

B. O. Juliano, ed. 1985. Rice chemistry and technology, 2nd ed. Am. Assoc. Cereal Chemists, St. Paul, MN.

CHAPTER 12

CRITERIA AND TESTS FOR RICE GRAIN QUALITIES

BIENVENIDO O. JULIANO

*Cereal Chemistry Department
International Rice Research Institute
Los Baños, Laguna, Philippines*

I. INTRODUCTION

Grain quality denotes different properties to different sectors of the rice industry—farmers, processors and millers, retailers, shoppers who buy the milled rice in the market, the consumers themselves, and nutritionists and policymakers (Barber and Juliano, 1971; Juliano 1972a; Chandler, 1979). Unfortunately, criteria for price and market quality of milled rice are not related to criteria for cooking and eating quality and for nutritional quality of the cooked rice. An excellent review of methods for measuring various aspects of rice grain quality and of quality criteria in selected rice-producing countries is based on a 1978 workshop on this subject (IRRI, 1979a). A practical manual on rice improvement has also been published (Jennings et al., 1979).

Appreciation of aging or storage changes is essential in the effective implementation of tests for grain quality. The freshly harvested grain undergoes texture changes during the first three months of harvest; hence, milling tests and tests for cooked rice texture are preferably done on aged rice. Aging is discussed later in this chapter, followed by a section of quality preferences in various rice-producing countries.

II. MARKET QUALITY

Market quality, which affects farmers' prices, depends on the processing quality of the rough rice. In most of tropical Asia, aromatic or scented rices have premium prices, together with waxy or glutinous rices. Traditional rices with good eating quality, such as dry-land varieties, also bring a higher market price. In addition to these special considerations, the rough rice is judged in terms of purity, absence of field deterioration, percentage of hull, total milled rice recovery, head milled rice recovery, and percentage of immature or green grains. Physical properties desired of milled rice are whiteness (being well milled and not

having grain discoloration) and hardness (del Mundo and Juliano, 1981).

A recent study relating market price to milled rice properties in Philippine markets confirmed that IR42 brings a high price despite its hard gel consistency (Unnevehr et al., 1985). IR42 has a grain size and shape similar to that of the traditional fine-grain variety Wagwag and fewer immature grains than other shorter-duration IR rices. Its translucent, slender grains are given the premium price by consumers, although when cooked it is harder than most other varieties. Wagwag has an intermediate gelatinization temperature (GT), high amylose content, and soft to medium gel consistency (Juliano, 1972c).

A. Milling Quality

Various laboratory mills that simulate production conditions have been proposed to measure the milling quality of rough rice. The McGill system is used in the United States. Satake units are becoming popular because they allow dehulling and milling of smaller batches of samples. Maximum head-rice yields are obtainable with emery abrasive mills, even with overmilling. The metal rollers of the McGill mill minimize overmilling, as this mill utilizes friction among grain surfaces for milling. Milling is described in Chapter 9.

Total milled-rice yield is usually expressed as a weight percentage of rough rice rather than of brown rice because this method allows direct estimation of total milled-rice recovery and the percentage of hull from rough rice. Since bran-polish is the difference between 100% and the sum of total milled rice and hull, the data can readily be converted to a brown rice basis.

Head-rice yield also carries monetary implications, particularly in international trade. Various sizing devices are available: the vibrating gravity sizing device, which uses two plates per indentation size, or the rotating type, from which the brokens are continuously removed by gravity into a collecting tray as the drum rotates upward. The latter type is more efficient, particularly for samples with a high percentage of brokens.

Fissures or cracks in the rice caryopsis contribute to grain breakage during milling (Indudhara Swamy and Bhattacharya, 1982). They may be classified as single transverse, multiple transverse, and longitudinal or irregular (with or without transverse) cracks. Sorption of water leads to regular transverse cracks (Desikachar and Subrahmanyam, 1961), whereas longitudinal cracks are formed mostly upon fast drying. Varietal differences in critical moisture level for crack formation (14.2–18.3%) have been demonstrated (Srinivas et al., 1978), and an intravarietal selection technique has been developed for low fissure (crack) susceptibility in rice grain (Srinivas et al., 1981). Crack resistance was related to higher GT, pentosan content, and amylograph viscosity of milled rice (Bhashyam et al., 1985).

Grain hardness has also been determined with instrumentation, but its relationship to tolerance to grain cracking has not been demonstrated. A manually-operated Kiya hardness tester measures cracking (breaking) and crushing hardness of individual brown rice grains (IRRI, 1966). The rate of increase in pressure and area under pressure are not readily reproducible. An Instron-type unit has been used to measure breaking and crushing hardness of rough, brown, and milled rice (IRRI, 1983a). In addition, bending strength of rough rice has been measured, using a three-point bending cell on the grain

(IRRI, 1984; Nguyen and Kunze, 1984). Hardness of the surface of a cross section of brown rice has been measured using a Vickers hardness tester (Nagato and Kono, 1963) and an Instron-type machine (Hoki, 1979). Tensile strength may also be determined using an Instron machine (Kunze and Choudhury, 1972).

B. Chalkiness, Translucency, and Whiteness

Chalkiness is measured visually in the breeding program of the International Rice Research Institute (IRRI) (Khush et al., 1979). The scale used is 0 = none, 1 = small (< 10%); 5 = medium (10–20%); and 9 = large (> 20% of the area). White belly can easily be counted if the grains are arranged in a small groove between two plates such that either the belly (ventral) or back (dorsal) side shows. The total number of grains with ventral or belly side up is counted, and then the number with white bellies is determined (Ikehashi and Khush, 1979). White core can be counted from 50 grains arranged in small holes a little less than the size of the grain in a plastic plate. When the plate is lighted from below, the transparency of the grains is readily detected through the lighted core (Ikehashi and Khush, 1979).

Kushibuchi and Fujimaki (1975) tested an optical instrument for measuring grain translucency, the grain quality tester by Motoyama Engineering Works Co. Ltd. The tester differentiated well among samples differing widely in quality, but for samples with only slight differences in the proportion of damaged grains and chalkiness, visual grading differed somewhat from optical grading. Visual rating discerns even slight chalkiness that would not appreciably decrease translucency. It can readily distinguish between waxy and nonwaxy grains. On the other hand, optical measurement is affected by grain weight and color, which are not variables in visual rating. The tester was never used widely for rice inspection even in Japan.

Recently, the Japan Seed Inspection Association has been using an inexpensive rice translucency meter. However, translucency values were not simply related to visual scores for chalkiness at IRRI.

Another important property of milled rice in connection with degree of milling is whiteness. The whiteness of rice increases sharply during milling but reaches a maximum value beyond which it does not increase further with additional milling. The maximum whiteness reading with the Kett Whiteness Meter, however, is also affected by the inherent color of a given variety and by chalkiness (Ikehashi and Khush, 1979). Hence, no fixed standard for whiteness exists among varieties, and standard brown and well-milled rices of each sample are needed. The method is not widely used even in Japan, except in laboratories. With IR rices, whiteness values do not correlate significantly with total milled rice yield and with degree of milling (IRRI, 1983b).

C. Degree of Milling

An important property of rice in the rice trade is degree of milling, which is still determined subjectively by visual inspection by trained technicians. Despite extensive studies, a rapid simple test for degree of milling still has not been developed (Barber and Benedito de Barber, 1979; Webb, 1980). Rices differ in grain hardness, size and shape, thickness of bran layers, and depth of surface

ridges (see Chapter 2), and mills differ in efficiency of bran removal (Shams-ud-Din and Bhattacharya, 1978). Emery mills remove more grain weight than metal rollers to yield a milled rice of a given pigment or fat content. Most methods require the standard brown rice sample in order to calculate degree of milling.

Methods for degree of milling have been reviewed (Hogan and Deobald, 1965; Webb and Stermer, 1972; Barber and Benedito de Barber, 1979). Barber and Benedito de Barber (1979) classify the methods into 1) those estimating the quantity of removed bran or residual bran, and 2) those measuring the effects of removal of outer layers of the rice grain on either the chemical composition or the optical characteristics of the final milled rice.

Visual inspection of bran remaining in grain grooves is commonly used in determining the degree of milling.

Visual estimation of bran is facilitated by qualitative differential dye-staining procedures. In contrast to most methods, the May-Grünwald reagent (Tani et al., 1952) used by the Food Agency of Japan differentiates between outer and inner bran layers. The reagent is a solution of eosin and methylene blue in methanol, with which the outer bran layer stains green, the inner bran layer and germ blue, and the endosperm pink. The degree of milling is judged by comparing the color of the test sample with the color of a set of standard samples of known degrees of milling. The colored bran balance (CBB) index uses planimetry of a magnified plane image to estimate the percentage of the milled grain area still covered by bran after May-Grünwald dye-staining (Barber and Benedito de Barber, 1979).

Solvent extraction of bran pigments, followed by colorimetric determination of the color intensity is the basis of quantitative tests such as that of Bhattacharya and Sowbhagya (1972a). The method consists of extraction of bran pigment with alkaline alcohol (2% KOH and 2-propanol, 1:2, by volume) and colorimetric measurement of the yellow-brown extract at 400 nm. Not all varieties tested fall into the same curve relating pigment absorbance to degree of milling (Barber and Benedito de Barber, 1979).

Numerous methods have exploited the fact that several nutrients decrease progressively with milling; examples are fat, ash, silica and crude fiber, proteins, phytin, phytin phosphorus, and thiamine (Barber and Benedito de Barber, 1979). Common to all these methods is the problem that the concentration gradient may not be identical among varieties. These methods generally require carefully controlled laboratory procedures and are time-consuming. A procedure based on oil content is shortened by the use of nuclear magnetic resonance spectroscopy (Pomeranz et al., 1975) or by near-infrared reflectance (NIR) spectroscopy. Miller et al (1979) described a rapid, objective method involving a 5-min extraction of 10 g of whole milled rice with 40 ml of 50% 2-propanol and measurement of the electrical conductivity (in $\mu\text{mho}/\text{cm}$) of the extract.

Methods based on optical characteristics of the milled rice employ mainly optical reflectance or transmission properties in the visible portion of the spectrum (Barber and Benedito de Barber, 1979). Although accurate for a single variety grown in a particular locality, they fail in wide usage because grain color influences the readings. The Kett Whiteness Meter also shows that the whiteness reading improves with milling, but values among samples vary widely (Ikehashi and Khush, 1979). Chalky grains and waxy rices also give higher values than translucent grains. One method (Stermer, 1968) employs the far-red (660 nm) and near-infrared (850 nm) regions of the spectrum, which reduces the

interference from grain color. The readings, however, were affected by moisture content, abnormal grains, and the age of the milled rice. Ebata (1978), using the "Rice Inspector," reported that relative transmittance values of brown rice are low at 420 nm due to bran absorption and used 420 nm to estimate degree of milling of a waxy and two nonwaxy rices ($r = 0.96^{**}$, $n = 30$). At 710 nm, grain translucency may be estimated and also degree of ripening without the influence of bran layers.

The ICC Working Group 21/I, titled "Test Methods for Rice—Milling Properties," under Dr. S. Barber of IATA, Valencia, Spain, undertook a cooperative study in 1980 involving five rices and five degrees of milling plus brown rice per sample (S. Barber, unpublished data). The rices were the Spanish rices Bahia and Sequial, a parboiled rice, IR36, and IR29 (waxy). Eight cooperators in seven countries analyzed the samples for degree of milling by weight loss, the CBB method, and percent bran pigment removal (Bhattacharya and Sowbhagya, 1972a). Considerable variation was obtained in values for all three methods among laboratories for all the samples, even though the same mill was used for all samples. Manual estimation of CBB was time-consuming, since the method required assessment of 15 grains per sample. Although the brown rice samples differed in pigment content by $2.2\text{--}3.0 \text{ A/g } 10 \text{ mL}^{-1}$, the actual absorbance reading related well to the other indexes without the need for the brown rice sample (IRRI, unpublished data, 1981) (Fig. 1).

The NIR units now used for measurement of protein, oil, moisture, and fiber would have the potential to measure degree of milling, particularly if surface lipids or fiber could be determined without grinding the sample. Grinding definitely reduces the contents of lipid and fiber due to dilution by endosperm. The NIR units that measure moisture can now accommodate whole rough rice directly instead of requiring that it be ground to a flour.

D. Grain Size and Shape

An important varietal characteristic is grain size and shape, which is one of the most stable properties of the variety. Consumers have definite preferences for milled rice size and shape, based on the cooked rice texture they prefer. A most extensive study of varieties and grades of rice moving in world trade, in terms of U.S. official rice standards, was undertaken in the late 1950s in 31 countries (Rivenburgh et al, 1961). A corresponding analysis of cooking quality characteristics of these rices is also available (Simpson et al, 1965). Standards for grain size and shape vary by country.

Jennings et al (1979) classify milled rice length as extra long ($> 7.50 \text{ mm}$), long ($6.61\text{--}7.50 \text{ mm}$), medium ($5.51\text{--}6.60 \text{ mm}$), and short ($< 5.50 \text{ mm}$). The shapes of milled rice in terms of length-width ratio are slender (> 3.0), medium ($2.1\text{--}3.0$), bold ($1.1\text{--}2.0$), and round (< 1.1).

III. COOKING AND EATING QUALITIES

Discussions of cooking and eating qualities should go hand in hand because the texture of cooked rice depends on the degree of cooking. In addition, rice breeding programs have developed rapid simple indexes of cooking and eating qualities that allow screening of hundreds of samples daily (Juliano, 1973,

1982a). Because of the possibility of planting two or more rice crops per year in the tropics, the screening period is much shorter there than in temperate countries, where usually only one rice crop is grown per year.

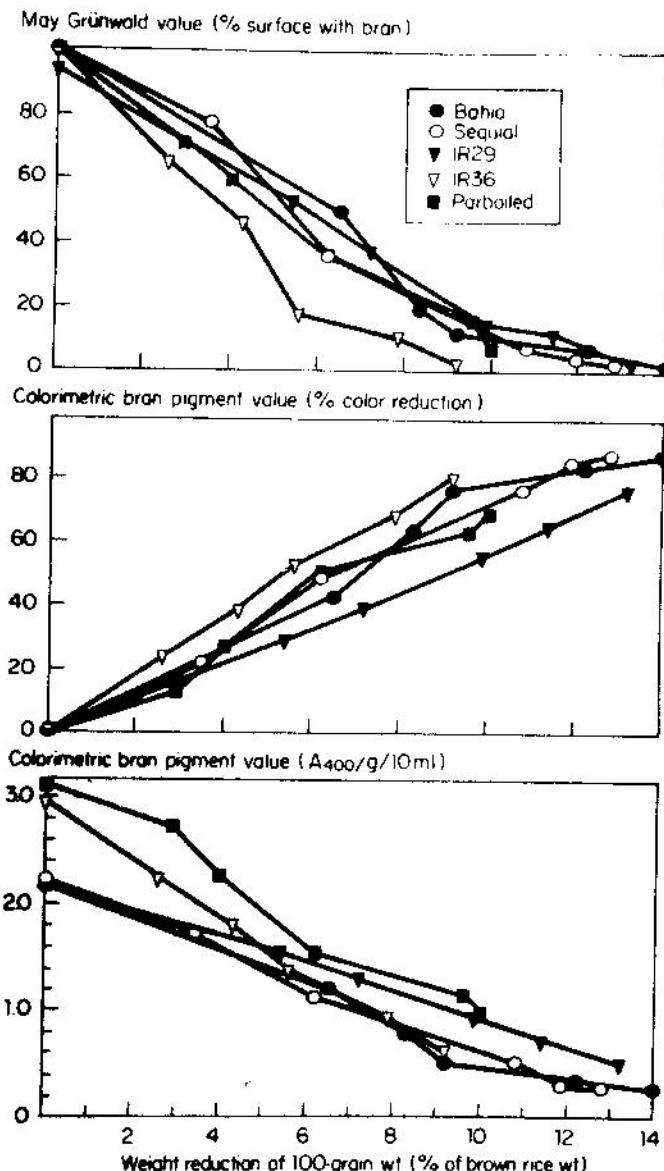


Fig. 1. Effect of degree of milling based on weight reduction of brown rice on May-Grünwald value and colorimetric bran pigment values of five rices at six levels of milling. (IRRI unpublished data for ICC Study Group 21/I)

A. Cooking Quality

The subject of quality tests on milled rice was reviewed by Tani (1958), Refai,¹ Batcher et al (1963a, 1963b), Juliano et al (1964b), Borasio (1965), Simpson et al (1965), and Hampel (1968) and more recently by Chikubu (1975), IRR^I (1979a), Juliano (1982a), and Bhattacharya et al (1982). These reviews have mainly emphasized methods employed in a country or region and have not indicated the extent to which the methods have actually been adopted in the various rice quality laboratories in the world. Barber et al (1979) recommended two priority research areas for the assessment of grain quality in rice-breeding programs: 1) characters of cooked rice and 2) inheritance studies on characteristics influencing grain quality.

As the initial activity of the ICC Working Group 21/II, a survey was made in 1981 of methods used by rice scientists for evaluating the cooking and eating qualities of milled rice (Juliano, 1982a).

COOKING METHODS

Based on a survey of foreign rices (Simpson et al, 1965), Batcher et al (1963a) classified the various methods of cooking milled rice into groups, which are described below. These methods are: 1) oven cooking method, 2) cooking in a small amount of water (Burma, Egypt, France, Greece, India, Indonesia, Japan, Korea, Thailand), 3) cooking in a medium amount of water (Argentina, Burma, Portugal, Spain), 4) cooking in a large amount of water (Australia, West Germany, Italy, Thailand), 5) steaming (Indonesia), 6) steaming with oil added (Iran), and 7) cooking in water with oil added (Brazil, Chile, Ecuador, West Germany, Mexico, Peru). In addition, modifications of the methods according to customs are reported: Rice is added to cold water rather than to boiling water in France, Korea, Burma, Thailand, Japan, and Philippines; rice is soaked before cooking in Japan and India; in Italy, Burma, and Thailand, excess moisture is allowed to evaporate after the rice is cooked and drained; and a rinsing or washing procedure, to remove dust and foreign particles, is a common practice in many countries except Australia.

Oven cooking. A predetermined amount of boiling water (220–260 ml, based on a cooking trial on 8 g of rice cooked in 60 ml of water for 20 min), is added to rice (100 g) in a 1-L Pyrex baking dish, which is covered. The rice is then cooked at 176°C for 28 min. The lid is removed and the rice is steamed in the oven for another 5 min. Parboiled samples are cooked for 33 min.

Small amount of water. In a covered Pyrex saucepan, 200 ml of water is brought to a boil. Rice (100 g) is added, boiled 2 min, then simmered 18 min in the covered container. An asbestos pad is placed under the pan during the simmering period. In Burma, France, Japan, Korea, and Thailand, rice samples are added to cold water rather than to boiling water. In India and Japan, samples are soaked 30 min and drained before they are added to the boiling water. Parboiled samples are simmered 23 min and may require more water if not presoaked.

Medium amount of water. In a covered aluminum saucepan, 400 ml of water is brought to a boil. The rice (100 g) is added, boiled 2 min, then simmered 13 or 18 min in the covered container. Excess water is removed before serving. For

¹F. Y. Refai, Test methods on rice. Paper presented at Congress of the International Association for Cereal Chemistry, Vienna, June 6–9, 1962, 27 pp.

Burmese rice, samples are added to cold water rather than to boiling water and, after cooking, the drained cooked rice is placed uncovered in a 176°C oven for 5 min to steam dry. Parboiled rice is simmered 23 min.

