with a moisture content of about 40%, is carried by a vibratory conveyor to a predrier designed to take a full batch of wet paddy. Here the moisture content is reduced, and the product is then unloaded into two or more column driers, where drying is continued until a moisture content of 13% is reached. The milled parboiled paddy is pale in color.

Central Food Technological Research Institute Process

The parboiling system developed by the Central Food Technological Research Institute (CFTRI), of Mysore, India, has improved the quality of the rice, shortened the processing times, and reduced the equipment costs.

A boiler supplies steam to the steeping and steaming containers. The steam enters through perforated pipes running the length of the cylindrical container. At the bottom, there are perforated pipes, arranged radially to provide the best possible distribution. The base of the steeping and steaming cylinder is cone-shaped and is closed at the bottom by a watertight hatch. At the side of the hatch, there is a valve for draining off the steeping water.

The steeping and steaming cylinders are raised about 1 m above ground level. The cylinders are fed with water, which is heated by steam injection to 85°C. The paddy is poured manually into the soaking and steaming tank. The temperature of the water drops from 85°C to 70–75°C when all the paddy has been poured in. After 2–3.5 hr of steeping the water is drained off. Pressurized steam is then admitted, and heating is continued until the hull begins to crack open. The condensate is drained off at the bottom of the tank when a drain valve is opened.

The wet rice is unloaded by opening the bottom hatch and is transported to the drying floor, where it is spread out. In order that the steeping water is prevented from fermenting, a pump may be provided to regenerate the water continuously through a filter. After filtering, the water is kept at high temperature by continued steam injection.

The batch parboiling process is similar to the CFTRI method but with some improvements. A bucket elevator and a screw conveyor raise the paddy from ground level to the steeping and steaming cylinders of the closed autoclave type. Steeping water and steam are fed from the bottom of the container. A valve at the top acts as a water overflow and as an air outlet when pressurized steam is admitted. Steeping water and steam condensate are drained off by a valve at the bottom of the container. The wet parboiled paddy falls out by itself when the hatch is open.

Jadavpur University Process

In the parboiling process developed at the University of Jadavpur, India, the operations are fully automatic. The average processing time is about 5–6 hr.

Steeping is completed in water at 60–70°C within 2.5–3 hr, whereas steaming requires only from 3–5 min. The high temperature of the water and the short steeping time contribute to the production of a good-quality parboiled rice.

After steaming, the paddy is rapidly cooled. Drying takes place in a rotary, steam-jacketed, high-temperature air drier to 13% moisture. The rice is then milled. In this process, two different systems may be applied. With the first, the steeping and steaming take place in the same tank whereas, with the second, these two operations are performed separately in a horizontal apparatus. In both cases, saturated steam is used. The steamed paddy is rapidly cooled in a draft of cold air.

Avorio Process

The Avorio process was developed in Italy. It is a mechanized and automatic process. Steeping is done by mechanically submerging baskets filled with paddy in a tank of medium-temperature water. A chain conveyor passes the baskets through the tank. The water is kept in continuous circulation and aerated by compressed air. Steeping time is controlled by the speed at which the baskets pass through the tank and varies from 50–120 min, depending on the variety of paddy used. After steeping, the paddy is steamed in autoclaves containing rotating perforated cylinders through which the steam spreads throughout the paddy. The paddy is loaded and unloaded through special valves that function alternately. Steaming times and pressures may be varied according to the variety of the paddy. Pressure may be raised up to 1 kg/cm^2. The steamed paddy is *cooled by a stream of cold air and then transferred to a series of vertical*-column driers utilizing air at 45–50°C.

This process is well controlled at all stages and produces a parboiled rice of high head yields with excellent properties.

Crystal Rice Process

The Crystal rice process was developed in Italy. The paddy is first washed in cold water to remove impurities and the lighter grains. Steeping takes place in a stationary autoclave, applying first vacuum and then high hydrostatic pressure using water at a controlled temperature. Steaming and drying are carried out in a rotary autoclave that is fitted with a steam jacket and coils for heating the paddy. The process permits variations in time, temperature, and pressure and can produce various types of parboiled rice.

Rice Conversion Process

This process was the first parboiling process adopted in the United States in 1941–1942 (Fig. 4-6).