Large amount of water. In a covered aluminum saucepan, 800 ml of water is brought to a boil. The rice (100 g) is added, boiled 12 or 20 min in the uncovered container, and then drained before serving. Australian rice is not washed before cooking. In West Germany, rice is covered during cooking. Thai rice is added to cold water rather than to boiling water. Italian and Thai cooked rices are steam dried, after draining, in a 176°C oven for 5 min. Parboiled rice requires 25 min of boiling.

Steaming. In Indonesia, rice (100 g) is steamed over boiling water for 15 min in a perforated steamer insert, placed in a solid-bottomed insert with an equal volume of boiling water, and allowed to stand 10 min. The pan is then placed over boiling water in the steamer and steamed for 30 or 45 min. Indonesian respondents describe the method as precooking rice with 1.5 times the weight of water until the water is absorbed (5 min), and then steaming 30 min in a perforated pan at zero gauge pressure (Juliano, 1982a).

Steaming with oil added. In a covered aluminum saucepan, 800 ml of water is brought to a boil. In Iran, rice (100 g) is added, boiled 5 or 15 min in the uncovered saucepan, drained, transferred to a solid-bottomed steamer pan containing 1 tablespoon (14.9 ml) of oil and 60 ml of hot water, and steamed 15 min over boiling water.

Cooking in water with oil added. Rice (100 g) is first cooked 2 or 5 min in 1 tablespoon (14.9 ml) of cottonseed oil in an aluminum saucepan. Water (200 or 250 ml) is then added, and the rice is simmered 20, 25, or 28 min in the covered pan. An asbestos pad is placed under the pan after the rice has cooked 15 min. In Ecuador and Peru, the oil and 250 ml of water are first brought to a boil; the rice is added and simmered 30 min in a covered saucepan.

RATIONALE OF COOKING METHOD IN EXCESS AND OPTIMUM WATER LEVELS

An arbitrary or constant cooking time in excess water has been used to measure water absorption and volume expansion of rice during cooking (Juliano, 1982a). Since rices differ in optimum cooking time in boiling water for 15–24 min without presoaking (Juliano et al, 1981a), predetermination of minimum cooking time is usually employed for cooking in excess water. Minimum cooking time is generally determined by the method of Ranghino (1966). Starting after 10 min of cooking in boiling water, at least 10 grains are pressed between two glass plates every minute; cooking time is when 90% of the grains no longer show an opaque center. Optimum cooking time is minimum cooking time plus 2 min (Juliano et al, 1981a).

Although Bhattacharya and Sowbhagya (1971) observed that all rices have about 73% water content on cooking to optimum cooking time in excess water, differences in water content of samples (71–76%) are observed that are traceable to differences in cooking time and to differences in starch GT and also grain thickness (Juliano et al, 1981a; Juliano and Perez, 1983; Juliano et al, 1984a). Only nonwaxy samples show the relationship between cooking time and water content (Fig. 2). Waxy starch shows only a one-stage gelatinization and reaches peak viscosity in the amylograph shortly after the onset of gelatinization.

Norwaxy starch has a two-stage gelatinization, probably reflecting the melting of the amylose-lipid complex. The relationship may be explained in part by differences in starch GT, which were shown earlier to relate to cooking time (Juliano, 1979a). The two low-GT rices with cooking time of more than 20 min had wider grains (2.6–2.7 mm) than the others (2.0–2.3 mm), and the thicker grain probably prolongs cooking time without affecting the actual water content of the cooked rice.

Correlation coefficients between cooking time and starch final GT were highly significant ($r = 0.75^*$), more significant than correlation of cooking time with surface area per grain ($r = 0.35$) (Juliano and Perez, 1983) (Fig. 3). Correlation coefficients ($n = 10$) with cooking time for several variables are: grain width, 0.20; thickness, 0.37; length, 0.01; 100-grain weight, 0.57; surface area per grain, 0.35; surface area per gram, -0.49; and alkali spreading value, 0.73*. The longer cooking time of two low-GT samples is due to their coarser grain, which, however, did not affect the water content of the cooked rice. When these two varieties are excluded from the correlations, the coefficients ($n = 8$) of cooking time with starch final GT and alkali spreading value improved to 0.93** and -0.89**, respectively. The correlation with starch GT, an indicator of reactivity of the grain to cooking, supports the findings of the kinetic studies of Suzuki et al (1976, 1977) and Cheigh et al (1978) on japonica rices: at 100°C and lower, cooking rate, as indexed by cooking time, is limited by the reaction rate of rice components with water. With the coarse rices, the rate of water diffusion through the cooked layer toward the interface of uncooked core may also become limiting.

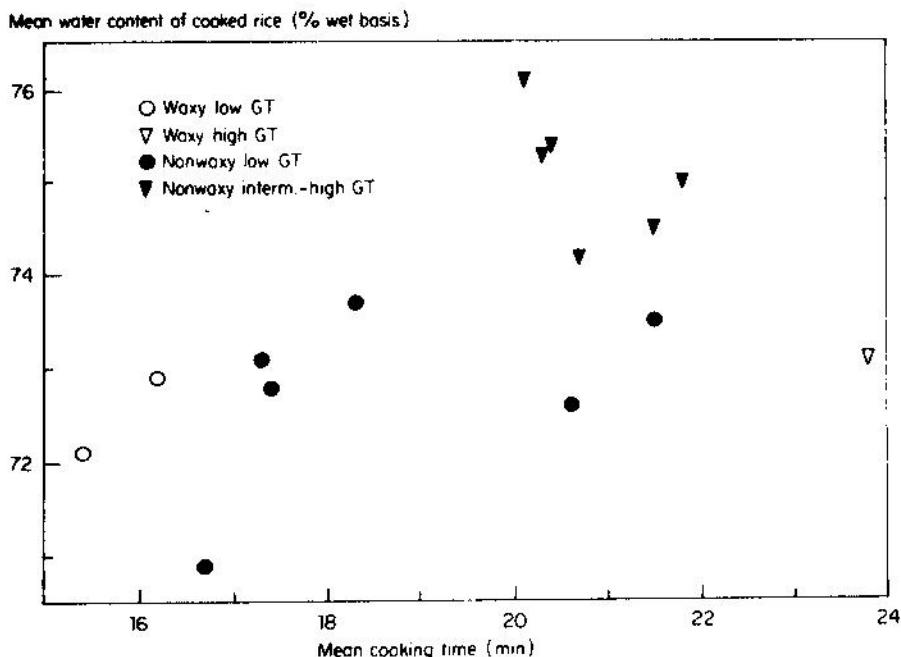


Fig. 2. Effect of mean optimum cooking time on mean water content of three waxy and 12 nonwaxy milled rices. GT = gelatinization temperature. (Data from Juliano et al., 1981a; Juliano et al., 1984)

Despite the criticism of the optimum water level method of cooking, particularly the use of different water-rice ratios for various amylose types (Deshpande and Bhattacharya, 1982), the recent ICC Working Group 21/II survey showed 19 employing this method and 16 employing the excess water method (Juliano, 1982a). Waxy rices are cooked at a water-rice ratio of 0.8–1.3, low-amyllose rices at 1.2–1.7, and intermediate- and high-amyllose rices at 1.7–2.5, verifying the assumption that scientists actually adjust the water-rice ratio to obtain optimum texture with the rice cooker method.

Comparison of reproducibility of water content by the excess water method with predetermined optimum cooking time and by the double-boiler method with measured water and fixed cooking time showed the superiority of the latter as a screening method (Juliano et al., 1984a) (Table I). Water content is so critical at this high water content (75%, wb) that hardness values of cooked rice correlated better with amylose content in the double-boiler method because of the closer water contents of Calrose, Labelle, and IR32. Overlapping of values for these varieties is observed in the excess water method because of the lower

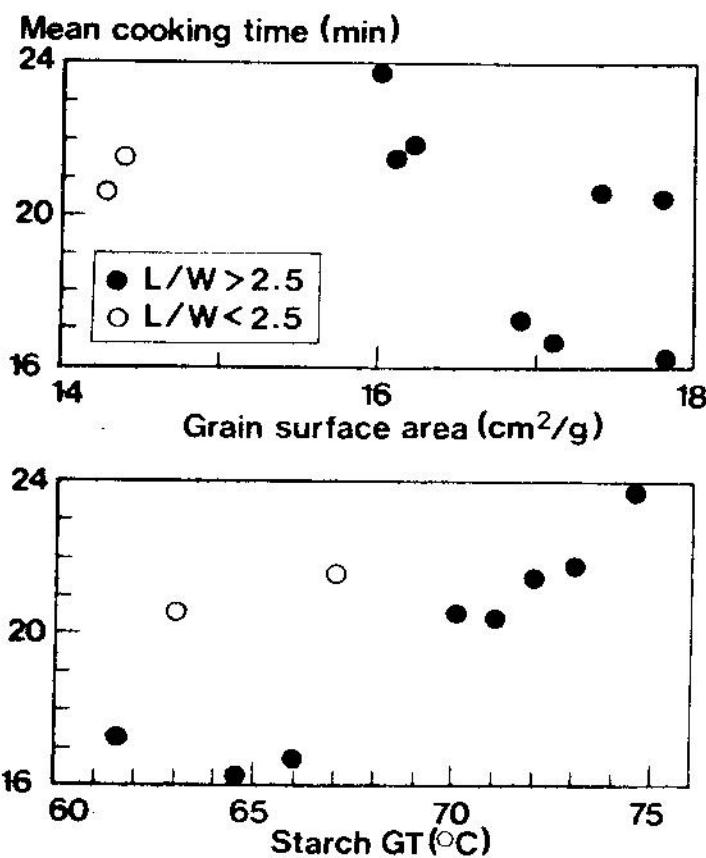


Fig. 3. Relationship of starch gelatinization temperature (GT) and grain surface area with mean cooking time of 10 milled rices differing in amylose content and length-width ratio. (Adapted from Juliano and Perez, 1983)

water content of Calrose. A precaution with the double-boiler method is the need to get the sample for texture determination from the center, since the bottom layer is overcooked and the top layer is undercooked. Sampling is no problem in the excess water method.

A study of the effect of water-rice ratio on Instron hardness of cooked rice in the double-boiler method demonstrated the primary role of this factor on cooked rice hardness (Juliano and Perez, 1983). The water-rice ratio for acceptable soft texture (less than 10 kg of Instron hardness) increases with increasing amylose content: 0.9–1.1 for waxy rice, 1.2–1.4 for low-amylase rice, 1.5–1.6 for intermediate-amylase rice, and 1.7–2.0 for high-amylase rice (Juliano and Perez, 1983) (Fig. 4). The total range of hardness values for the four rices representing the amylose types was 3 kg at the water-rice ratio of 2.65, corresponding to 75% water, characteristic of the excess water method. The spread of hardness values was much larger for lower ratios: 5 kg at a water-rice ratio of 2.1, 6 kg at ratios of 2.0 and 1.9, 7 kg at a ratio of 1.8, and 8 kg at a ratio of 1.7. Thus, for a screening technique, a constant water-rice ratio of 1.7–2.0 would be most sensitive for samples covering all the amylose types. For programs with a narrower range of amylose types, the water-rice ratio may be adjusted correspondingly, based on Fig. 4.

Using Fig. 4 and the IRRI modified rice cooker method, which uses a water-rice ratio of 1.3 for waxy rice, 1.7 for low-amylase rice, 1.9 for intermediate-amylase rice, and 2.1 for high-amylase rice (Juliano and Pascual, 1980), differences were also 3 kg among the four samples (Fig. 4, thick arrows), and relative hardness values corresponded to amylose content also, as in the case of the excess water method. Interestingly, the hardness values obtained by the IRRI method correspond to a line that passes the origin in Fig. 4 (dotted line). The range of hardness values is similar to that obtainable at 75% water content, i.e., the excess water method (narrow arrow). Despite the water-rice ratio lower than 2.65 needed for 75% water, acceptable texture is achieved in the rice cooker method, probably due to the use of water washing in some cases, to cold water, and most important, to the several minutes of standing of the covered cooker after the heat is turned off. Even with this adjusted water-rice ratio based on amylose content, amylose content still correlated with cooked-rice Instron hardness ($r = 0.59^{**}$, $n = 266$) and stickiness ($r = 0.82^{**}$, $n = 268$) (Juliano and

TABLE I
Water Content of Rice Cooked to Optimum Cooking Time in Excess Boiling Water and
in Measured^a Water in a Double Boiler^b

| Variety | Amylose (% db) | Alkali Spreading Value | Mean Optimum Cooking Time (min) | Excess Water Method | Double Boiler Method |
|---------|----------------|------------------------|---------------------------------|---------------------|----------------------|
| RD6 | 1.2 | 7.0 | 15.4 | 72.1 | 73.4 |
| Calrose | 19.2 | 7.0 | 18.3 | 73.7 | 74.5 |
| Labelle | 21.8 | 5.0 | 20.3 | 75.3 | 74.6 |
| IR32 | 27.8 | 5.0 | 20.1 | 76.1 | 75.5 |
| IR42 | 28.2 | 7.0 | 17.4 | 72.8 | 73.9 |

^a To obtain rice with 75% water content after cooking for 20 min.

^b Source: Juliano et al (1984); used by permission.

Pascual, 1980). Hardness values ranged from 3.0 to 10.1 kg. Because of differences in the water-rice ratio used, volume expansion and water absorption correlated positively with amylose content.

A fixed water-rice ratio of 1.6 for taste panel evaluation of boiled rice was originally used at IRRI (Juliano et al, 1965). Because people commonly adjust water level to obtain soft enough cooked-rice texture, subsequent sensory tests involved a trial cooking step and employed 360–380 ml of water to 200 g of rice, with 40 ml in the outer pot (del Mundo, 1979) for predominantly high-amylase and intermediate-amylase rices. Batcher et al (1963b) also reported that the relative texture ratings of rices are little affected by cooking method.

The use of tap water or the addition of sodium chloride is employed by several laboratories to simulate actual conditions for cooking milled rice (Juliano, 1982a). However, salts are known to alter the gelatinization characteristics of starch, depending on the concentration and type of salt added (Ghosh and

Instron cooked-rice hardness (kg)

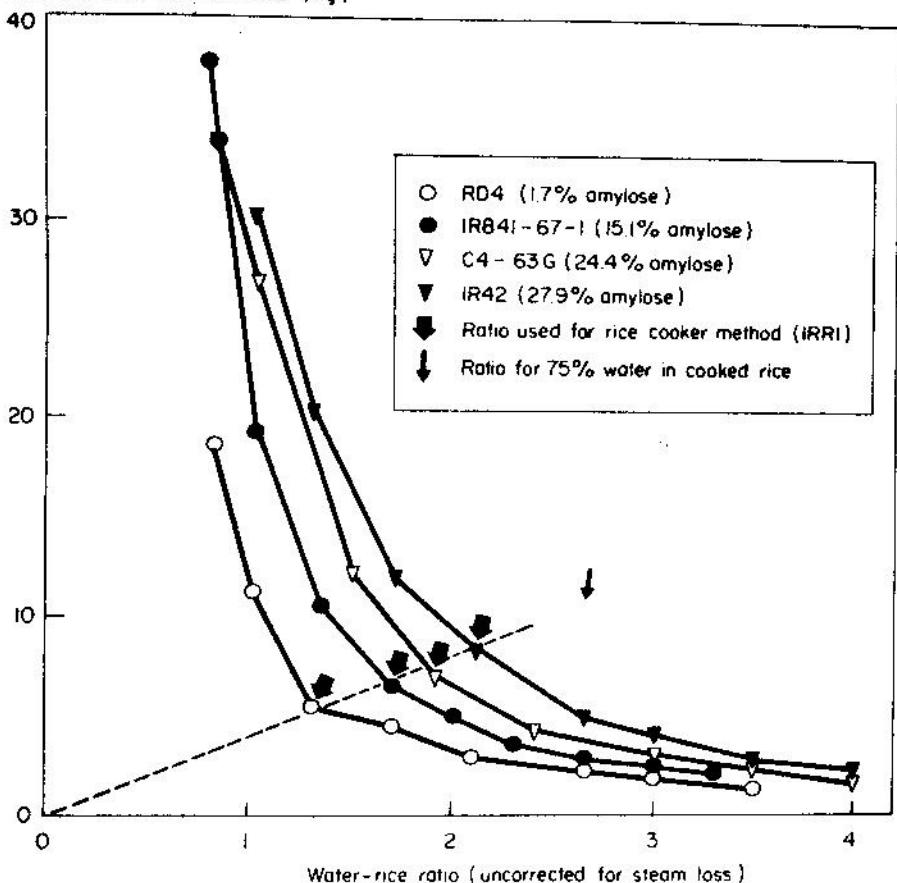


Fig. 4. Effect of water-rice ratio (uncorrected for steam loss) on cooked rice Instron hardness of four milled rices representing the four amylose types. (Reprinted, with permission, from Juliano and Perez, 1983)

Sarkar, 1959). The salts in a rice grain would also influence the gelatinization characteristics of the grain. Magnesium sulfate increases water absorption and solubles; calcium chloride reduces water absorption; and sodium chloride, sodium sulfate, and magnesium chloride do not increase water absorption. All except magnesium sulfate reduce solubles in cooking water. The pH of the cooking water is reported to affect the hardness of cooked rice, and tap water with pH 6.9–7.1 is preferred to deionized water with pH 5.6–6.5, since pH 5.6 adversely affects the hardness of cooked rice (Okabe, 1979).

GRAIN ELONGATION DURING COOKING

Respondents to the ICC Working Group questionnaire (Juliano, 1982a) perform elongation tests on rice (Azeez and Shafi, 1966) with 0–30 min of presoaking and a constant boiling time ranging from 10 to 30 min or a variable boiling time corresponding to the minimum cooking time predetermined by the Ranghino (1966) test. If presoaked, the grains are placed directly in boiling water, either by direct dropping, by using in a wire cage or basket, or by placing the container of presoaked rice and water into the vigorously boiling water bath. In addition, because Basmati rice tends to curl and disintegrate on overcooking (15-min cooking), undercooked rice is preferred to overdone rice in the elongation test.

A presoaking time of 30 min has previously been found optimum for the elongation test. With this presoaking time, the actual minimum cooking time of selected samples decreased to 11 min or less (Juliano and Perez, 1984).

A simplified method, assessed in 1982–1983 by 19 cooperators in 16 countries, involved five samples showing variation in grain elongation (Juliano and Perez, 1984). The method consisted of a 30-min presoak of rice in a wire cage in water, a 10-min treatment in boiling water, and cooling. Although considerable interaction was shown between laboratory and sample, the simplified method resulted in more of the variance being due to the sample and less to determinations, replications, or both. The elongation ratio (the mean length of 10 cooked grains divided by the mean length of 10 raw grains) is the preferred means of expressing grain elongation, rather than the elongation index (length-width ratio of cooked grain:length-width ratio of raw grain), in contrast to observations of Sood and Siddiq (1980). Some respondents make only one measurement, the overall length of 10 grains arranged end-to-end.

VOLUME EXPANSION AND WATER ABSORPTION DURING COOKING

Purposes for determining water absorption and volume expansion during laboratory boiling in excess water vary. Use of an arbitrary cooking time of 15 or 20 min will be subject to varietal differences in cooking time if the samples differ considerably in GT types. Bhattacharya and Sowbhagya (1971) observed that water uptake during 20 min of boiling correlated significantly ($r = -0.84^{**}$, $n = 20$) with optimum cooking time. If cooking time is adjusted to optimum cooking time, all rices will have absorbed similar amounts of water—about 75% (Bhattacharya and Sowbhagya, 1971). However, weighing of cooked rice remains a means of checking whether the cooking of samples for texture evaluation has proceeded normally.

Batcher et al (1956) cooked 8.0 ± 0.01 g of milled rice in a wire cylinder 76 mm high and 38 mm in diameter by lowering it into a 300-ml tall-form beaker with 160 ml of boiling distilled water at low heat for 12, 16, 20, 24, and 28 min, with the beaker covered with a watch glass. The rice was drained for 2 min.

Actual severity of cooking is affected by the size of the bath relative to the number of samples cooked at any time (that is, by the water-rice ratio) and by the actual contact time with boiling water. With the direct addition of rice to boiling water, cooking time and boiling time are practically the same. In cases where the rice is placed in containers with cold water and the containers are immersed in the boiling water bath, cooking time and boiling time are not the same, unless the time is considered from the moment the cooking water in the container starts boiling. In such a case, some degree of presoaking is involved.

Water absorption is usually determined by the increase in weight of rice during treatment (Juliano, 1982a) or by the decrease in volume of cooking water (Halick and Kelly, 1959). In the excess water method, the estimation is approximate because of the solids lost in the cooking water. Actual water determination by loss of weight from 24 hr of drying at 105°C would be a good verification of the method. In addition, another source of error is the blotting step to remove free water from the cooked-rice surface. Of course, the method does not distinguish between absorbed and adsorbed water in the cooked grains.

Water absorption values determined below boiling water temperature do not correspond to actual water absorption during cooking, but they do differentiate rices based on starch GT. Halick and Kelly (1959) presoaked 2 g of milled rice, previously surface-defatted with petroleum ether, in 6–8 ml of water for 30 min in a stoppered 25 × 100-mm test tube and immersed it for 45 min in a 77°C water bath. The water uptake number, determined from the volume of unabsorbed water, was expressed as milliliters of water absorbed by 100 g of rice. This number distinguishes between low-GT and intermediate- to high-GT rices, since only the low-GT grains are gelatinized completely at these temperatures.

Determining the rice swelling number (*Reisquellzahl*) involves cooking 1 g of rice with 2 ml of water in a test tube at 70°C for 10 min, then at 45°C for 2 hr. Then 3 ml of a solution of formic acid-ammonium sulfate-sulfosalicylic acid is added to the cooked rice, which is then ground in a mortar (Pelshenke and Hampel, 1958). After the rice has been mixed, filtered, and boiled in the presence of hydrogen peroxide, and iodine has been added, equivalent copper tetramine is determined with a Lange colorimeter with a green filter. The swelling number does not correlate significantly with the amylose content ($r = -0.38$) but does correlate with starch GT ($r = -0.88^{**}$) (Hampel, 1968).

The water content of parboiled rice at 60°C or below starch GT (50° or 65°C, depending on the GT) (Bhattacharya, 1979c) and at 98°C is calculated from the increase in weight after a 20-min treatment in water. The water content ratio below starch GT and at 98°C is an index of degree of parboiling (Indudhara Swamy et al, 1971a; Bhattacharya, 1979c).

Volume expansion is measured usually as bulk volume or as displacement volume using a hydrophobic solvent such as xylene (Juliano, 1982a). The increase in the height of cooked rice in a container of known dimensions is the usual index of volume expansion (Batcher et al, 1956), expressed as the ratio of volume of cooked rice to volume of raw rice.

Volume expansion values below boiling water temperature is also useful in differentiating rices into GT types, as is the water uptake number. The expansion test of Refai and Ahmed (1958) measures the increase in volume of 5 g of milled rice in a covered, 100-ml graduated cylinder with 40 ml of water in an 80°C water bath at times of 0, 20, 30, 40, 50, 60, 70, 80, and 90 min. The expansion ratio is the maximum volume of rice divided by the initial volume. Only low-GT samples are completely gelatinized at 80°C.

SOLIDS IN THE COOKING WATER

Some laboratories also measure solids in the cooking water during cooking (Juliano, 1982a). Solids are determined by drying an aliquot of the cooking water in a tared evaporating dish to evaporate the water as steam. Kurasawa et al (1962), in addition, determined the starch-iodine blue value of the cooking gruel of japonica rice, which correlated with the amylose content of the grain, probably because of similarity in the GT and in the grain size and shape of the samples. Batcher et al (1956) also determined the starch-iodine blue color of the residual cooking liquid at 530 nm expressed as percent transmittance. Calculation of the data into starch using a standard rice starch powder sample is not quantitative because of varietal differences in the amylose content of starch and the relative solubility of amylose in boiling water (see Chapter 3).

Priestley (1977) further measured the apparent solubility of the starch that is released after the cooked grains are macerated, in addition to measuring cook water loss, to permit estimation of soluble and insoluble amylose and amylopectin. The soluble amylopectin content (14–72%) correlates with the amylose content of rice ($r = -0.82^{**}$) and may be related to the stickiness of cooked rice. Priestley (1976) reported that the alkali-digestibility pattern according to Bhattacharya and Sowbhagya (1980) is related to the apparent solubility of cooked milled rice. However, Maniñgat and Juliano (1978) found apparent solubility to correlate better with the amylose content of 16 samples than with the alkali digestibility pattern.

Webb (1979) determined the canning stability of 5 g of parboiled rice in 100 ml of water, after the rice had been precooked 20 min at 95°C, cooled to room temperature with tap water, autoclaved for 1 hr at 121°C (1.05 kg/cm² of gauge pressure), and cooled to room temperature with tap water. Solids loss, measured as the decrease in dry weight from that of the starting parboiled rice, was determined by collecting cooked rice over a 1.6-mm wire screen, drying it at 70°C overnight in a forced draft oven, and weighing it. Parboiled rice is more resistant to disintegration during cooking than is corresponding raw rice, but its stability is affect by various other factors (see Chapter 15).

Borasio (1965) proposed the use of the Bühler apparatus to study the cooking properties of milled rice in excess water. Milled rice (50 g) of known volume is placed in a steel pan with 1 mm perforations and introduced into a container with 750 ml of boiling water. The water and rice are stirred for 5 sec, the container is covered, and the boiling is allowed to continue for 10 and 30 min. The pan is lifted out; the rice is drained for 5 min and weighed, and its volume is computed by volumeters. Solids in 200 ml of cooking liquid are estimated by drying at 105°C and weighing. The coefficient of disruption is determined as solids per 100 g of milled rice. Because the cooking rates differ, rices are then cooked to a fixed degree of disruption (say, 5%) for comparison, based on plots of the 10- and

30-min cooking times. The coefficient of disruption is considered an index of resistance to cooking and, indirectly, of rice consistency, seen in the bursting of the grains during and after cooking.

STARCH-IODINE BLUE TEST

Solubility tests on rice flours are related to those done on whole grains. The starch-iodine blue test of Halick and Keneaster (1956) involves 1 g of rice flour (<0.5 mm) in 100 ml of water in 250-ml Erlenmeyer flasks that are immersed in a 77°C water bath for 45 min. A 10-ml aliquot is then used for iodine coloration at 600 nm, and values are expressed as percent transmittance. However, only low-GT samples are completely gelatinized, and high-GT samples such as Century Patna 231 give very poor absorbance (high transmittance) readings (Juliano et al., 1964b). Nonetheless, absorbance readings of starch-iodine blue color at 77°C correlate with total amylose content (Williams et al., 1958; Juliano et al., 1964b).

Hall and Johnson (1966) reported that, in a test using an extraction temperature of 99.5°C, the starch-iodine blue test (75 mg of flour in 30 ml of water) gave absorbance values that correlated with amylose content of U.S. rice varieties. When the test was used on rices representing all amylose types, some high-amylose (>25%) rices showed lower soluble amylose levels than expected (Juliano et al., 1968a). Since the phenomenon is independent of the water-rice ratio, the low values must reflect in situ retrogradation of amylose. About 30% of the amylose and 10% of the amylopectin of waxy rices are solubilized; 55–70% of the amylose and 5–15% of the amylopectin of low-amylose and intermediate-amylose rices are solubilized; and about 60% of the amylose and 30% of the amylopectin of high-amylose soft-gel-consistency IR32 rice, and 40% of the amylose and 10% of the amylopectin of high-amylose hard-gel-consistency IR42 rice are extracted in boiling hot water (Juliano, 1979a) (Table II). Thus, both amylopectin and amylose are less soluble in the hard-gel-consistency high-amylose IR42 rices than are the starch fractions in the soft-gel-consistency high-amylose IR32 rice, in which amylopectin is more soluble than in lower-

TABLE II
Solubility of Starch, Amylose, and Amylopectin of Milled Rice Flour in
Boiling Water as Affected by Starch Properties^a

| Variety or Line Name | Final GT ^b (°C) | Gel Consistency (mm) | Amylose (% db) | | Hot-Water Soluble Starch (% db) | Solubilization in Hot Water (%) | | |
|----------------------|----------------------------|----------------------|----------------|-------------------|---------------------------------|---------------------------------|---------|-------------|
| | | | Total | Hot-Water Soluble | | Starch | Amylose | Amylopectin |
| UPI-Ri-1 | 65 | 100 | 1.4 | 0.4 | 10.2 | 11 | 29 | 9 |
| C441-4 | 77 | 100 | 5.4 | 1.6 | 12.8 | 14 | 30 | 13 |
| IR2071-137-5 | 76 | 74 | 13.2 | 9.3 | 13.8 | 16 | 70 | 6 |
| IR351-38-3 | 68 | 92 | 16.6 | 9.5 | 18.5 | 21 | 57 | 12 |
| Kuban | 76 | 95 | 18.4 | 10.6 | 21.4 | 24 | 58 | 15 |
| BPI-121-407 | 66.5 | 96 | 24.1 | 14.0 | 22.7 | 26 | 58 | 14 |
| C4-63G | 75 | 92 | 23.8 | 14.5 | 22.7 | 25 | 61 | 12 |
| IR32 | 73.5 | 100 | 27.1 | 16.5 | 37.0 | 41 | 61 | 33 |
| IR42 | 63 | 30 | 26.7 | 11.2 | 16.0 | 18 | 42 | 8 |

^aSource: Juliano (1979a); used by permission.

^bGelatinization temperature.

amylose rices, and soluble starch is highest for IR32-type rices. GT had little effect on soluble amylose at 100°C, except for the relation of GT to gel consistency among high-amylose rices.

Bhattacharya et al (1978) reported on the importance of percentage insoluble amylose, calculated from total amylose and soluble amylose at 100°C, as a determinant of rice quality. High-amylose rices (>26%) are classified into three types based on insoluble amylose of >15%, 12.5–15%, and <12.5%. This division correlates with increasing amylograph breakdown, increasing stickiness, and decreasing consistency of cooked rice (Bhattacharya et al, 1982). Because of the small differences involved, differentiation by gel consistency is more sensitive as a screening procedure than is insoluble amylose at 100°C. Gel consistency correlated negatively with amylograph setback ($r = -0.58^{**}$) and consistency ($r = -0.60^{**}$) for 302 samples and with cooked rice Instron hardness ($r = -0.63^{**}$, $n = 266$) and positively with cooked rice stickiness ($r = 0.40^{**}$, $n = 268$) (Juliano and Pascual, 1980).

B. Eating Quality

Various methods for assessment of the texture of cooked rice have been reviewed recently (IRRI, 1979a) and involve the measurement of hardness, stickiness, or consistency by the use of instruments or sensory tests. Because of the change in texture of cooked rice during cooling and storage, the handling of cooked rice is standardized to reduce further variables to the assessment. The cooked rice is usually covered during cooling to minimize water loss. Cooked rice is usually assessed within 1 hr of cooking (Juliano, 1982a). Okabe (1979) reports that a holding time of 1 hr at 18–24°C or 1.5 hr above 25°C ambient temperature is required for the sample to reach room temperature. This is important because poor thermal equilibration of the cooked rice will cause poor reproducibility of texture measurements, especially of stickiness.

SENSORY EVALUATION

Sensory evaluation of cooked rice has been described by Batcher et al (1957) and reviewed by del Mundo (1979). Cooked nonwaxy rice is usually assessed within 1 hr after cooking, but a few laboratories also assess the cooled rice 6–24 hr after cooking (Juliano, 1982a). Waxy rice is presented as a rice cake cooked in coconut milk instead of as boiled rice (del Mundo, 1979) and is presented cold to the panel 10–12 hr after cooking. In the ICC Working Group 21/II survey, 26 laboratories employed mainly judges or panel members rather than consumers (Juliano, 1982a). Sensory evaluation was done by three to 24 judges or 30–100 or 200 consumers. The number of samples assessed at the same time ranged from 3 to 20. Early studies indicated that large consumer panels gave descriptions of the eating quality characteristics of boiled milled rice similar to those of a small taste panel of well-selected and trained judges (Oñate and del Mundo, 1966).

Cooked-rice characteristics frequently assessed were aroma, flavor or taste, tenderness or hardness, cohesiveness or stickiness, appearance, and whiteness or color (Juliano, 1982a). The number of points in the judging scale ranged from two to 11. A six-point scoring scale system is used for consumer tests (del Mundo, 1979). The ranking scores of Larmond (1977) are used in consumer tests, and the samples are presented in a randomized manner. Consumers are also asked to give

three reasons for choosing the best of up to five samples ranked in the order of decreasing importance based on the scoring system for six properties.

AROMA TEST

In addition to the routine taste panel evaluation for aroma as part of the assessment of cooked rice by several laboratories, separate aroma tests are performed in some laboratories. The evolution of aroma is facilitated by boiling the rice in water, except that 10 ml of 1.7% KOH added to 2 g of brown rice released aroma within 10 min (Sood and Siddiq, 1978). Boiling time ranges from 10 to 20 min, but one laboratory warms the rice to 40–45°C for only 5 min before scoring (Nagaraju et al., 1975). Descriptive scores are *absent, faint, normal, or strong* (IRRI, 1971) or involve comparison with a standard aromatic variety. A more objective test is definitely needed. Adding 1.7% KOH to rice is effective in volatilizing 2-acetyl-1-pyrroline, the major aroma component of rice (R. Butterly, personal communication).

INSTRON TESTER

The Instron tester consists of a mechanical drive system, a load cell for measuring forces generated either in compression or tension, and a recorder. The mechanical drive system is a horizontal crossbar (crosshead) driven vertically. Various cells have been used for measurement of hardness and stickiness of cooked rice with the Instron food tester (Blakeney, 1979b; Juliano et al., 1981a). Most of the methods for hardness are compression methods. Lisch and Launay (1975) used duplicate runs on four cooked grains compressed with a plunger at 0.5 cm/min and calculated hardness as the slope of the force-compression curve (in N/m) measured at a force of 0.7 N. Texture profile analysis (Bourne, 1978) can also be made on one, three, or five cooked grains, which gave better data than rice mold or pellets (IRRI, 1979a; Blakeney, 1979b). However, the method is complicated by varietal differences in grain thickness, since the plunger has to travel a fixed proportion (three fourths) of the thickness of the sample. A pellet has been tried using a 1-cm diameter cork borer to sample a rice sample manually compacted for 1 min in a Carver press mold. The rice pellet 1 cm thick (1 cm diameter) is then used instead of grains, with a cross head speed of 5 cm/min and a 5-kg load cell. This double-bite technique is only sensitive for hardness, which is the maximum force for the first compression or bite, but not sensitive for stickiness (Juliano et al., 1984). However, for a screening method, a constant compression clearance may be used, particularly if the varieties have similar grain thickness.

The Kramer shear cell (with 10 blades 2.9 mm thick or 13 blades 1.6 mm thick), utilizing 100 g of cooked rice and a crosshead speed of 9 or 10 cm/min, has been applied for hardness measurement, corresponding to maximum force for compression and extrusion (Blakeney, 1979b; Juliano et al., 1981a). A smaller Kramer shear cell with one half the dimensions of the 10-blade standard cell requires one eighth of the volume of the sample and will allow the use of 15 g of cooked rice. The texture curve can be resolved into two peaks, apparently representing sample compression and extrusion. As degree of cooking and overcooking increases, the compression component decreases more rapidly than the extrusion component (Blakeney, 1979b). Lisch and Launay (1975) also described a Kramer shear press method for cooked French rice.

The Ottawa texture measuring system (OTMS) uses a 50-cm² cell with 6-mm holes modified with four side liners to reduce the cell cross section to 15% of the original and is used with a 2.6 × 2.5 cm plunger. It measures hardness on 17 g of cooked rice instead of 100 g, giving values that are 15% of the values for the standard cell (Perez and Juliano, 1979). Samples are pressed with 145 g of weight for 1 min; the crosshead speed for extrusion is 10 cm/min. Recently the 10-cm² OTMS cell has been used with 17 g of cooked rice and gives hardness values per square centimeter of plunger surface similar to those of the smaller-area 2.6 × 2.5 cm plunger (Juliano et al., 1984; IRRI, unpublished data).

The Instron tester with a 50.9-mm diameter back extrusion cell with a 3.15-mm annulus gap has been used for measuring hardness of 50 g of cooked rice at a crosshead speed of 20 cm/min (Juliano et al., 1981a; Juliano, 1982a). Its standard back-extrusion cell and plunger with a 4-mm annular gap filled with 100 g of cooked rice could not differentiate between hard-gel IR8 and soft-gel IR32 (IRRI, unpublished data). Better results were obtained with a Carver press mold with a 10.5-mm annulus as the back extrusion cell, in which IR8 gave higher values than IR32. The crosshead speed is 10 cm/min; 100 g of cooked rice sample is pressed briefly with the 1.7-kg piston of the Carver press before the 36-mm diameter plunger is pressed down with a load cell of 5–50 kg. However, the sample requirement is greater than that of the OTMS cell method.

Stickiness measurements with the Instron usually involve measuring the work or maximum force required to lift the Instron plunger from pressed rice grains at an arbitrary pressure for a given length of time (Juliano et al., 1981a; Juliano, 1982a). Sample weights differ, being 2, 2.5, 4, or 150 g of cooked rice. The total pressure on the cooked rice sample and the time period are 500 g for 10 sec, 13.63 N while zeroing the chart pen, 640 g for 10 sec, and 4 kg for 20 sec; crosshead speeds used are 0.2, 0.5, 5, and 10 cm/min (Juliano et al., 1981a; Juliano, 1982a). A fixed compression pressure of 4 kg is preferred to a fixed compression clearance of 0.4 mm, since the latter overtaxed the 5-kg load cell and resulted in variable compression pressure among samples (Juliano, 1982a; IRRI, 1983a) (Table III). The method allows the use of 2.5 g of cooked rice with the 3.6-cm diameter plunger instead of 17 g with the 6.9 × 6.9-cm OTMS plunger. Stickiness is measured as the work in gram-centimeters required to lift the plunger, based on the work curve area by planimetry (Perez and Juliano, 1979; Juliano et al., 1981a; Mossman et al., 1983) (Fig. 5). Lisch and Launay (1975), however, consider adhesiveness to be the maximum force in Newtons required to lift the plunger instead of the total work.

TABLE III
Comparison of Stickiness Values of Cooked Rice by Constant Clearance and by Constant Pressure^a

| Cooked Sample | Amylose Type | Stickiness Value at | | | | |
|---------------|--------------|---------------------------------|-------------------------|--------------------------------|--------|-------------------------|
| | | Constant Clearance ^b | | Constant Pressure ^c | | |
| | | (g·cm) | (g·cm/cm ²) | (g) | (g·cm) | (g·cm/cm ²) |
| IR8 | High | 68 | 1.42 | 131 | 4.1 | 0.40 |
| IR32 | High | 108 | 2.25 | 344 | 10.0 | 0.98 |
| IR24 | Low | 150 | 3.12 | 554 | 15.6 | 1.53 |
| IR833-6-2 | Waxy | 505 | 10.5 | 542 | 31.8 | 3.12 |

^aSource: IRRI (1983a); used by permission.