The entire rice kernel is completely gelatinized following a number of operations. The parboiled product is pale in color and completely vitreous. There are no grains with white starchy centers. Steeping is done in an autoclave, where the paddy is deaerated under a vacuum to facilitate water saturation. A pressure treatment is applied to the steeping water in such a way that the combination of the vacuum and pressure processes reduces steeping time to less than 3 hr.

Steaming is carried out in a rotating, steam-jacketed autoclave. The pressure is kept at less than 1 kg/cm^2 for about 1 hr, after which a vacuum is applied to free the grain of excess water. The drying takes place while

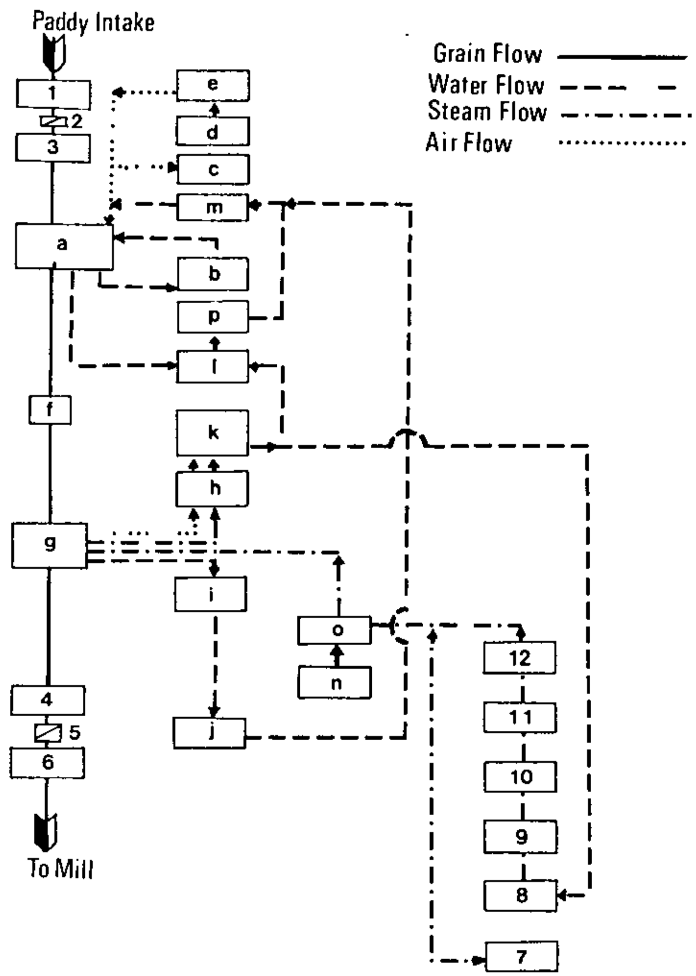

Figure 4-6. Rice conversion process: (1) Paddy floater (to float off shrunken and dead grains); (2) elevator; (3) bin for paddy; (4) drier discharge hopper with elevator feed regulator; (5) grain elevator; (6) mill feed bins; (7) exhaust from existing steam engine; (8) economizer; (9) boiler feed water tank; (10) boiler; (11) steam accumulator; (12) steam oil separator; (a) stationary pressure steeping tank; (b) circulating water pump; (c) dry vacuum pump; (d) air compressor; (e) air compressor tank; (f) double outlet hopper with wire mesh and drain; (g) combined steaming vessel and vacuum drier; (h) balanced nonreturn valve; (i) condensate collecting tank; (j) hot-water pump; (k) wet vacuum pump; (l) water settling tanks; (m) hot-water tank, adjustable ball valve, level indicator; (n) reducing valve cold-water tank; (o) reducing valve. (From Gariboldi 1974.)

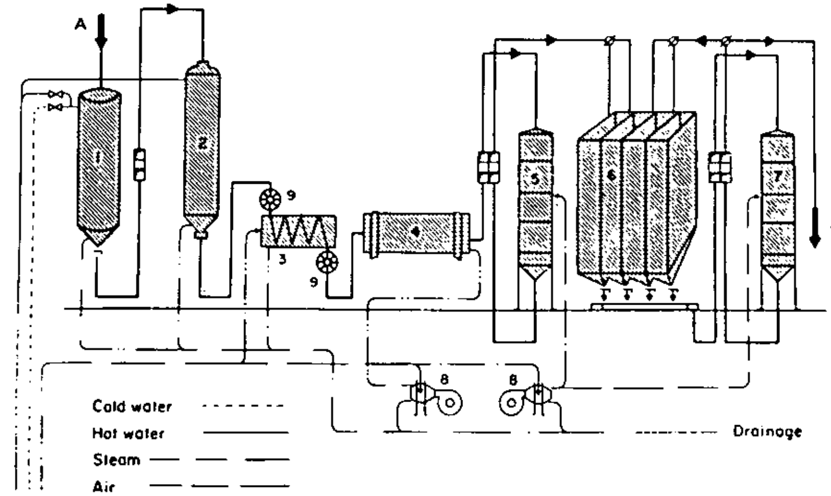

Figure 4-7. Rice Growers Association of California process: (A) raw paddy, (B) Parboiled paddy: (1) cold- or hot-water soaking, (2) hot-water soaking tank, (3) steaming autoclave (pressure steamer), (4) hot-air drier, (5) column drier, (6) tempering bins, (7) column drier, (8) air heaters and blowers, (9) steaming autoclave rotary valves. (From Gariboldi 1974.)

the paddy is still in the autoclave; a vacuum is applied, and the paddy is kept hot through contact with steam-heated surfaces. The drying process is completed in a rotating drier utilizing medium-temperature air to carry away the moisture.

Malek Process

This process produces an amber-colored and fully gelatinized parboiled rice. The paddy is steeped in tanks with high-temperature water for 3–6 hr. It is then steamed by injecting steam into a vertical-cylindrical autoclave that has a truncated conical base and is fitted with inlet and outlet valves. The paddy is let in and taken out of the autoclave by gravity.

Drying is carried out in two stages. In the first stage, hot air is blown into a steam-heated, rotary-cylindrical drier; in the second, air is forced through a vertical drier at lower temperatures.

Rice Growers Association of California Parboiling Process

The Rice Growers Association of California has developed a parboiling process at its Sacramento plant (Fig. 4-7). The raw paddy rice is soaked in moderately warm water, depending on the variety, for several hours.

Then the rice paddy is moved to another tank, where it is soaked again in higher-temperature water (varying from 40–90°C) for 1–10 hr. It is then steamed under pressure in a continuous cooker for a very short time, ranging from 15 sec to 3 min. The steam pressure varies between 1 and 5 kg/cm^2.

After it is drained, the parboiled paddy is dried first with hot air, followed by several passages through a column-drier stage. The drying process includes long intervals of tempering. The main features of the process are the long soaking time and the extremely short exposure to steam at high pressure; the resulting product is very pale. The process gives a good milling yield. The parboiled rice so obtained possesses good characteristics. It is usually applied to rice with a short, round grain typical of the varieties grown in California.

Similar Processes

Barber et al. (1975) developed a new hydrothermal process similar to parboiling and have tested it for the retention of nutrients in comparison to the normal parboiling process.

Three processes were used. Process A involves soaking the paddy for 1 min at room temperature and then autoclaving at 130°C for 3 min. With process B, paddy is autoclaved for 8 min. With process C, the paddy is soaked for 2 hr at 70°C and autoclaved at 121°C for 15 min. In all cases, drying is carried out at room temperature.

All processes caused slight increases in protein concentration in the outermost layer. These did not appreciably affect the distribution of crude grain fiber in the grain.

The three processes caused some loss of available lysine, tryptophan, and methionine. The losses were larger in the outermost layer than in the intermediate layers. All three processes caused significant decreases in thiamin content in the outermost layers and an increase in the center portion.

The effects of the process on fat, protein, and fiber contents were limited to the outermost layers; the contents of these constituents in the well-milled kernel remained unchanged. Available lysine, tryptophan, and methionine contents of milled rice from process A were similar to those of the raw rice, but there were large losses in processes B and C. All treatments increased the thiamin content of milled rice.

The outer brans from all the processes were richer in fat and somewhat higher in protein than the raw rice but lower in available lysine, tryptophan, methionine, and thiamin. In general, all treatments decreased the nutritive value of the brans.

A summary of parboiling processes for rice is presented in Table 4-1.