^bClearance of 0.4 mm using a plunger 6.9-cm square (area 48.0 cm²).

^cConstant pressure of 4 kg using a plunger with a 3.6-cm diameter (area 10.2 cm²).

The above Instron stickiness tests are probably adaptations of the beam-balance method of Kurasawa et al (1962). With the left weight pan and the right metal pan of a triple-pan counterscale balanced, 10 cooked grains are arranged on a plywood board, and a smooth Bakelite plate is pressed below and connected to the right metal pan by putting a 500- or 800-g weight on the pan for 2 min. The weight is removed carefully and a beaker placed on the left weight pan. Water is added to the beaker through a buret until the Bakelite plate is detached from the rice grains. The weight of the beaker plus the water in grams is the stickiness value, and the mean of 10 measurements is reported (Villareal et al, 1976). Manohar Kumar et al (1976) used sand instead of water to determine adhesion values after pressing a plunger with a 38-mm diameter for 1 min with a 235-g weight after 10 g of cooked rice had been flattened for 4 min with a 1.5-kg metal weight. Waxy rice cake prepared with coconut milk may be assessed for stickiness by the beam balance method (Antonio et al, 1975).

The effect of water content, storage temperature, and storage time on cooked rice texture is demonstrated by Lisch and Launay (1975) (Table IV).

Kato (1979) employed compression and extension with an Instron-type empirical creep test instrument (Tensilon UTM-II) to study 1) load-deformation (compression) and relaxation curves (hysteresis curve) of individual boiled rice

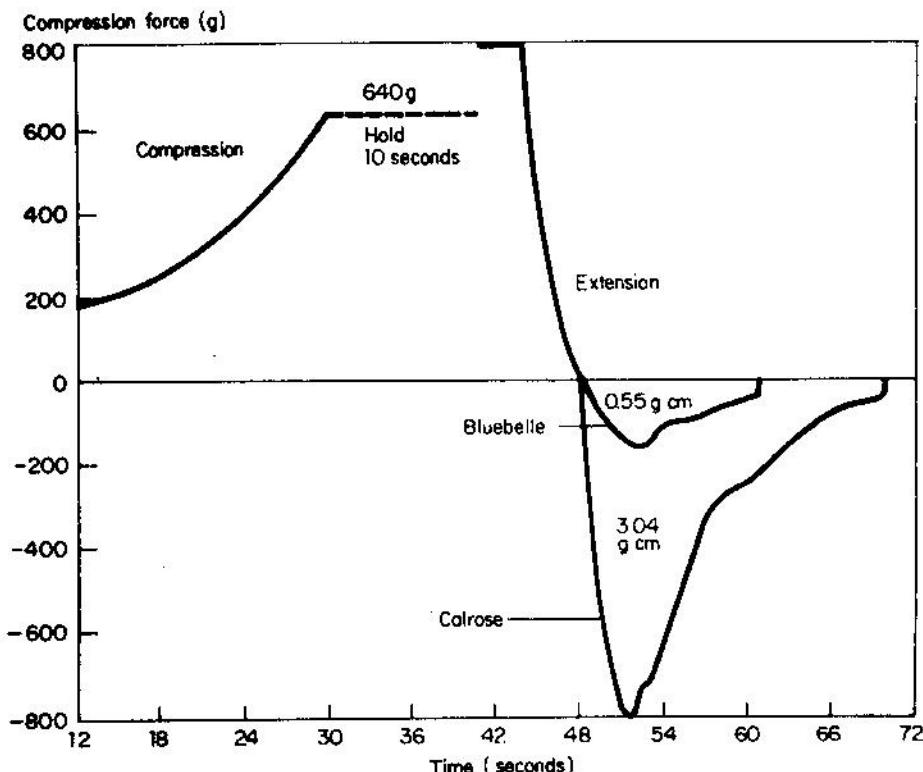


Fig. 5. Instron stickiness curve for low-amylose (Calrose) and intermediate-amylose (Bluebell) cooked rice. Stickiness is the area of the work required to lift the crosshead after pressing 10 sec with 640 g of pressure. (Reprinted, with permission, from Mossman et al, 1983)

grains compressed into an extended thin film at a constant compression load of 200 g at a crosshead speed of 4 mm/min and 2) a hysteresis curve of boiled rice molded into a truncated cone with a 40-mm upper diameter, 48-mm lower diameter, and 33-mm height at a constant compression load of 1.9 kg and a crosshead speed of 40 mm/min.

PABST TEXTURE TESTER

The Pabst texture tester TT-2 is an instrument for compression/shear force measurement and force distribution analysis of bite-sized food units (Juliano et al., 1981a; Juliano, 1982a). The tester has a Kramer-type shear cell of 2.54 cm diagonal distance with 16 shear planes of 0.16-cm nominal spacing. It determines hardness of 13 g of cooked rice, using a 13.6-kg load cell at a test stroke velocity of 0.6 cm/sec (Juliano et al., 1981a). Firmness is the maximum force in kilograms that is obtained in the compression-extrusion curve and that occurs before the onset of extrusion. The plunger travels about 37 mm, of which 23 mm is compression and 14 mm is extrusion; the test cycle time is 9 sec.

TEXTUROMETER

The General Foods-Zenken Texturometer is a denture tenderometer that simulates the motions of mastication by means of a mechanical chewing arrangement (Friedman et al., 1963; Suzuki, 1979b). It consists of a mechanical masticator, a sensing device placed under the platform supporting the food, a 1/16-hp motor driving the arm holding the plunger, and a high-speed recorder for the force-time curve that indicates the behavior of the test food under the disintegrating action of the plunger. The plunger is either Lucite or nickel and the lower plate is aluminum. The texture profile with a texturometer differs from that of the Instron tester because of the arch-shaped path of the plunger, which not only presses on the cooked rice but also produces a rubbing motion. By the use of a dual arm instead of the standard arm and an attenuator for hardness and an amplifier for adhesiveness, adhesiveness and adhesive power differences are amplified (Yoshikawa et al., 1974; Endo et al., 1980).

TABLE IV
Influence of Various Factors on Cooked Rice Texture Measured by Different Methods^a

| Factor and Value | Kramer Shear Press (J) | Extrusion Cell (kg) | Instron Hardness (N/min) | Instron Adhesiveness (N) |
|-------------------------|------------------------|---------------------|--------------------------|--------------------------|
| Water content, % | | | | |
| 65 | 1.23 | 6.40 | 4,030 | 1.21 |
| 75 | 0.30 | 1.41 | 2,070 | 2.73 |
| Storage temperature, °C | | | | |
| 4 | 1.22 | 6.06 | 4,100 | 0.51 |
| 20 | 0.66 | 3.46 | 2,800 | 2.48 |
| 37 | 0.43 | 2.61 | 2,300 | 2.92 |
| Storage time, wk | | | | |
| 3 | 0.73 | 1.57 | 2,900 | 2.34 |
| 5 | 0.81 | 2.03 | ... | 1.63 |
| 7 | 0.78 | 1.82 | 2,900 | 1.35 |
| 9 | 0.76 | 1.90 | 3,350 | 1.17 |

^aSource: Lisch and Launay (1975); used by permission.

From the curve of the first and second chew (Fig. 6), hardness (H) is the height of the first chew normalized to a 1-voltage input (Suzuki, 1979b). Adhesiveness is the area A_3 in arbitrary units, of the negative peak below the baseline of the profile after the first chew and represents the work necessary to pull the plunger from the sample. Adhesive power, or stickiness (Okabe, 1979), is the height of this negative peak. Cohesiveness is the ratio of the area, in arbitrary units, under the second peak (A_2) to the area under the first peak (A_1). Springiness or elasticity is the difference between the distance from the initial sample contact to the contact on the second chew and the distance for the same measurement made on a completely inelastic standard material such as clay. Gumminess is the product of hardness and cohesiveness, and chewiness is the product of gumminess and springiness, or hardness times cohesiveness times springiness.

Differences in clearance between the plunger and the aluminum plate, sample height, voltage, and bite speed are evident among laboratories (Juliano, 1982a). Samples are compressed to 25–10% of the original height (thickness) during the first chew, based on information on sample height and clearance (Juliano, 1982a). Clearances for individual grains range from 0.2 to 0.5 mm. Sample size ranges from one or three grains to 30–40 grains up to 20 g of cooked rice. Okabe (1979) demonstrated that a full-cup or bulk technique gives poor reproducibility because the upward displacement of rice grains by the plunger results in variation in the depth of the compressed layer of rice. Hence, he recommends using three

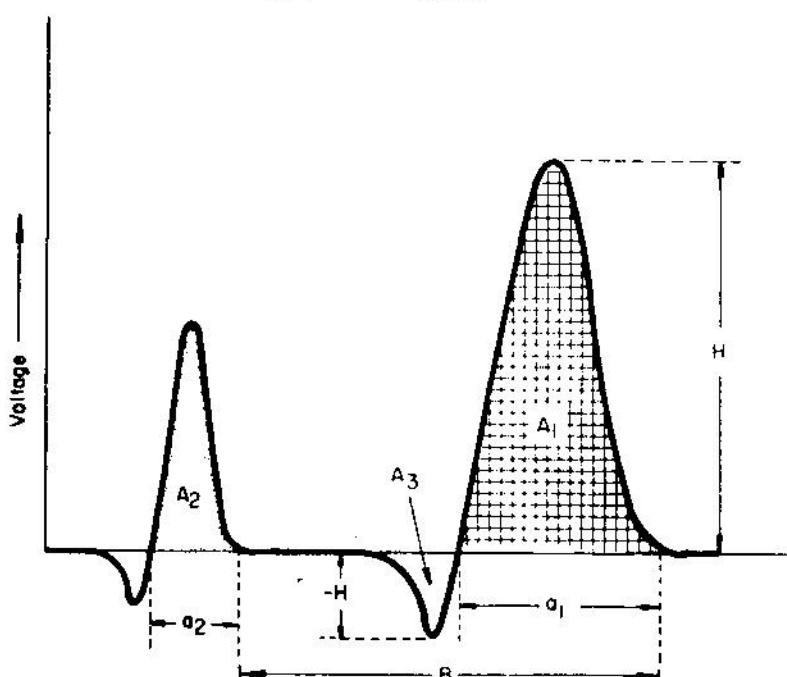


Fig. 6. Texture profile of cooked rice using a texturometer double bite technique. H = hardness, A_2/A_1 = cohesiveness, A_3 = adhesiveness, $-H$ = stickiness; $B_{\text{new}}/B_{\text{old}}$ = elasticity. Ebata and Hirasawa (1982) also define a_2/a_1 as springiness. Chart paper direction: right to left. (Reprinted, with permission, from Ebata and Hirasawa, 1982)

grains arranged in a row and reporting the mean of five determinations. Suzuki et al (1983) found 30–40 grains to be the optimum sample size for hardness and stickiness determinations.

Okabe (1979) measures cohesiveness separately from hardness and stickiness, covers the grains with a thin (0.02-mm) polyethylene film, and increases clearance from 0.2 mm to 0.7–0.8 mm. The test for cohesiveness only needs partially deformed grains (to allow for some sample recovery and minimize permanent deformation), and results are not adversely affected by degree of compression since it is a ratio (A_2/A_1). The polyethylene film prevents contact of rice with the plunger surface, which would otherwise pull the rice grains up in its upward motion and change the shape of the second peak.

Okabe (1979) recommends one chewing cycle for cooked nonwaxy rice in the texturometer but four chewing cycles with cooked waxy rice. Although waxy and nonwaxy rices progressively decrease in cooked rice hardness on successive chews, waxy rice becomes progressively stickier, whereas nonwaxy rice becomes progressively less sticky.

The texturometer has replaced the parallel plate plastometer in texture measurement of cooked rice in Japan. The plastometer, with temperature regulation at 35°C, measures the deformation of a cooked-rice sample between horizontal plates under load and the recovery when the weight is removed (Chikubu et al, 1964). Viscosity and elasticity of cooked rice are calculated, but the instrument requires much skill and has poor reproducibility (Juliano, 1982a). Texturometer adhesiveness values are significantly correlated negatively with apparent viscosity and positively with elasticity of cooked rice, as measured by the parallel plate plastometer (Endo et al, 1976). The ratio of texturometer hardness to adhesiveness value is significantly correlated with plastometer values for apparent viscosity (positively) and elasticity of cooked rice (negatively).

TENSIPRESSER

The Tensipresser TPP-50 is a tension-compression testing device wherein 10 grains per replicate of cooked rice are measured individually at 50 and 90% compression (Juliano et al, 1981a; Tsuji, 1981). It has a sensitive sensor, an integrator, a differentiator, a data processing system, and a monitor scope. The thickness of each individual grain is measured, and the travel distance of the 25-mm diameter plunger needle is adjusted for each test sample to give the desired compression depth (50 and 90%) at a speed of 240 mm/min. Care is needed so that the plunger fully contacts the outer surface of the grain. Because rice grains do not have a flat surface, the area of contact with the plunger increases as the compression (or biting) progresses. Texture profile analyses for hardness, cohesiveness, adhesiveness, and springiness follow those of the texturometer (Friedman et al, 1963), determined using two cycles or bites per measurement at 50 and 90% compression. With an increase in compression between 30 and 80%, hardness increased only slightly but adhesiveness increased sharply and cohesiveness decreased sharply (Fig. 7). Hence, the two-point measurement (two compression ratios) gives a better picture of texture than the usual one-point measurement (compression ratio) used for the texturometer. Although Tsuji (1981) says that the tensipresser showed the highest percentage of variation due to sample in the 1979 cooperative study on instrument methods for rice texture, the raw data he submitted were already the means of 10 individual

cooked grains rather than the individual values for the grains (Juliano et al., 1981a). Thus, variation between determinations within replications was reduced to zero and tended to make the method seem comparatively better than did the data submitted by others for individual grains using other instruments.

VISCOELASTOGRAPH

The Chopin-INRA Viscoelastograph is used for evaluating the viscoelastic properties of food products (Laignelet and Feillet, 1979). Three cooked rice grains are placed on the sample-holder, and the viscoelastogram records the thickness of grains with a load of 700 g for 40 sec, followed by a recovery time (with the load removed) of 20 sec. From the strain-time curve showing the change in thickness of the sample relative to the time during and after loading (Fig. 8), firmness (F) and elastic recovery (ER) are calculated as follows:

$$F = 100 \times (e_1/E)$$

$$ER = 100 (e_2 - e_1)/(E - e_1)$$

where E is initial thickness, e_1 is thickness before loading off, and e_2 is final thickness, all in millimeters. Samples are rice grains cooked to optimum cooking time and to optimum cooking time plus 10 min.

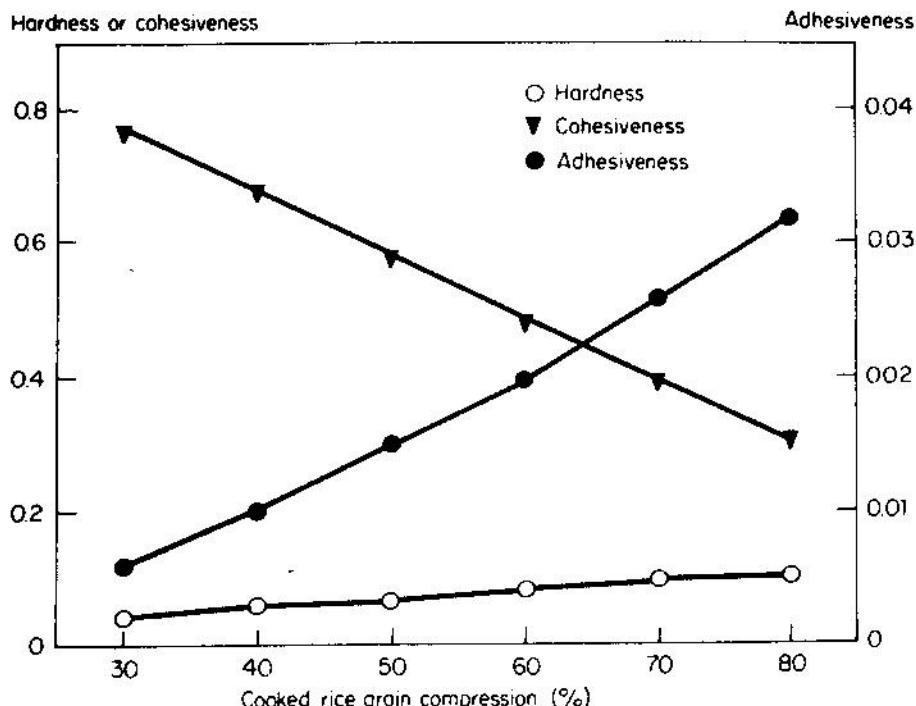


Fig. 7. Relationships between degree of compression of cooked waxy rice grain and its hardness, cohesiveness, and adhesiveness. (Reprinted, with permission, from Tsuji, 1981)

HAAKE CONSISTOMETER

The Haake consistometer is a tester for viscosity and hardness measurements on highly viscous materials. For cooked rice, the perforated plunger and measuring body VIIc originally used by Hampel (1968) are employed (Manohar Kumar et al, 1976; Deshpande and Bhattacharya, 1982) in a room with constant temperature. Three to five cylinders are prepared for each sample with 20 g of cooked rice each and are kept in a water bath (at room temperature) until use. After one cylinder has been fixed in the instrument, the plunger is made to penetrate into the rice mass until the dial gauge records a reading of 5 mm; the apparatus is stopped at this stage for 1 min for equilibration. The requisite weight or load (1–10 kg, usually 5 kg) is then loaded onto the level arm and the instrument is released. The time taken for the plunger to travel from the 10-mm to the 15-mm, the 20-mm, and the 25-mm marks on the gauge is recorded, and the average time taken for the plunger to travel a distance of 5 mm between the 10-mm and 20-mm marks is calculated. All the cylinders prepared at a time are read consecutively without washing the plunger. Consistency (apparent viscosity) of the cooked rice is calculated from the formula:

$$\text{Consistency (cp)} = \frac{G T K \times 100}{S}$$

$$= 0.4 G T K \times 10^5$$

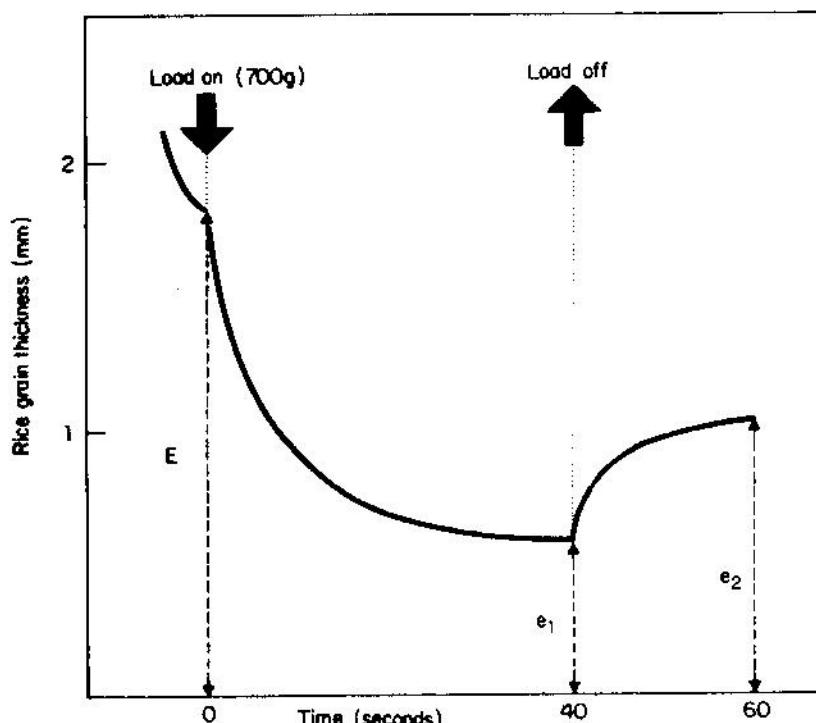


Fig. 8. Typical viscoelastograph strain-time curve of three grains of cooked French rice. E = initial thickness, e_1 = thickness before loading off, e_2 = final thickness. (Reprinted, with permission, from Laignelet and Feillet, 1979)

where G = load (5 kg), T = time of penetration (sec), S = distance of penetration (5 mm), and K = plunger constant.

Because of the pseudoplastic nature of cooked rice, an increase in shear stress or load between 1 and 9 kg results in a decrease in consistency values, so consistency by the Haake consistometer should be measured at a constant load among samples (Deshpande and Bhattacharya, 1982).

OTHERS

Sieve test for stickiness. The wire sieves in the initial procedure (Manohar Kumar et al, 1976) are not suitable, because of the sticking of rice particles, and are replaced by brass 16-gauge plates that have round perforations 8.00 and 7.25 mm in diameter and that are cut to fit into Bühler sieve frames 27.9 cm in diameter (Deshpande and Bhattacharya, 1982) after moderate buffing. Two sets of sieves are made, and a pair is used for one test together with a collecting plate. Two such pairs are mounted in a laboratory Bühler sifter, type MI.U-300, and used simultaneously. Duplicate cooked rice samples (25 g) are weighed into the center of the top (8 mm) sieve, and sieving is done for exactly 2 min at 180 rpm. The grains retained on each sieve are then carefully collected and weighed, and the index of stickiness is expressed as percent by weight of rice retained by each of the two sieves. Values of both sieves are used because, although the top (8-mm) sieve gives better differentiation among sticky samples, the bottom (7.25-mm) sieve seems to differentiate better among the less sticky rices (Deshpande and Bhattacharya, 1982). Stickiness value is not greatly affected by cooking in water-to-rice ratios of 1.5, 2.0, and 2.5, but it decreases after 24 hr, slightly at room temperature and markedly at 4°C (Deshpande and Bhattacharya, 1982).

Extrusion test. An improvised extruder is used to measure the palatability of cooked milled rices (Mohandoos and Pillaiyar, 1980). Triplicate cooked rice samples (15 g) are placed in an extruder consisting of a 5-mm diameter hollow cylinder of anodized aluminum with a movable plunger and a detachable perforated bottom disk having 36 equally distributed holes of 1-mm diameter. A lever attached to the movable arm with a loaded weight of 5 kg is placed on the plunger, which extrudes the rice for exactly 5 min. The material that is extruded is collected in a Petri dish below the extruder, weighed, and expressed as grams per gram of cooked rice. All sides of the base in which the Petri dish rests are provided with glass doors. Cooked unparboiled rice and cooked rice previously parboiled at 70 and 80°C are more or less entirely extruded within 5 min, but cooked severely parboiled rices are not.

Penetrometer. The softness of cooked waxy rice cakes cooked in coconut milk may be estimated by an improvised penetrometer such as a cork borer sharpener weighing 206 g and having an angle of 22.5° (Antonio et al, 1975). The pointed end of the sharpener is held freely on top of the cake for 15 sec, and the surface diameter of the resulting hole is measured to the nearest 0.1 mm with a vernier caliper. The sharpener is calibrated for diameter-depth relationship, and the diameter is therefore converted to depth of penetration as an index of cake softness.

CORRELATION AMONG TEXTURE METHODS

The textures of 10 milled rices cooked to optimum cooking in excess water were measured by taste panel, Instron with back extrusion, Kramer shear,

OTMS and plunger cells, tensipresser, Pabst Texture Tester, texturometer and viscoelastograph. They showed significantly correlated values for hardness, stickiness, and cohesiveness indexes of cooked rice (Juliano et al, 1981a). Instrument indexes were generally more sensitive than the corresponding taste panel scores in discriminating among the 10 cooked rice samples. Most hardness indexes showed significant negative correlation with stickiness indexes. Most hardness indexes are positively correlated with amylose content, whereas stickiness indexes are negatively correlated with amylose content. Lisch and Launay (1975) also found significant correlation between Kramer shear press and extrusion hardnesses ($r=0.92^{**}, n=24$) and Kramer shear press and Instron hardnesses ($r=0.95^{**}, n=18$). Moritaka et al (1971b) reported that adhesiveness and the hardness-adhesiveness ratio in the texturometer correlated significantly with sensory scores for cohesiveness and hardness.

C. Indirect Methods of Quality Determination

Indirect methods refer to indexes of cooking and eating quality for which the sample is not cooked in the usual manner. In the 1981 survey of rice laboratories by the ICC Working Group 21/II (Juliano, 1982a), 30 of the 41 respondents determined amylose content, 27 determined alkali spreading value, and 17 screened for gel consistency. Laboratories employing gel consistency involved high-amylose rices in their program. Amylography of rice flours was reported by 15 respondents, and 10 respondents ran protein analyses.

Tests specific for waxy rices (Kongseree, 1979b) and parboiled rices (Bhattacharya, 1979c) have recently been published.

AMYLOSE CONTENT

The iodine colorimetric technique for measurement of the amylose content of milled rice flour consists of dispersing the flour (100 mg) in 9 ml of 1*N* NaOH overnight at room temperature or for 10 min in a boiling water bath, followed by iodine colorimetry (Juliano, 1979b). Some of the factors affecting the amylose assay are degree of milling (lipid content) of the sample, purity of the amylose and amylopectin standards, pH of the rice-iodine solution, and wavelength used for colorimetry (Juliano, 1979b). However, considerable variation among laboratories was noted in two international ring tests for amylose content of milled rice, in which the same method and set of milled rice flour and amylose standards were employed (Juliano, 1971b; Juliano et al, 1981b). Recently, Morrison and Laignelet (1983) developed an improved method for measuring amylose in starch using a 6*M* urea-dimethyl sulfoxide (1:9, v/v) dispersion for 60–90 min at 100° C. The iodine concentration is 4 mg/100 ml and the potassium iodine 40 mg/100 ml, as in the method of Williams et al (1958), but the starch concentration is lower in the new method. Rice starch is most difficult to disperse, and milled rice would be worse since the protein and cell walls would be insoluble in urea-dimethyl sulfoxide.

In 1958, Williams et al reported a method of amylose assay based on cold gelatinization of partially defatted milled rice flour in 1*N* NaOH (1–2 days at 40° C), adjustment of the pH to 10 with hydrochloric acid using a pH meter, and iodine colorimetry. Although the method minimizes but does not eliminate amylopectin-iodine complex interference, reproducibility is difficult because the

pH meter readily clogs and the resultant incompletely neutralized alkaline solution produces an unstable starch-iodine blue color. Iodine is unstable in alkaline pH.

Although phenolphthalein indicator reduces the problem of alkaline pH (Sowbhagya and Bhattacharya, 1971), the current method in use is based on the simplified amylose assay; a constant amount of acetic acid is added to the alkaline starch dispersion to obtain an equimolar mixture of 0.0045*N* sodium acetate and 0.0055*N* acetic acid with pH 4.5–4.8 (Juliano, 1971b). The color development is very reproducible, but the color obtained is greenish rather than blue.

Flours milled to pass a 40- to 60-mesh screen can be adequately dispersed in the alkali. The Wig-L-Bug amalgamator may also be employed on 10-grain samples ground for 40 sec, since the unit almost completely damages the starch granules, which are more readily dispersed in alkali than undamaged granules. A sample of 20 grains of milled rice is optimum for amylose determination based on reduction of sampling variation (Paule et al., 1979). Within the range of 10–500 mg, 100 mg or more should be used for amylose determination for reduced sampling variation. Bulk sample is preferable to grains from an individual panicle because of the large variation in amylose content among panicles within a hill (1.8–3.4% vs. 3.1–7.4% coefficient of variation). Amylose content may vary by as much as six percentage points within a variety (Juliano et al., 1964a; Juliano and Pascual, 1980).

Among substances that interfere with amylose assay are the amylopectin-iodine complex and lipids, specifically fatty acids, since the lipid is essentially saponified in the NaOH solution. Nonstarch lipids are readily extracted with refluxing 95% ethanol or cold water-saturated butanol, but these only extract 80% of starch lipids (Choudhury and Juliano, 1980; Russell and Juliano, 1983). Morrison and Laignelet (1983) reported that 95% ethanol was not a satisfactory solvent for defatting cereal starch and recommend either the more toxic 85% methanol or water-saturated butanol. Defatting with aqueous alcohols at 100°C was satisfactory (Morrison and Coventry, 1985).

At acid pH, interference from the amylopectin-iodine complex is greater than at alkaline pH, but the reverse is true for lipid interference (Perez and Juliano, 1978) (Table V). When milled rices of known amylose content are used for the standard curve, interference from amylopectin is already taken care of (Juliano

TABLE V
Effect of Defatting and pH on the Amylose Value of Four Milled and Brown Rice Flours*

| Treatment | Apparent Amylose Content (% db) | | | | | | | |
|--------------------------|---------------------------------|------|------------|------|-------------|------|------------|------|
| | pH 4.5 | | | | pH 10.2 | | | |
| | Milled Rice | | Brown Rice | | Milled Rice | | Brown Rice | |
| | Range | Mean | Range | Mean | Range | Mean | Range | Mean |
| Undefatted | 10.8–28.7 | 19.5 | 9.2–23.6 | 15.9 | 6.1–19.7 | 12.2 | 4.9–12.8 | 8.9 |
| Reflux petroleum ether | ... | ... | 10.3–26.9 | 18.0 | 7.2–26.4 | 16.1 | 6.9–21.4 | 13.9 |
| Cold 95% ethanol, 18 hr | 12.1–29.2 | 20.3 | 11.6–27.7 | 19.0 | 8.8–28.8 | 17.9 | 8.6–24.5 | 16.0 |
| Reflux 95% ethanol | 12.4–30.0 | 21.2 | 12.8–28.8 | 20.0 | 11.7–31.8 | 21.4 | 11.8–28.5 | 19.6 |
| Cold 2.5% butanol, 18 hr | 13.6–30.2 | 21.5 | ... | ... | 14.7–31.7 | 22.6 | ... | ... |

*Source: Perez and Juliano (1978); used by permission.

et al., 1981b). The amylose content of the defatted milled rice standards can also be determined in pH 4.5–4.8 0.0045*N* sodium acetate buffer if amylopectin is also added to the amylose standard (Juliano et al., 1981b). The use of 0.0072*M* phosphate buffer (pH 8) produces a blue color, but a higher electrolyte level such as that from 0.0255*M* phosphate buffer (pH 8) results in starch-iodine precipitation (Juliano et al., 1981b). The 0.0075*N* bicarbonate-0.0045*M* carbonate buffer (pH 10) (Perez and Juliano, 1978) eliminates amylopectin interference, as does glycine (pH 10) buffer (Juliano, 1971b), but iodine color tends to be unstable at pH 10.

Perez and Juliano (1978) proposed a constant factor of 2.0 percentage points to convert apparent amylose content to absolute amylose content based on methanol defatting (Table V). By contrast, Sowbhagya and Bhattacharya (1971) recommended a constant multiplication factor of 1.15 to convert apparent amylose to the absolute amylose content of milled rice. Bolling and El Bayâ (1975) proposed a factor of 1.25, based on the fact that the amylose content of 22 milled rice samples increased 21.2–26.5% (25% mean increase) after being defatted with hot water-saturated butanol. Petroleum ether defatting increased amylose content only –0.1–2.4 percentage points (mean, 1.1%), and water-saturated butanol further increased amylose content 3.0–5.5 percentage points (mean, 4.2%), for a total of 3.0–7.4 percentage points (mean, 5.3%) (Bolling and El Bayâ, 1975). Morrison and Laignelet (1983) found amylose content to be 5.9 and 6.7 percentage points higher after defatting two rice starch samples.

When NaOH is used as the solvent, all lipids are converted to soap and to free acids on acidification. By contrast, 6*M* urea-dimethyl sulfoxide (1:9, v/v) maintains the integrity of lipids, particularly lysophospholipids. Morrison and Laignelet (1983) observed that lysophospholipids complex with amylose differently than free fatty acids do by complexing incompletely with all available amylose molecules, leaving short amylose segments that form iodine complexes with a lower λ_{max} . By contrast, free fatty acids tend to complex completely with some of the available amylose molecules, leaving the rest unaffected, so that absorbance decreases with only a small shift in λ_{max} . In milled rice flours, oleic acid (1% of rice) depressed apparent amylose content of nonwaxy rice more than did lysolecithin, and the effect was less on undefatted (3.1 vs 0.5%) than on methanol-defatted (1.2 vs. 0.4%) flour (IRRI, unpublished data).

Further comparison of refluxing 85% methanol, 95% ethanol, and water-saturated-butanol for defatting milled rice confirmed that higher amylose values are obtained with water-saturated butanol than with 85% methanol and 95% ethanol (IRRI, 1984) (Table VI). Water-saturated butanol on reflux gelatinizes rice starch granules, which may explain its effectiveness in extracting starch-complexed lipids. The correction seems to follow the level of starch lipids discussed in Chapter 3, which tend to be highest for intermediate-amylase rice IR480-5-9 (Table VI). Thus, data for apparent amylose content of undefatted nonwaxy rices may be converted to true amylose content by adding 2% amylose to the raw data. The factor is satisfactory for high-amylase rice, slightly overrates low-amylase rice, but slightly underrates intermediate-amylase rice. The factor of 2% corrects for amylose content in a waxy starch standard and the interference of residual starch lipids on amylose-iodine complexing.

When this assay is used as a screening method, in which milled rice samples are not defatted, it is imperative that the degree of milling be kept constant so that

lipid interference is minimized. For example, milled rice from a test tube miller, which results in undermilled rice, has one percentage point lower amylose content than samples milled with a McGill mill No. 3 (Paule et al, 1979). Defatting of many ground samples together in Soxhlet extractors would be ideally preferred but requires additional effort. An alternative step is to use, as check samples for calibrating a standard curve, undefatted milled rices of which the amylose content has been previously determined at pH 10.2 by the method of Williams et al (1958) after defatting (Perez and Juliano, 1978). Defatting of the alkaline starch dispersion with carbon tetrachloride is also effective (Sowbhagya and Bhattacharya, 1979) but again entails an extra step with a toxic solvent and requires more operator time than the simultaneous defatting of many ground samples in Soxhlet extractors (Juliano et al, 1981b).

The purity of the amylose standard is also a source of variation in amylose values. Recrystallized amylose is extremely expensive. Magnesium-sulfate precipitated potato amylose (Avebe amylose V) is an inexpensive pure standard, but it is no longer manufactured by Avebe (Veendam, Holland).

Waxy rices require a lower iodine ratio to obtain true amylose values (Lee et al, 1976; IRRI, 1983a). When the iodine in the solution was reduced to one seventh of the level in the standard procedure, the iodine preferentially complexed with amylose rather than with amylopectin and resulted in values of 0.4–0.9% amylose, as compared to the 1.5–2.5% amylose found by the standard AutoAnalyzer method (IRRI, 1983a).

STARCH GT

Gelatinization temperature (GT) of raw starch granules is an important property of raw rice grain, as reviewed in Chapter 3. GT relates to many properties of the raw grain and is indexed in the rice breeding program by the alkali digestibility test of Little et al (1958). The method involves incubating six grains of milled rice in 10 ml of 1.7% KOH at room temperature or at 30°C for 23 hr and measuring the degree of spreading using a seven-point scale as follows: 1, grain not affected; 2, grain swollen; 3, grain swollen, collar incomplete and narrow; 4, grain swollen, collar complete and wide; 5, grain split or segmented, collar complete and wide; 6, grain dispersed, merging with collar; and 7, grain

TABLE VI
Comparison of Amylose Values of Undefatted Milled Rice Flours and
Flours Defatted with Various Alcohols^a

| Sample | Undefatted | Amylose Content (% db) | | | Water-Saturated Butanol |
|---------------|-------------------------|------------------------|--------------|------|-------------------------|
| | | 95% Ethanol | 85% Methanol | | |
| IR29 | 0.3 (0.3) ^b | 0 | 0.1 | 0.2 | |
| IR3351-38-3-1 | 10.3 (12.3) | 11.6 | 11.8 | 11.7 | |
| IR480-5-9 | 19.4 (21.4) | 21.0 | 21.0 | 21.7 | |
| IR8 | 23.2 (25.2) | 23.6 | 24.4 | 25.2 | |
| Mean | 17.6 (19.6) | 18.7 | 19.1 | 19.5 | |

^aSource: IRRI (1984); used by permission.

^bValue corrected by adding 2.0% to nonwaxy rice amylose values.

completely dispersed and intermingled. Alkali spreading values correspond to GT as follows: 1–2, high ($74.5\text{--}80^\circ\text{C}$); 3, high-intermediate; 4–5, intermediate ($70\text{--}74^\circ\text{C}$); and 6–7, low ($<70^\circ\text{C}$). GT cannot be determined on parboiled rice. Representative alkali reactions of milled rice are shown in Fig. 9 (IRRI, 1964).

Methods for estimating starch GT have been reviewed by Bhattacharya (1979b): starch granule alteration, increase in viscosity, increase in light transmittance, swelling or water uptake of rice grain, and end point or fixed input. Actual GT determinations involve determination of birefringence endpoint temperature (BEPT) with a polarizing microscope with hot stage (Schoch and Maywald, 1956), photometric clearing of a turbid flour suspension (Ignacio and Juliano, 1968), or amylograph 20% paste viscosity increase (Halick et al, 1960). BEPT is the temperature at which 90–98% of the granules lose their birefringence (gelatinize) under polarized light. Photometric clearing uses a 0.5% suspension of milled rice or rice starch in water and a modified 18-mm tube adapter to the colorimeter to allow heating and mixing with a magnetic stirring bar. The temperature corresponding to an increase in transparency (% T) of 5 percentage points over the original value at 525 nm is considered the final GT (Ignacio and Juliano, 1968). Amylograph GT is the temperature of initial increase in viscosity of a 20% paste, wet basis (Halick et al, 1960). In practice, it is simpler to use the intercept of the 20-BU line as the GT (Juliano et al, 1985).