Table 4-1. Summary of Parboiling Processes

Process	*Soaking*	*Steaming*	*Drying*
Schule	Batch system in medium temperature water followed by a second stage in high-temperature water under pressure in the same tank	Steaming is not required. Starch gelatinization obtained by soaking in high-temperature water under pressure	In high-temperature air, followed by medium-temperature air
CFTRI	Batch system in high-temperature water. Continuous circulation of high-temperature filtered water	Batch system in the open tank used for soaking. Steam is pressure-injected through perforated pipes	Sun drying or mechanical drying by medium-temperature air
Jadavpur Univ.	Batch system in high-temperature water	Batch system in the open tank used for soaking. Steam is pressure-injected through perforated pipes. Alternatively, continuous system with steam at ambient pressure in an autoclave equipped with a screw conveyor	Cooling before drying. This is done by using high-temperature air, followed by medium-temperature air
Avorio	Continuous system in medium-temperature water	Continuous steaming under pressure in an autoclave equipped with mechanical conveyors	Cooling before drying. This is done by using medium-temperature air
Crystal rice	Batch system in high-temperature water under vacuum, followed by hydrostatic pressure	Batch system in a rotary autoclave under steam pressure	Under vacuum in the same autoclave. Final drying may be done after milling
Malek	Batch system in high-temperature water	Continuous steaming under pressure in a vertical stationary autoclave	By high-temperature air, followed by medium-temperature air
CRGA parboiling	Batch system in medium-temperature water, followed by higher-temperature water	Continuous system in a horizontal cooker under high steam pressure for a short time	In high-temperature air, followed by medium-temperature air

Source: Gariboldi (1974).

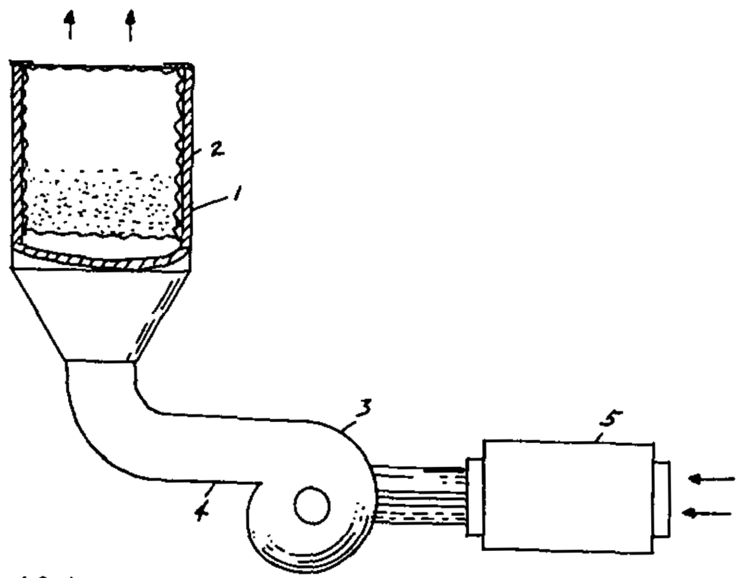

Figure 4-8. Apparatus for heating quick-cooking parboiled rice developed by Mickus and Brewer (1957). (From Daniels 1970.)

QUICK-COOKING PARBOILED RICE

One disadvantage of untreated parboiled rice is that the parboiling process extends the required cooking time. Whereas milled rice may require 20 min of cooking, the same rice when parboiled must be cooked for 30–40 min. Mickus and Brewer (1957) have developed a patented process that eliminates this problem. Milled parboiled rice is heated in a dry condition after the rice has reached its normal moisture content of 14%. Such heating has the effect of accelerating the breakdown of the starch structure of the rice that is started by the parboiling step.

The dry-heating step may be carried out in several ways. One method is to circulate rapidly moving hot air around the rice kernels at 149–260°C. If the exposure of the rice to the hot air at the above temperature is continued for a period of 30–60 sec, the resultant product may be completely cooked in a minute or less. If this dry-heating step is performed on ordinary rice that has not been parboiled, no reduction in the subsequent cooking time is effected.

The apparatus for carrying out this step is illustrated in Fig. 4-8. A vertically extending conduit was designed (1), in which a basket (2) of wire mesh may be inserted for supporting the rice within the path of the airflow through the conduit (1). A blower (3) is provided for conducting air through

a pipe (4) into the lower end of the conduit (1). Before reaching the blower (3), the air may be heated to the required temperature by means of any conventional type of heater (5).