Three fixed input methods that apply heat in water are available. Determination of heat alteration values at 62°C (Little and Hilder, 1960a) involves microscopic examination of blended rice flour heated for 30 min at 62°C under phase contrast illumination and scoring of degree of gelatinization. Low-GT samples show a higher score. The method may be used as a screening method for GT in the absence of a polarizing microscope with hot stage. Similar results, in differences in behavior of the sediment and in alteration of starch granules, were obtained from treatment of rice flour with a Millon reagent containing trichloroacetic acid and mercuric acetate (Little and Hilder, 1960b). Water uptake at 77 and 82°C may also be used to screen for starch GT. The soluble amylose ratio (Bhattacharya et al, 1972) of rice flour values at 65 and

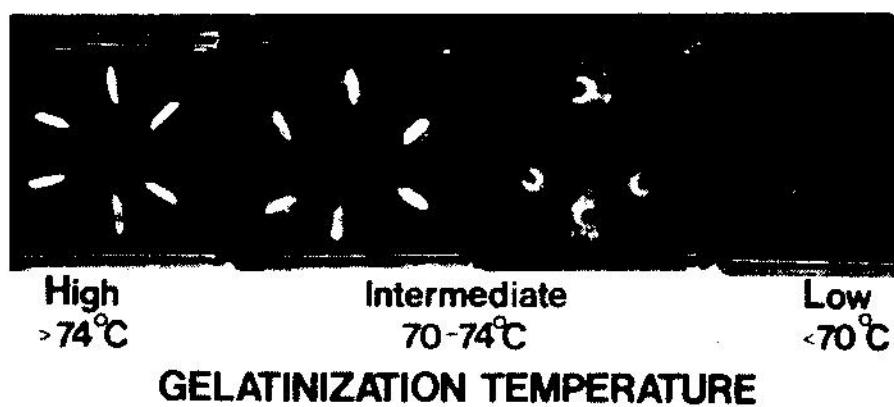


Fig. 9. Results of alkali digestibility test of Little et al (1958) on milled rices differing in starch gelatinization temperature. (Reprinted, with permission, from IRRI, 1964)

96°C correlates well with the alkali score ($r = 0.92^{**}$, $n = 40$) and inversely with GT.

Fixed end-point methods that apply alkali for GT estimation include alkali viscometry (Suzuki and Juliano, 1975; Suzuki, 1979b), light-scattering alkali-amylography (Murayama and Suzuki, 1965), and a modified alkali test (Bhattacharya and Sowbhagya, 1972b). Alkali viscometry has been applied mainly to rice starch because of the interference of rice protein in the viscosity (see Chapter 3). Gelatinization normality corresponding to viscosity 22.5 cp is related to starch GT (Suzuki and Juliano, 1975). In the light-scattering test, the intensity of scattered light given by 10 ml of a 0.2–0.5% starch suspension to which increments of 0.1 ml of 3*N* KOH are added is determined in the light-scattering alkali-amylograph. S-shaped curves are obtained, and alkali normality corresponding to a given light-scattering value is an index of GT of the samples. In the modified alkali test, the minimum alkali normality needed to completely gelatinize the grain (to give a score of 7) is determined by using 0.1*N* increments of alkali (Bhattacharya and Sowbhagya, 1972b). Each variety is attacked only by a certain concentration of alkali and then completely gelatinized by an increment of 0.10–0.13*N* alkali. This minimum alkali normality required for gelatinization is directly proportional to GT (Bhattacharya, 1979b).

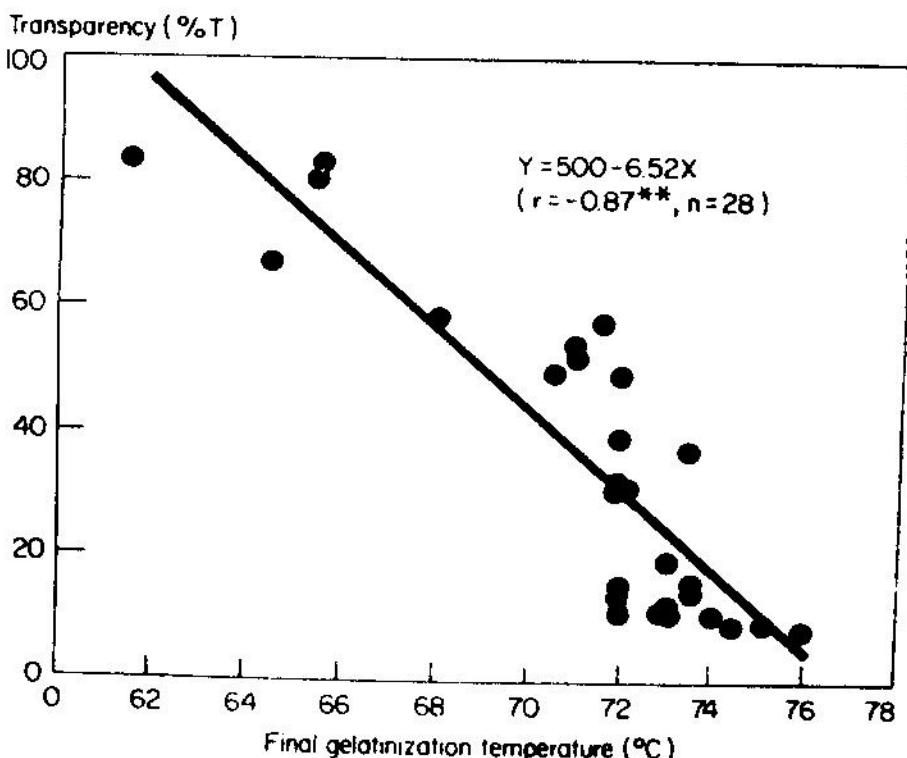


Fig. 10. Relationship between starch gelatinization temperature and transparency at 620 nm of 0.5% milled rice flour in 1.6% KOH after 24 hr at 30°C. (Reprinted, with permission, from IRR1, 1978)

Fixed input methods that apply alkali for GT estimation are alkali photometry (Ebata, 1968; IRRI, 1978), the soluble amylose ratio in alkali (Priestley and Birch, 1973), and the alkali test (Little et al, 1958). Alkali photometry is a modification of the whole-grain method. Chemists at IRRI (1978) used an adaptation of the method of Ebata (1968) to screen defatted brown rice flour that had been analyzed for amylose content for GT. Flour (50 mg) is soaked in 10 ml of 1.6% KOH for 24 hr at 30°C. Percentage transmittance of the slurry is then measured at 620 nm with a probe colorimeter with a 8-mm light path. The high-GT samples gave <10% T; the intermediate-GT samples gave 21–50% T; and the low-GT group gave >60% T (Fig. 10). Priestley and Birch (1973) found that the ratio of amylose contents extracted from 200-mesh rice flour by 0.4N and 1.0N KOH correlated well with alkali score ($r = 0.98^{**}$, $n = 14$).

Modifications of the alkali test of Little et al (1958) have been proposed, notably that of Bhattacharya and Sowbhagya (1972b), which uses a nine-point scoring system and 20 ml of 1.4% KOH in a 7-cm diameter Petri dish. In addition, they proposed the use of alkali degradation patterns: type A is characterized by progressive cracking and corrosion; type B by progressive grilling and cottony transformation; type B₁ by whole and uncracked grain with increasing hairy growth and step-by-step cottony transformation; type C by opening and splitting with gradual dense cottony transformation; and type D (waxy) by a more exaggerated type of C reaction but in which the collar is negligible and transparent from the very beginning, when exposed to successively higher concentrations of KOH (Bhattacharya, 1979b; Bhattacharya and Sowbhagya, 1980).

In an international cooperative test of the alkali digestibility values for five milled rices, using 1.1, 1.4, and 1.7% KOH in 11 laboratories, comparable results were obtained by the scoring methods of Little et al (1958) and Bhattacharya and Sowbhagya (1972b) (Juliano et al, 1982). The 1.7% KOH gave better varietal differentiation of starch GT by both methods than did 1.1 and 1.4% alkali (Fig. 11). Use of different alkali concentrations mainly affected the scores of the three samples with intermediate-alkali reaction. Major sources of variation are variety, alkali concentration, and scoring method. Cooperators, however, had difficulty assigning Bhattacharya's pattern types to the five samples. These observations may explain why 26 out of 27 respondents to the ICC Study Group 21/II 1981 survey used mainly the original method of Little et al (1958) for the alkali test (Juliano, 1982a).

The 1.7% alkali concentration is useful only if all GT types are present in the breeding program or for initial screening (Juliano et al, 1982). A lower KOH concentration of 1.4 or 1.15% can further differentiate among low-GT types, and a higher alkali concentration of 1.85% can verify the classification of rices into intermediate-GT and high-GT types (Manigat and Juliano, 1978) (Table VII).

The alkali test cannot be run by the usual manner on parboiled rice because its starch is already gelatinized. A modified test for determining degree of parboiling uses 1.0% KOH and a soaking time of 1 hr (Ali and Bhattacharya, 1972) and is applicable even to low-GT rices such as IR22 (IRRI, 1974).

GEL CONSISTENCY

Gel consistency was originally developed in 1972 to differentiate among high-amylose rices with contrasting amylograph pasting viscosities (Cagampang et al, 1973). The method and measurement of gel viscosity have been reviewed by

Perez (1979). The method consists of dispersing 100 mg of milled rice flour wetted with 0.2 ml of 95% ethanol containing 0.025% (w/v) bromthymol blue in 11 × 100-mm culture tubes in 2.00 ml of 0.2N KOH, using a vortex mixer. The tubes are covered with glass marbles and placed for 8 min in a vigorously boiling water bath, making sure that the tube contents reach up to two-thirds the height of the tube. The tubes are removed from the water bath for 5 min, mixed again with a vortex mixer, and cooled in an ice-water bath for 20 min. The cooled tubes are laid horizontally over ruled graph paper, and gel length is measured after 1 hr.

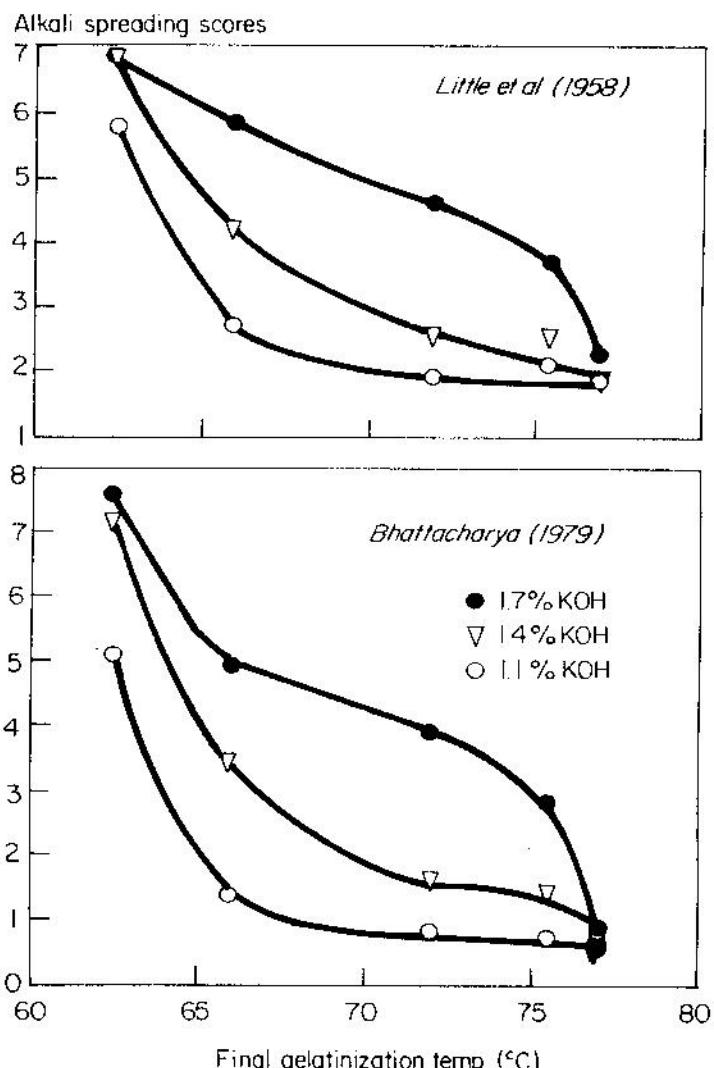


Fig. 11. Relationship between starch gelatinization temperature and alkali spreading value in 1.1, 1.4, and 1.7% KOH by the scoring systems of Little et al (1958) and Bhattacharya (1979b). (Reprinted, with permission, from Juliano et al, 1982)

The minimum possible height of the gel from the bottom of the tube is 25 ± 1 mm. The gel consistency values may be classified as soft (61–100 mm), medium (41–60 mm), or hard (26–40 mm). Standard check samples representing the three gel types are run with experimental samples. Typical gel consistency ratings are shown in Fig. 12 (Cagampang et al., 1973).

Gel consistency is a good measure of gel viscosity of milled rice obtained with a Wells-Brookfield cone plate microviscometer ($r = 0.69^{**}$, $n = 61$). Rices with an

TABLE VII
Alkali Spreading Values of Representative Rices Differing in
Gelatinization Temperature at Four Potassium Hydroxide (KOH) Levels^a

| Variety or Line | Alkali Spreading Value | | | |
|-------------------|------------------------|----------|----------|-----------|
| | 1.15% KOH | 1.4% KOH | 1.7% KOH | 1.85% KOH |
| Century Patna 231 | 2.0 | 2.0 | 2.0 | 4.6 |
| IR2071-137-5-1 | 2.0 | 2.0 | 3.0 | 3.0 |
| IRS | 2.0 | 2.0 | 3.2 | 5.0 |
| IR20 | 2.0 | 2.0 | 5.8 | 7.0 |
| Tongil | 2.5 | 5.5 | 7.0 | 7.0 |
| Jinheung | 5.0 | 6.0 | 7.0 | 7.0 |
| IR8 | 6.0 | 7.0 | 7.0 | 7.0 |
| LSD (5%) | 0.71 | 0.86 | 0.69 | 0.49 |

^aSource: Maningat and Juliano (1978); used by permission



Fig. 12. Typical gel consistency values of milled rices. Groups, left to right: hard, medium, and medium or soft gel consistency. (Reprinted, with permission, from Cagampang et al., 1973)

amylograph consistency of over 600 BU are of hard-medium gel consistency (Cagampang et al., 1973). Linear correlation coefficients with amylograph setback are 0.44** ($n = 41$) for high-amyloses rices and 0.64** ($n = 88$) for low- and intermediate-amylose rices; coefficients with amylograph consistency are -0.70** ($n = 29$) for high-amylose rices and -0.76** ($n = 88$) for intermediate- and low-amylose milled rices (Perez, 1979).

Factors affecting gel consistency values have been reviewed (Perez, 1979). A major factor is fat (lipid) content of the rice sample. All brown rices give hard gel consistency and all brown rices defatted with refluxing 95% ethanol have soft gel consistency (Perez, 1979). Thus, degree of milling is an important factor affecting gel consistency, mainly from its effect on the fat content of the sample. For this

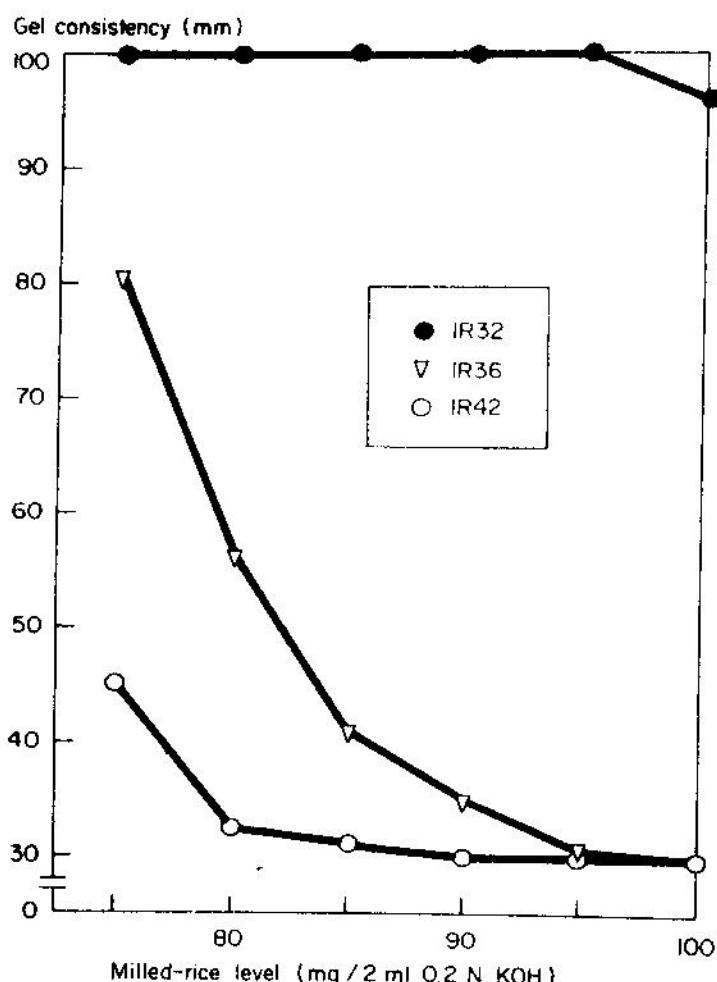


Fig. 13. Relationship of flour concentration and gel consistency of rice flour in 2.0 ml of 0.2N KOH. Optimum flour concentration for the gel consistency test may vary between 80 and 100 mg, as shown by the medium gel-consistency IR36 check samples. (Reprinted, with permission, from IRR1, 1983a)

reason, check samples are preferably milled the same way as the samples to be analyzed. If the check samples do not give the expected gel values, the flour concentration may be adjusted, as in Fig. 13 (IRRI, 1983a). In this example, IR36 had hard gel at 100 mg/2 ml of KOH. A concentration of 80–85 mg produces typical values for the three check samples, since IR32 has soft gel and IR42 has hard gel.

Although milling with the Wig-L-Bug amalgamator was considered the method of choice for flour preparation (Cagampang et al, 1973), a Udy cyclone mill with a 60-mesh (250 μm) sieve gives satisfactory results. Thus, starch damage from ball-milling with the amalgamator is not required for good dispersal—only a fine enough flour of 60 mesh. Although the Wig-L-Bug amalgamator produces an essentially 100-mesh (150- μm) flour (10 grains for 40 sec), a few large pieces are sometimes left unground, which may cause a problem in dispersion. Incomplete dispersion will result in softer gels.

Parboiled rices require a longer dispersion period than raw rice (IRRI, 1980). In addition, the parboiled grain is harder to grind in a Wig-L-Bug amalgamator, and a Udy cyclone mill with a 60-mesh (250- μm) sieve is preferred. Only 16% of the flour of parboiled rice is finer than 150 μm after 40 sec in the Wig-L-Bug amalgamator, as compared to 39% for flour from raw rice. Sieving flour through a 100-mesh (150- μm) sieve improved gel consistency from 92 to 50 mm for two Sri Lankan parboiled rices at 8-min boiling, but increasing the dispersion time to 15 min resulted in a gel consistency of 34 mm, which compares with a gel consistency for raw rice of 28 mm. Thus anomalous soft gel values for parboiled rice by the standard gel consistency procedure are due to incomplete rice dispersion resulting from grain hardening during parboiling.

The solvent 0.2*N* KOH gives better dispersion than 0.15*N* KOH, and KOH gives slightly harder gel than NaOH (Perez, 1979). Potassium acetate (0.15*M*) gives consistency values similar to those shown by gels in 0.2*N* KOH, but gels in 0.2*N* alkali are generally more stable to liquid phase separation. With water as solvent, poor reproducibility of results is observed because of clumping of samples, which is reduced by the addition of a four-mesh Hengar granule (IRRI, 1981). However, stability of the gel is also less in water than in KOH, particularly for high-amylase rice.