The dry-heating step must be done quickly. For this reason, it is preferable not to insert the rice into the airstream until the air from the heater has been raised to the desired temperature. Naturally, the time required depends on the temperature of the air but, as stated above, the time may be made as short as 30 sec if the air temperature is around 260°C and, if the temperature is reduced to 149°C, the time may run to as long as 60 sec.

DIELECTRIC HEATING

Another method of carrying out the dry-heating step is to use dielectric heating, whereby the rice is made the dielectric between a pair of opposed-facing plates acting as a capacitor. The rice is placed in bags supported on a conveyor belt for movement between a pair of plates. The plates are connected to a source of high-frequency alternating current such as a vacuum-tube oscillator so that a dielectric heating effect is imposed on the rice.

The dielectric heating process heats the interior of the rice first; hence, the final temperature need not be as high as that used in hot-air heating. When the temperature of the rice reaches 66–82°C, its condition is the same as when it is heated by means of hot air at 149–260°C.

If various frequencies between 1 and 30 megacycles, with a power input of 1.8 kW, are used an exposure of 30 sec is required to break down the starch structure so that the rice may be cooked in less than 1 min.

The above description assumes a relatively lightweight package, such as cellophane. With heavier containers, such as cardboard, a greater amount of energy must be employed or the exposure time lengthened. This process is particularly applicable to the processing of rice for making breakfast cereals. Such rice cereals have been puffed or exploded by various operations to make the kernels edible without further cooking.

Puffed rice may be made with less expensive equipment by using parboiled rice because the dry-heating step returns the rice kernel to its original whiteness. To puff the rice, it is merely necessary to continue the heating step beyond 149°C for 60 sec.

The dry-heated rice may be eaten without any additional cooking and makes a particularly tasty breakfast cereal, especially if sugar and cream are added. Thus, whether whole kernels or broken kernels are used, the above described process produces either a quick-cooking rice if prepared in the conventional manner or a ready-to-eat product having a high nutritive value.

Serbia and Benett (1968) patented a method for producing quick-cooking parboiled rice. The parboiled rice is soaked in water at 71.1°C for 10–15 min until the moisture content is 40%. It is next steamed for 18–25 min at 100°C, resulting in a 5% increase in moisture content. The steamed rice is immersed in water at 15.6°C to cool the rice, thereby toughening the grains and arresting the cooking.

The rice, now containing 50% moisture, is retreated with steam and soaked two more times. Following this treatment, the moisture content increases to 65%.

The soaked, cooked rice is then drained of free water and fed to a three-section, through-circulation, continuous belt drier. Air temperatures in the drier vary from 104–121°C in the first section to 82–110°C in the third section. The dried product has a terminal moisture content of 10–13% and shows no evidence of puffing.

Rice treated in this manner can be immersed in gently boiling water and allowed to simmer for 7 min in an open or covered pot. Alternately, the rice may be added to boiling water, removed from heat and allowed to stand for 10 min. The cooked product will have a better overall eating quality—better texture, flavor, and aroma—than untreated parboiled rice.

RECENT DEVELOPMENTS

Continuous Parboiling

McPhail (1975) devised a method for introducing materials into, or removing materials from, a hermetically sealed vessel. The apparatus consists of several sealed vessels in series, with means for transferring the contents from one vessel to the next without breaking the seal. This device is useful in the process of parboiling rice, where soaked rice maintained at ambient pressure is transferred to a cooking vessel that is at a higher pressure. This apparatus is used for continuously parboiling steeped rice with steam under pressure.

Rubber Rollers

Sarda (1975) reported that rice milling can be carried out by traditional disk-sheller or huller types of machines. The advantages of the rubber-roller shellers were demonstrated during a pilot study of seven modern mills. Based on these results, modern rubber-roller shellers were introduced into several Indian rice mills.

Difficulties with the poor life of rubber rolls, black coloration of rice, and low capacity of shelling were due to faulty adjustment and operation and to improper cooling of the rollers.

After installing an air-circulation system for continuous cooling of the rubber rolls, an output of about 250 metric tons in winter and about 200–250 metric tons of parboiled paddy in summer were obtained per pair of rubber rolls. The moisture content of the parboiled paddy before milling was kept at 15%.

Black color in the rice could be due to insufficient cooling of the rolls or improper operation of the paddy separator, which returns a high proportion of brown rice to the rubber rolls.

The rubber rolls can prevent removal of bran during shelling and can increase output of rice by 0.5%. The oil content in the bran from the polishers has been found to be slightly higher also. The use of rubber-roller shellers in the milling of parboiled paddy has been found to be beneficial. However, a disadvantage faced by the millers using a rubber sheller is the presence of dark-colored or brownish-colored grain in the milled product, caused by infested or immature grains. These are normally removed with the hull in conventional milling of rice but are recovered and retained when rubber rollers are used. Methods of eliminating this problem in milling rice with rubber rollers are therefore necessary.

Parboiled Rice Bran

Haumann (1989) summarized recent developments in rice-bran stabilization and rice-oil production.

ECONOMICS

Parboiling involves a large capital investment for machinery. The processing cost is also higher as fuel oil or steam is used for heating the air in the drying process. The modern mills, however, produce a clean, wholesome product with higher milling yields.

The modern mill complex obtains freshly harvested paddy and handles sequentially the operations of cleaning and drying, silo storage, parboiling by the hot soaking method, mechanical drying of the parboiled paddy, milling by a modern rubber-roller type of mill (Schule make), and extraction of purified bran with hexane by a batch extraction method. All the processes are largely mechanized and controlled. The steam for the parboiling is obtained from a boiler with a capacity of 1100 kg steam/hr. The drier is one of the LSU type, and the air is heated by mixing with burned gases after fuel oil is turned in a combustion furnace.

The traditional mill uses an old disk-type sheller mill of the same Schule make, and it runs on a steam engine from a boiler. Paddy hull is used as fuel. Parboiling is carried out by the traditional method, followed by drying. A simple huller-type mill also operates on the same premises.

The modern mill may give lower returns than the disk-sheller mill although the former gives higher rice yield (with fewer brokens) and better-quality bran. The higher processing costs of the modern mill more than offset the advantages of higher yield. The processing cost could be brought down by (1) using hull instead of furnace oil for heating the air in the driers; (2) using rubber rollers that will have lower wear and tear and longer life; (3) realizing better market value for the processed rice since it has a lower percentage of brokens and refractions than the usual commercial rice; and (4) reducing high investment costs on silo storage. As a result of these methods, it should be possible to make the economics of processing in the modern mill more attractive than the customary methods of storage and processing.

PRESSURE PARBOILING

A method of pressure parboiling was developed by Shivanna (1974). The paddy is washed in water in a pressure vessel, kept under saturated steam, and then steamed at high pressure to ensure full gelatinization of the starch.

Gandrala (1986) made a thorough study of pressure parboiling of paddy, with special reference to changes in starch, protein, and fat. The process consists of wetting the paddy, followed by steaming under pressures of 0, 1, 2, and 3 kg/cm^2 and at steaming times of 5, 10, 15, and 20 min, respectively. Gandrala's results confirm many of the earlier findings on the properties of parboiled rice. The properties of parboiled rice are, in a large measure, attributable to the changes brought about during or following the hydrothermal treatment given to the paddy in parboiling. There is a redistribution of some nutrients. Notable among these are fats, including fatty acids that tend to migrate outward, enriching the bran layers. A part of the soluble proteins may move inward so that the milled rice has a slightly higher total protein content. Hardening of the grain due to gelatinization of starch during parboiling results in reduced breakage of the grain and therefore a higher head rice yield during milling. The total parboiling and drying costs are 50% lower for the pressure parboiling process. Ali and Bhattacharya (1982) made a detailed study of the pressure parboiling process. They studied the effect of grain moistures and the

times and temperatures of steaming on the color, hydration property, and starch retrogradation. Grain discoloration and hardening are inherent in the process and cannot be avoided as long as the rice is fully gelatinized up to the center of the grain. However, the great technological advantages of the process can be retained and the discoloration and resistance to cooking reduced by adopting such processing conditions as leaving a small "white belly" in the center of the grain. These conditions consist of washing the rough rice in water and steaming under 1–2-kg/cm^2 gauge pressure for 10–20 min. The proposed modification has been tested satisfactorily on a commercial scale.

Additional advantages of the pressure parboiling process are:

(1) The grain becomes quite hard in response to the pressure steaming, resulting in reduced breakage during milling.
(2) Total processing time is reduced by about 50% and, therefore, production capacity can be greatly increased.
(3) The oil content in the bran is much higher than that obtained from the hot soaking.