TABLE VIII
Comparison of Gel Consistency of Six High-Amylose Milled Rice Flours*

| Variety Name | Gel Consistency (mm) | | |
|--------------|-----------------------------|-------------------------|--|
| | Starting Flour ^b | Aged Flour ^c | Flour from Aged Milled Rice ^d |
| IR8 | 29.0 | 32.5 | 32.0 |
| IR42 | 31.0 | 28.5 | 29.0 |
| IR20 | 46.5 | 33.5 | 34.0 |
| IR26 | 54.2 | 43.0 | 43.0 |
| IR5 | 99.0 | 100.0 | 100.0 |
| IR32 | 100.0 | 100.0 | 100.0 |

*Source: Juliano et al (1980).

^bTested four months after harvest.

^cSame flour, tested 13 months after harvest.

^dTested 13 months after harvest.

An international cooperative test, in 10 laboratories in eight countries, on gel consistency of six high-amylase milled rice flours representing the three gel types showed good reproducibility for samples with hard and soft gels; those of the medium-gel samples were variable (Juliano et al., 1980) (Table VIII). The dispersion of the flour in the boiling water bath is a critical step, and the cooperators' relative experience and familiarity with the method is a major contributing factor. Some hardening of gel consistency may occur during the first three to four months of storage after harvest (Perez and Juliano, 1981), and aged samples were used in this study.

Oxidation of nonstarch lipids, rather than fat hydrolysis, may be involved in the change in gel values for IR20 and IR26, inasmuch as all are converted to soap in the KOH solvent. Addition of 20 μ l of formaldehyde did not change the gel consistency of IR32 milled-rice and starch in water but changed the gel consistency in 0.2N KOH from 100 to 35 mm (Juliano et al., 1980). Thus, carbonyl compounds formed from fat oxidation readily condense with starch and protein at alkaline pH but probably not in water or in amylography. Hence IR32 stored as rough rice has a gel consistency of 81 mm after 14 months of storage as compared to one of 92 mm when freshly harvested, but its gel consistency is 44–46 mm after storage as milled rice for five to 14 months (Perez and Juliano, 1981), since oxidation is minimal in rough rice.

Although 100 mg of flour is optimum for gel consistency of high-amylase rices, 110 or 120 mg of flour provides better differentiation in 0.2N KOH among low-amylase and intermediate-amylase rices (Perez, 1979; Perez and Juliano, 1979; Merca and Juliano, 1981). However, the usefulness of gel consistency in discriminating among specific low-amylase and intermediate-amylase samples needs to be verified, unlike its usefulness in discriminating among high-amylase rices, which is well established. KOH gives essentially soft gels with waxy rices. A neutral gel consistency test gelatinizes 200 mg of rice flour in 1 ml of 0.3N KOH for 8 min in a boiling water bath, and the warm gel is neutralized with 1 ml of 0.3N acetic acid before being cooled and mixed (Antonio and Juliano, 1974; Juliano et al., 1974). Optimum flour concentration may be 175–200 mg, since the range of gel lengths is narrower than in the standard method for nonwaxy rices (Kongseree, 1979b; Perez et al., 1979).

AMYLOGRAPHY OF RICE FLOUR

The Brabender Visco/Amylograph is basically a recording cup torsion viscometer for measuring and recording apparent viscosity at fixed temperatures or at temperatures varied at a uniform rate, usually 1.5°C/min (Suzuki, 1979a; Shuey and Tipples, 1980). Although the term "amylograph" originally referred to the instrument without a cooling accessory, the term is more popularly used for the viscograph or the visco/amylograph, which has a cooling accessory (M. Brabender, 1979, personal communication). The 700 cm³/g cartridge is usually employed for rice amylography, and the 1,000 BU range of the chart is equivalent to 6.85×10^3 dyne/cm torque. Suzuki (1979a) reviewed the use of rice amylography in Japan.

Laboratories differ in the mill and sieve used for preparing the rice flour for amylography (Juliano, 1982a; Juliano et al., 1985). Aside from particle size, the degree of starch damage during milling may differ among the various mills and

has been shown to affect amylograph viscosity (Nishita and Bean, 1982). Some laboratories run amylography within one day of flour preparation. Sieve openings range from 0.15 to 0.8 mm (Juliano, 1982a; Juliano et al, 1985).

The procedure of Halick and Kelly (1959) disperses 50 g of rice flour in 300 ml of water for 1.5 min in a Waring Blender at low speed, and an additional 150 ml of water (total volume, 450 ml) is used to facilitate the transfer of the adhering flour from the blender into the amylograph bowl. One laboratory uses a milk shake machine with stirrer motor above the solution for dispersion. Some laboratories use 40 g of rice and 360 ml (240 plus 120 ml) of water without apparent decrease in amylograph viscosity (Perez and Juliano, 1979; Bhattacharya and Sowbhagya, 1981), but one instrument records lower viscosity when the amount of paste is decreased from 500 to 400 g (Juliano et al, 1985). Others predetermine the moisture content of rice flour to ensure comparable dry weights of flour. A lower paste concentration of 40 g of milled rice dry weight (45 g at 12% moisture) in 450 ml of water is used by some laboratories.

Halick and Kelly (1959) used a temperature program of heating from 30 to 95°C at 1.5°C/min (43.3 min), cooking at 95°C for 20 min, followed by cooling from 95 to 50°C at 1.5°C/min (30 min). A few start at 25°C because of the problem of maintaining the temperature at 30°C. Cooking temperature ranges from 92 to 97.5°C for 10, 15, or 20 min, followed by cooling to either 50 or 30°C (Juliano, 1982a). The cooling phase cannot be performed in units without a cooling accessory. Some laboratories keep the cooling probe down throughout the run but turn on the cooling water only during the cooling phase, evidently to avoid the sudden drop in viscosity when the cooling probe is brought down into the paste at the start of cooling (Shuey and Tipples, 1980). However, the manufacturer's manual recommends that the cooling probe be brought down only during the cooling phase.

Data of interest are peak viscosity, final viscosity on cooking at 92–97.5°C, and viscosity on cooling to 50 or 30°C, all in Brabender Units (Fig. 14). From these three values, breakdown, setback, and consistency may be calculated. Breakdown is the decrease in viscosity (in BU) during cooking at 92–97.5°C; setback is viscosity when cooled to 50 or 30°C minus peak viscosity; and

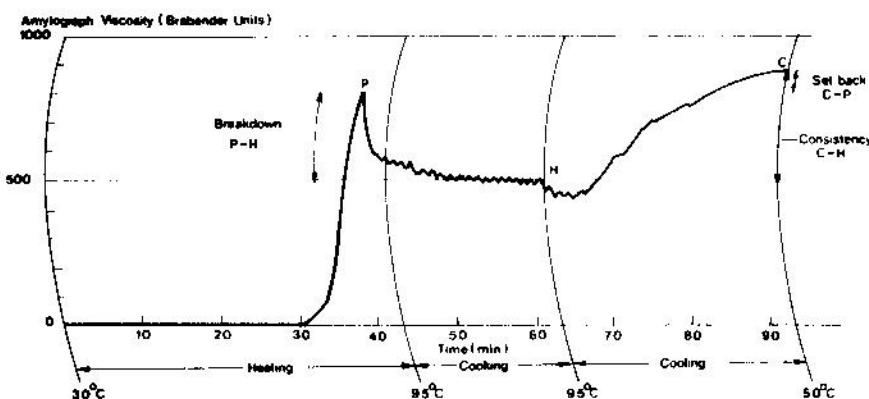


Fig. 14. Representation of an amylogram of milled rice flour and viscosity values derived from it. P = peak viscosity, H = final viscosity at 95°C, C = viscosity when cooled to 50°C.

consistency is viscosity when cooled to 50 or 30°C minus final cooking viscosity at 92–97.5°C.

Peak viscosity is affected by many factors, such as aging or storage of the sample, protein content, and amylose content. The relationship of amylograph viscosity and protein content is negative, probably due to suppression of gelatinization (Juliano et al., 1964b, 1964c; Juliano and Pascual, 1980). Correlation with amylose content is variable (Halick and Kelly, 1959; Juliano et al., 1964b, 1964c; Juliano and Pascual, 1980). Breakdown viscosity during cooking is correlated with amylose content ($r = -0.74^{**}, n = 51$) (Juliano et al., 1964c). Final viscosity at 95°C, viscosity on cooling to 50°C, setback, and consistency are all positively correlated with amylose content (Juliano, 1964b, 1964c; Juliano and Pascual, 1980). However, among high-amylose rices, those with soft gel consistency have lower amylograph peak viscosity, setback, and consistency than those with hard gel consistency (Juliano, 1979a, 1982b), which have setback values >400 BU (Cagampang et al., 1973) and amylograph consistency >600 BU (Perez, 1979).

An ICC Working Group 21/II cooperative test on rice flour amylography in 1982–1983 showed differences among laboratories for the same four rice flours from IRRI (Juliano et al., 1985). However, many instruments gave similar results. Amylographs of flours prepared by various mills often differed from those of flours from IRRI prepared with the Udy mill but were similar in laboratories that also used the Udy cyclone or Tecator mill. Slight variations in methodology did not change the viscosity values much.

Since only four or five amylograms may be performed during a working day (93.3 min actual running time is needed per sample), abridged amylograph methods have been proposed. Webb et al (1963) proposed starting the run at 60°C and concluding it after 10 min of cooking at 95°C, concentrating mainly on peak viscosity and breakdown after 10 min of cooking. Blakeney starts his amylograph at 50°C instead of 30°C (Juliano, 1982a). Similarly, Bhattacharya and Sowbhagya (1981) proposed a starting temperature of 60°C (reducing the heating phase by 20 min), reduction of the cooking time at 95°C to 10 min, and cooling to 50°C with the thermoregulator initially set at 70°C instead of 95°C (13.3 min cooling time); thus, the total run is 46.7 min without appreciably altering the curve pattern.

Bhattacharya and Sowbhagya (1979) recommend the running of up to five amylographs per sample (5–16% db) or at least two at 6 and 11% db to enable plotting of peak viscosity (P), final viscosity at 95°C (H), and viscosity cooled to 50°C (C), with paste concentration similar to that of Mazurs et al (1957). The authors considered as characteristic of the different quality types of Indian rice grains those P values in which $P = C$ (zero setback) and $P = H$ (breakdown is zero), and the ratios H/P , C/P , and C/H and relative breakdown or $(P-H)/(C-H)$ when $P = 1,000$ BU. Although percentage change in viscosity is probably better than actual change in viscosity due to differences in peak viscosity at a given paste concentration, the proposed method is time-consuming. The paste concentration when $P = 1,000$ BU differs drastically among samples, and it conflicts with the proposed cooking method in excess water, requiring an identical water content of 73–75% for comparison (Deshpande and Bhattacharya, 1982).

The amylograph was developed primarily for high-amylose starches and does

not distinguish much among low-amylase and intermediate-amylase rices. However, the use of a higher (12%) paste level is particularly better suited to differentiate among intermediate-amylase and low-amylase rices (Table IX) (IRRI, 1979c; Perez and Juliano, 1979). Waxy rices, however, did not improve in amylograph differentiation with the increase in paste level (Merca and Juliano, 1981). The use of a decreasing rice-water ratio with an increase in amylose content is consistent with the higher water-rice ratio used with high-amylase rice in the rice cooker method of cooking rice. Similarly, 110–120 mg of flour per 2 ml of 0.2N KOH in the gel consistency test effectively differentiates among intermediate-amylase and low-amylase rices, compared to the 100 mg of flour optimum for high-amylase rice (Table X). However, the data at one paste concentration can only be used for comparison among the samples measured, because of the log relationship between viscosity and paste concentration (Mazurs et al., 1957).

In each of the four pairs of samples in Table IX, the first sample has softer

TABLE IX
Comparison of Amylograph Pasting Viscosity Among Rices of the Same Amylose Types at Similar Paste Levels and at 1,000-BU Peak Viscosity^a

| Variety or Line ^b | Amylose Type ^c | Paste Content (%) | Amylograph Viscosity (BU) | | | | Cooled to 50°C |
|------------------------------|---------------------------|-------------------|---------------------------|-----------|---------|-------------|----------------|
| | | | Peak | Breakdown | Setback | Consistency | |
| IR5 | H | 10.0 | 560 | 170 | 185 | 355 | 745 |
| IR8 | H | 10.0 | 915 | 155 | 610 | 765 | 1,525 |
| IR5 | H | 13.0 | 1,000 | 435 | 230 | 670 | 1,230 |
| IR8 | H | 10.3 | 1,000 | 200 | 600 | 800 | 1,600 |
| Rojolele | I | 10.0 | 910 | 410 | -130 | 280 | 780 |
| Bengawan | I | 10.0 | 915 | 435 | -165 | 270 | 750 |
| Rojolele | I | 12.0 | 1,365 | 765 | -255 | 410 | 1,010 |
| Bengawan | I | 12.0 | 1,675 | 1,015 | -485 | 530 | 1,190 |
| Rojolele | I | 10.6 | 1,000 | 460 | -210 | 250 | 790 |
| Benjawan | I | 10.2 | 1,000 | 480 | -160 | 320 | 840 |
| Jinheung | L | 10.0 | 625 | 265 | -85 | 180 | 540 |
| Tongil | L | 10.0 | 665 | 285 | -95 | 190 | 570 |
| Jinheung | L | 12.0 | 1,215 | 675 | -385 | 290 | 830 |
| Tongil | L | 12.0 | 1,235 | 715 | -250 | 425 | 985 |
| Jinheung | L | 11.5 | 1,000 | 520 | -270 | 250 | 730 |
| Tongil | L | 11.4 | 1,000 | 510 | -180 | 330 | 820 |
| Malagkit ^d | Wx | 8.0 | 360 | 130 | -75 | 55 | 285 |
| IR29 | Wx | 8.0 | 375 | 90 | -30 | 60 | 345 |
| Malagkit | Wx | 10.0 | 480 | 155 | -100 | 55 | 380 |
| IR29 | Wx | 10.0 | 655 | 255 | -135 | 90 | 520 |
| Malagkit | Wx | 12.0 | 735 | 285 | -185 | 100 | 550 |
| IR29 | Wx | 12.0 | 845 | 325 | -165 | 160 | 680 |
| Malagkit | Wx | 13.8 | 1,000 | 400 | -275 | 125 | 725 |
| IR29 | Wx | 12.9 | 1,000 | 410 | -225 | 185 | 775 |

^aData from IRRI (1979c), Perez and Juliano (1979), and Merca and Juliano (1981).

^bSample with lower cooked rice Instron hardness is presented first for each pair (see Table X).

^cTypes: H = high, I = intermediate, L = low, Wx = waxy.

^dMalagkit Sungsong.

cooked rice than the second, as determined by the cooked rice Instron hardness value (Table X). Of the high-amylose samples IR5 and IR8, IR8 has higher amylograph viscosity values and lower breakdown viscosity than IR5. Peak viscosity cannot be used as an indicator of cooked rice texture, since Jinheung and Tongil have similar peak viscosities even in 12% pastes. Breakdown viscosity only correlated with softness of cooked rice for IR8. Setback viscosity also is not necessarily lower for softer cooked rice. Only amylograph consistency showed values related to cooked rice hardness that were consistent for 10% paste for IR5 and IR8, 12% paste for Rojolele and Bengawan and for Jinheung and Tongil, and for 10 and 12% paste for Malagkit Sungsong and IR29. Also, the final viscosity cooled to 50°C correlated well with amylograph consistency and cooked rice hardness, since it is the closest to the actual viscosity of cooled cooked rice. A semilog plot of final viscosity at 50°C as a function of paste concentration for these four pairs of rices confirms the usefulness of this value as compared to peak viscosity (Fig. 15). The sample with harder cooked rice in each pair had the higher viscosity at 10% and/or 12% paste, as discussed above for amylograph consistency, with high-amylose rices having the highest values and waxy rices, the lowest. Mazurs et al (1957) considers that the viscosity of cooked starch paste that is cooled to 50°C is already a measure of the setback produced by cooling.

When the method of Bhattacharya and Sowbhagya (1979) is employed, interpolated amylograms of the four pairs at peak viscosity of 1,000 BU again do not reveal additional information, as only IR8 has lower breakdown values than IR5 (Table IX). The other three pairs have similar breakdown values. The biggest differences are for consistency rather than for setback, except for IR5 and IR8. This more elaborate method offers little advantage to the use of 10% paste for high-amylose and waxy rice and 12% paste for intermediate- and low-amylose rice. Cooled-paste viscosity at 50°C can be used directly in place of consistency as an index of cooked rice hardness, since it is not much influenced by peak viscosity.

TABLE X
Cooked Rice Hardness and Gel Consistency of Milled Rices^a

| Variety or Line Name | Cooked Rice Instron Hardness (kg) | Gel Consistency (mm) in | | | | |
|----------------------|-----------------------------------|--------------------------|-------------|-------------|--------------|---------------|
| | | KOH, 100 mg ^b | KOH, 110 mg | KOH, 120 mg | KOAc, 200 mg | Water, 100 mg |
| IR5 | 6.9 | 100 | ... | ... | ... | ... |
| IR8 | 8.2 | 30 | ... | ... | ... | ... |
| Rojolele | 6.1 | 63 | ... | ... | 99 | 87 |
| Bengawan | 7.1 | 46 | ... | ... | 82 | 55 |
| Jinheung | 5.7 | 89 | 82 | 76 | ... | ... |
| Tongil | 7.4 | 86 | 66 | 54 | ... | ... |
| Malagkit | | | | | | |
| Sungsong | 3.3 | 74 | ... | ... | 51 | ... |
| IR29 | 4.4 | 86 | ... | ... | 38 | ... |

^aSource: IRRI (1979c); used by permission.

^bSolvent (2 ml) and sample weight. KOH = potassium hydroxide, 0.2N; KOAc = potassium acetate, 0.15M.

Ferrel and Pence (1964) used the amylograph to measure changes induced in milled rice by mild hydrothermal treatment. Although the whole amylograph curve decreases with increasing degree of cooking, breakdown viscosity at 95°C seems to correlate best with the subjective evaluation of cooked rice, which decreases with the amount and severity of pretreatment. The method is applicable to both brown and milled rice. Parboiling generally results in a decrease in peak viscosity in the amylograph of brown rice (Raghavendra Rao and Juliano, 1970).

Final GT of starch may be obtained by amylography using 100 g of rice flour and 400 ml of water (Halick et al., 1960). It corresponds to the temperature of the initial viscosity increase of the paste. Determination of the initial viscosity increase is quite subjective; however, the ICC Working Group 21/II cooperative test on amylography observed that the temperature when viscosity crosses 20 BU corresponds well with photometric GT and BEPT (Juliano et al., 1985). A similar scheme is utilized in starch alkali viscometry, wherein gelatinization normality corresponds to the normality at a viscosity of 0.0225 Pa·sec (22.5 cp) (Suzuki and Juliano, 1975; Suzuki, 1979b).

Sandstedt and Abbott (1964) add 3.6 g of carboxymethyl cellulose (CMC) (0.8% db) (Hercules Cellulose Gum 7HP) to 25 g of starch (5.5% db) in 371.4 ml of water in amylography up to the cooking phase. The starch gelatinization curve is obtained by subtracting the viscosity of 0.8% CMC alone from the starch-CMC curve. A two-stage gelatinization is obtained with nonwaxy rice starch but only a one-stage gelatinization for waxy rice starch (Juliano and Perdon, 1975).