Changes in Properties of Rice During Parboiling

Parboiled rice differs greatly from raw rice and its properties, depending on the type and severity of parboiling. The changes during processing stand out as major contributors to its properties (Ali and Bhattacharya 1980b,c; Bhattacharya and Ali 1985; Kato et al. 1983).

The most obvious change is the gelatinization of starch. The characteristic properties of parboiled rice, such as grain translucence; milling quality; swelling and solubility; viscosity; heat-expansion behavior; and vitamin, sugar, and amino acid content are associated with the gelatinization process.

The important change is the retrogradation, or some form of reassociation, of the gelatinized starch during storage or drying of the grain after parboiling. The hardness of rice, milling quality, cooking rate, starch solubility, paste viscosity, and other properties are related to this starch reassociation. Whereas various properties strongly suggest regular starch retrogradation, x-ray diffractogram data suggest a lipid-amylose complex. Different types of processes yield varieties of rice with distinct quality profiles, presumably because they have different combinations of gelatinized and reassociated starch.

Another important change is alteration of oil globules in the rice kernel. Parboiling disrupts the oil globules and tends to push the oil toward the outer periphery of the kernel. This has a profound influence on the oil content of the bran obtained on milling. The same change, along with the destruction of native antioxidants by heat treatment, is responsible for an increased susceptibility of parboiled rice to oxidative rancidity.

Another set of changes is brought about by enzyme action during the period of soaking of paddy in water. Changes in sugars, amino acids (Ali and Bhattacharya 1980a, 1985), and other components take place during this period and undoubtedly affect the properties of the resulting rice. This is evident in the observation that subsequent reheating during the process of rice enrichment results in extra discoloration.

The discoloration is caused primarily by the maillard reaction, brought about by the heat treatment, and by changes in sugars and amino acids, brought about by enzyme action during soaking.

The heat treatment during parboiling disrupts and denatures the protein bodies, thus leading to considerable reduction in their solubility.

An important effect of parboiling is the presence of greater amounts of water-soluble constituents, especially thiamin, nicotinic acid, sugars, free amino acids, and various minerals in milled parboiled rice due to diffusion from the outer layers into the grain interior during processing.

A number of other effects are: better stability of the parboiled rice and bran due to destruction of enzymes, a vast improvement in milling quality, and greater oil content in the bran. Parboiled rice is used for making canned, expanded, and flaked rice, which cannot be made from raw rice.

There are, however, several drawbacks to this new process. The rice obtained has a deep yellow-brown color that may be unacceptable in some markets. The higher oil content in the bran tends to clog the polishing sieves.

Physicochemical Basis of Varietal Differences in Rice Expansion

Chinnaswamy and Bhattacharya (1983a) studied the extent of expansion of milled parboiled rice (10.5–11.0% moisture) in 35 rice varieties. They heated the milled parboiled rice with fine sand at a rice : sand ratio of 1 : 15 at 250°C for 10–12 sec. Results indicate that the degree of expansion correlated strongly with the amylose content, being optimum at 27% total amylose and/or 13.5% hot-water soluble in amylose. Protein content had a small negative correlation.

Chinnaswamy and Bhattacharya (1983b) studied the conditions for expansion of milled, parboiled rice. Optimum puffing was obtained by heating milled parboiled rice at a moisture content of 10.5–11.0% with 15 times its weight of fine sand at 250°C for 10–11 sec. Raw and mildly parboiled rice gave minimal expansion, which increased with increasing severity of parboiling up to a steam pressure of 1.5 kg/cm^2. Because of the difficulty in avoiding contamination with sand, the method seems inapplicable to commercial processing. The data presented are valuable for future research in rice puffing.

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5

Rice Quality and Grades

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CONCEPTS OF RICE OUALITY

Components of rice known and referred to as grain quality largely determine market price and consumer acceptance. The most important factors plant breeders consider in developing new rice varieties are grain quality and yield. If consumers do not like the flavor, texture, taste, aroma, appearance, cookability, or processability of a newly developed rice, any other outstanding attribute of the variety may be worthless (IRRI 1985).

The term *grain quality* has many meanings and is perceived differently depending on end use, field of interest, specialization, ethnic background, etc. In marketing, appearance is of foremost importance as a quality characteristic; producers and millers emphasize milling quality; food manufacturers insist on processing quality; dietitians require nutritional quality; and consumers demand a widely divergent array of cooking and eating

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