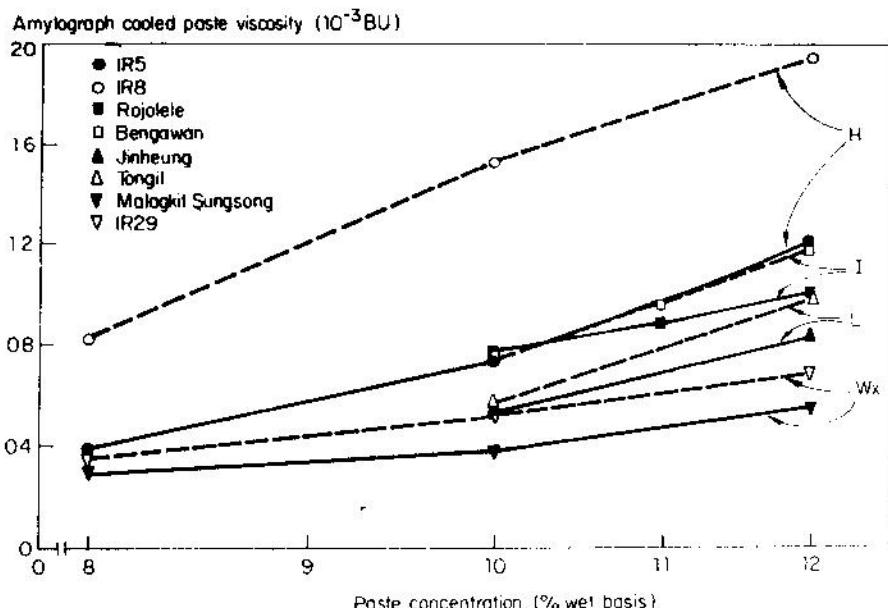


Fig. 15. Effect of paste concentration on the amylograph viscosity of rice paste cooled to 50°C of four pairs of rices, representing the four amylose types, differing in cooked rice Instron hardness. H = high, I = intermediate, L = low, Wx = waxy. (Compiled from Perez and Juliano, 1979; Merca and Juliano, 1981; IIRR, 1979c)

The method has been successfully tried on rice flour (28.0 g) and CMC (4.0 g) in 368.0 g of water for determination of starch GT at IRRI.

PROTEIN CONTENT

Methods of protein analysis are described in section IV of this chapter. Protein content, particularly in the surface layer of milled rice has been shown to correlate with cooked rice texture (Primo et al, 1962). Because of its hydrophobic nature, higher protein content in a variety directly affects cooking time by acting as a barrier to inward water diffusion into the cooking grain (Juliano et al, 1965). In addition, higher protein content makes the grain harder and more resistant to abrasive milling. Thus, reports of darker color of milled rice due to higher protein content may be due mainly to undermilling. A higher-protein rice is not necessarily darker than an average-protein rice at similar degrees of milling (Beachell et al, 1972; Juliano, 1972a; Juliano and Beachell, 1975). Thus, when cooked in rice cookers at a fixed water-rice ratio, high-protein rice is flakier than low-protein rice of the same variety (Oñate et al, 1964; Juliano et al, 1965; Ishima et al, 1974).

METHODS FOR PARBOILED RICE

Although the methods described are for raw rice, most of the methods are also applicable, with modification, to parboiled rice. Tests for parboiled rice were recently reviewed by Bhattacharya (1979c). Parboiled rice requires a longer cooking time, which may be appreciably reduced by presoaking for at least 30 min. As a consequence of starch gelatinization, parboiled rice shows, in contrast to raw rice, higher water uptake at 60°C, higher equilibrium water content at room temperature, higher soluble amylose extracted at 60°C or by 0.2N KOH, higher reactivity of rice grains when exposed to very dilute alkali, and higher viscosity of cold slurry and higher sedimentation volume in 0.05N HCl.

IV. NUTRITIONAL QUALITY

Methods for evaluating and breeding for nutritional quality in cereals have been reviewed (PAG, 1975; IAEA, 1977; Pellett and Young, 1980; Juliano, 1983a). The nutritional quality of rice protein is discussed in Chapter 3. Because of the extremely low levels of antinutritional factors in milled rice, the nutritional value of milled rice is readily indexed by crude protein analysis by the Kjeldahl method (Juliano, 1978).

A. Protein and Lysine Contents

In the breeding program (Coffman and Juliano, 1979), crude protein (Kjeldahl) analysis is usually done on brown rice instead of milled rice because of the extra effort required for milling and the difficulty of obtaining a uniform degree of milling with a few grams of sample (Juliano et al, 1968b). Besides, the protein contents of brown and milled rice are significantly correlated ($r = 0.96^{**}$, $n = 55$) (Juliano et al, 1964b). A minimum of 10 grains is needed to obtain a representative sample because of grain-to-grain variation in protein content even in the same panicle (Juliano et al, 1972b). Other screening methods include dye-binding capacity (DBC), the biuret test, and NIR spectroscopy. These

methods require flour of homogeneous size to obtain reproducible results, and a fast mill with a sieve, such as the Tecator Cyclotec or Udy cyclone mill with 40-mesh (420 μm) sieve, is ideal. The Wig-L-Bug amalgamator readily grinds 10 grains, but the flour size is not always 100 mesh (150 μm), particularly for large-grain and hard-grain samples.

Micro-Kjeldahl digestion may be done manually instead of being automated to conserve chemicals and samples, since only 50 mg of flour may be used. Then the ammonia in the manual digests may be determined colorimetrically at 602 nm by the alkaline phenol-hypochlorite method using an AutoAnalyzer (Juliano et al., 1968b), with a 1:1 sample-wash time ratio, rather than 2:1, to improve peak resolution (J. A. Varley, 1979, personal communication). Manual colorimetry for ammonia in digest can also be done, producing a stable color for several hours at room temperature. In this procedure, 100 μl of Kjeldahl digest together with standards containing 0–25 ppm of nitrogen, is pipetted into a clean, dry 25-ml test tube. The 5 ml of sodium salicylate-nitroprusside reagent (34 g of sodium salicylate, 25 g of sodium citrate, 25 g of sodium tartrate, and 0.12 g of sodium nitroprusside per liter) is added, mixed well, and let stand for 5 min. Next, 5 ml of the sodium dichloroisocyanurate-hydroxide reagent (30 g of NaOH and 0.5 g of sodium dichloroisocyanurate per liter) is added, mixed well, and let stand for at least 30 min before the absorbance at 655 nm is read.

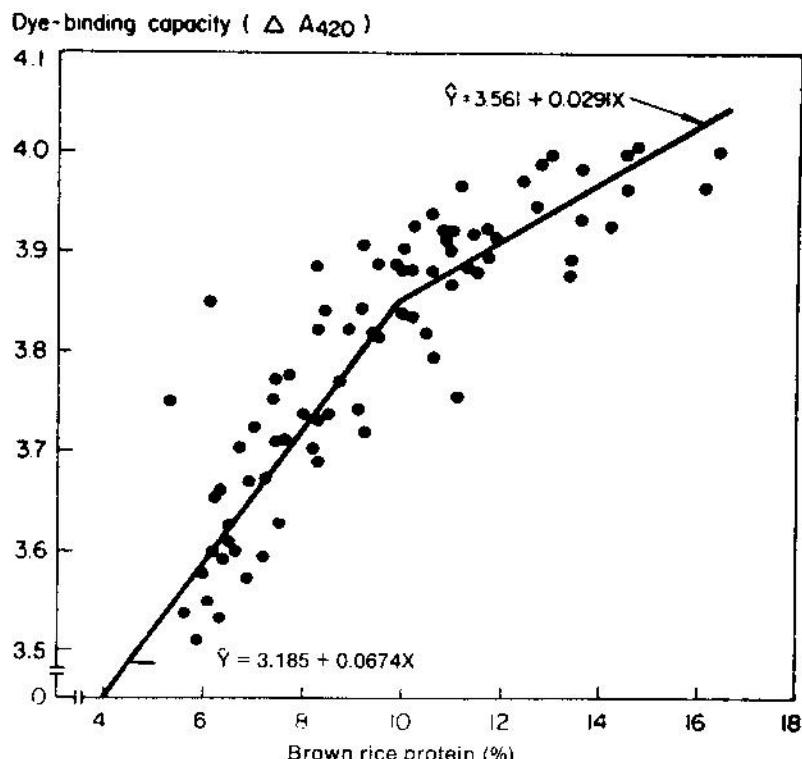


Fig. 16. Relationship between brown rice Kjeldahl protein and dye-binding capacity of brown rice flour below and above 10% protein. (Reprinted, with permission, from Juliano et al., 1973)

The DBC is based on the quantitative binding of the diazo dye, 1-phenylazo-2-naphthol-6-sulfonic acid monosodium salt (acid orange 12 or orange G), by the basic amino acids (lysine, arginine, and histidine) and the free amino terminal group of flour proteins (Mossberg, 1969). The unbound dye remaining in the solution after it is shaken with the flour is measured colorimetrically at 420 nm after filtration or centrifugation. DBC, as indexed by the drop in absorbance at 420 nm, may be used to measure protein content in the breeding program after calibration with Kjeldahl protein (Juliano et al., 1973) (Fig. 16).

Colorimetric estimation of alkali-extracted protein is readily accomplished with biuret reagent (Parial et al., 1970) or with Folin phenol reagent (Lowry et al., 1951), preferably using rice flour samples of known Kjeldahl protein content to prepare the standard curve. The biuret reagent has the advantage that no additional step is required except extraction directly with the reagent. With the Folin phenol method, the protein has to first be extracted with 0.1-1*N* NaOH solution.

The NIR spectroscopy method for protein analysis has the best prospect as a screening method, provided that maintenance of instruments can be guaranteed in developing countries. It also requires precalibration by flour samples of known Kjeldahl protein content (Williams, 1975). Calibration may be needed for every crop because of the possible effect on the NIR spectra due to season in each location or for crops from different locations. The grinding mill is very critical for this method, but an analysis takes less than 1 min and the protein content data may be either printed or displayed. A different calibration plot is needed for milled rice than for brown rice. Storage of samples in whole and ground form for several months, even at 4°C, resulted in decreased NIR protein values (IRRI, 1976). Least significant difference (5%) was 0.4% protein by the Kjeldahl method and 0.3% by the NIR method. After calibrating the NIR analyzer with 38 samples (6.7-11.5% protein), protein readings differed by more than 0.22% (the calculated standard deviation for protein) in four of the 38 samples; the maximum difference was 0.8% from Kjeldahl protein analysis. Good correspondence between the two sets of values ($r = 0.98^{**}$) may be due partly to the narrow range in contents of oil (2.1-3.2%) and moisture (11.0-12.2%) among the samples.

Kaul et al (1969) proposed a microscopic screening technique for protein characterization based on the observation that protein body distribution in brown rice cross section does not correlate with protein content. Rice grains are soaked in water and gently heated on a water bath at 40°C for 2 hr. Free-hand sections of the soaked grains are cut with a stainless steel blade. Several sections from exactly the middle portion of the grain are placed in a 0.5% aqueous solution of bromphenol blue. The stained sections are viewed under a microscope and scored. The section score is quantified by computing the ratio between thickness of the stained area and the radius of the grain expressed as a percentage. The coefficient of variation of the method is 40% (Kaul et al., 1978). Although Kaul et al (1982) found low significant correlation between protein content and section score in Bangladeshi rice ($r = 0.34^{**}$ for 1,297 germ-plasm samples), Kaul et al (1978) reported that the microscope section of 54 local Bangladeshi varieties and six semidwarf rices is highly correlated with protein content ($r = 0.97^{**}$). Because the microscope section score requires additional effort and because of the variation in protein content among grains even in the

same panicle (Juliano et al., 1972b), it is fortunate that very little of the starchy endosperm protein is lost during milling of brown rice (Ellis et al., 1985).

The relationship between brown rice protein and its fraction retained in milled rice of selected varieties at 10% (by weight) bran-polish removal in a McGill mill is curvilinear, showing an increasing proportion retained with increasing protein content (Juliano et al., 1973) (Fig. 17, top). Milled rice protein tends to approach brown rice protein as the protein content of the grain increases. Recent milling tests at 10% bran-polish removal on IR36 and IR42 brown rices containing 7.5–13% protein with a Satake mill showed similar 83% retention of brown rice protein in milled rice regardless of protein content, in contrast with the data above using a McGill mill. However, milled rice protein is still predictable from brown rice protein (Figure 17, bottom). The brown rice protein range is 8.1–12.8% (mean, 9.9%) for IR36 and 7.4–10.9% (mean, 9.2%) for IR42, which

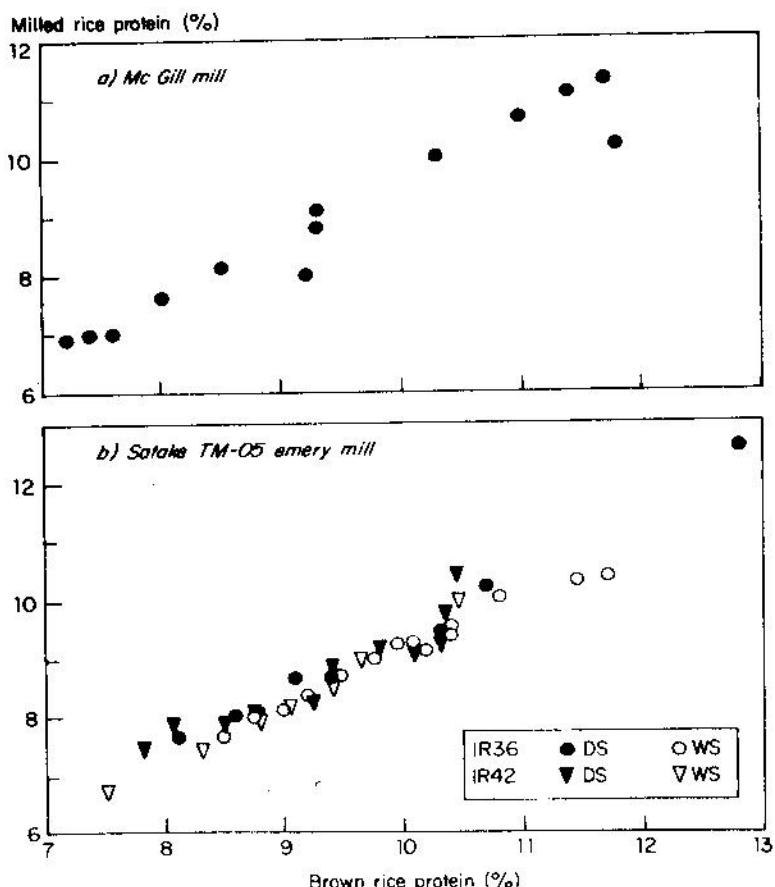


Fig. 17. Relation of brown rice protein to retained protein in milled rice with: 10% bran-polish removal with a McGill Mill No. 3 (top) and 10% bran-polish removal with a Satake TM-05 emery mill (bottom). DS = 1983 dry season. WS = 1983 wet season. (Reprinted, with permission, from Juliano et al., 1973 [top] and Ellis et al., 1985 [bottom].)

should have given 86% retention of brown rice protein based on the earlier curve (Fig. 17). The McGill mill removes bran from the rice caryopsis more effectively than the Satake mill at the same degree of milling, as shown by May-Grünwald staining (IRRI, unpublished data).

Lysine content is readily predicted from protein content. However verification of the lysine content may be done on advanced lines and is usually done on milled rice. For a large number of samples, DBC at the same weight of protein in the flour may be used to screen for differences in lysine content (Mossberg, 1969). Since the acid orange 12 dye binds with basic amino acids (lysine, arginine, and histidine), DBC has been used to select for high-lysine genotypes, which have higher levels of lysine and arginine relative to histidine (Mossberg, 1969). DBC was used to screen brown rice for higher-lysine cultivars by plotting the DBC of 50 mg of flour in 3 ml of 0.02% dye solution as a function of protein content (Juliano et al, 1973) (Fig. 16). DBC shows the break in the negative correlation between protein content and lysine (see Chapter 3) by the change in the slope of the protein-DBC curve above 10% protein in Fig. 16. A recent, modified DBC method measures lysine by determining the DBC of a sample with and without reaction of lysine with propionic anhydride; the difference in DBC is due specifically to lysine binding (Hurrell et al, 1979).

Colorimetric lysine assay at 390–400 nm on pronase digests using alkaline cupric phosphate reagent and a solution of 2-chloro-3,5-dinitropyridine (Villegas and Mertz, 1971; Tsai et al, 1972) works well on nonpigmented milled rice, provided there are adequate samples to run (IRRI, 1970). The results are similar to those obtained by a short-column run in an amino acid analyzer.

Lysine may also be screened in manual digests in 6*N* HCl by the lysine decarboxylase method, either manometrically (Juliano et al, 1968b) or by the AutoAnalyzer (Palter and Kohler, 1969). Flushing with nitrogen gas or evacuation is not needed during sealed tube hydrolysis in 6*N* HCl at 100°C for 23 hr, since lysine is relatively acid-stable. The same hydrolysate may be used for definitive lysine analysis by ion-exchange chromatography in an amino acid analyzer.

B. Rat Balance Assay

The protein efficiency ratio is still the screening method commonly used by industry to estimate the protein quality of foods in rats. Methods for evaluating nutritional value of foods including cereals have been reviewed (Pellett and Young, 1980). With the net protein utilization (NPU) method, one has the advantage of being able to estimate both the true digestibility (TD) and the biological value (BV) of the protein and to use only five rats and minimal sample. Eggum (1973) uses only samples equivalent to 7.5 g of nitrogen for nitrogen balance by the Thomas-Mitchell method in five growing Wistar-möll male rats weighing 65–68 g. The trial consists of four days of introductory feeding and a five-day balance period in which pooled feces and pooled urine are analyzed for Kjeldahl nitrogen. The rat's daily diet has a constant amount of dry matter (10 g) and nitrogen (150 mg). Autoclaved potato starch is used to reduce the nitrogen content of high-protein samples. Metabolic and endogenous nitrogen are determined by adding ether-extracted, freeze-dried egg equivalent to 4% protein to the nitrogen-free diet of autoclaved potato starch, sucrose, cellulose powder,

soybean oil, minerals, and vitamins. Egg protein at this level is completely utilized by rats. TD, BV, and NPU are calculated as follows:

$$TD = \frac{\text{dietary N} - (\text{fecal N} - \text{metabolic N})}{\text{dietary N}} \times 100$$

$$BV = \frac{\text{dietary N} - (\text{fecal N} - \text{metabolic N}) - (\text{urine N} - \text{endogenous N})}{\text{dietary N} - (\text{fecal N} - \text{metabolic N})} \times 100$$

$$NPU = \frac{\text{dietary N} - (\text{fecal N} - \text{metabolic N}) - (\text{urine N} - \text{endogenous N})}{\text{dietary N}} \times 100$$

$$= TD \times BV / 100$$

With the increased interest in energy utilization, adiabatic calorimetry has been routinely done on food and feces, and digestible energy is calculated by measuring the difference in energy content in food and feces (Eggum et al, 1982). Digestible energy in milled rice is close to 100%.

Human nutritional studies are probably not required routinely on all new rice varieties, since rice has a minimal content of antinutritional factors, as discussed in Chapter 3. More attention should be given to acceptability to ensure that the nutritional inputs will be accepted by the consumer. The more nutritious rice (high-protein and/or high-lysine) will find acceptance only if it can be incorporated into a variety without sacrifice in yield, market quality, and cooking and eating qualities. The effect of increased protein content on the nutritional value of rice grain is discussed in Chapter 3.

High protein content has been shown to increase grain hardness and grain translucency (Blakeney, 1979a; Juliano, 1979a). Head-rice recovery and total milled rice yield tend to be higher with nitrogen-fertilized crops of the same rice variety (Blakeney, 1979a). In addition, high-protein milled rice requires a longer cooking time than average-protein milled rice and thus requires more water than average-protein rice to compensate for additional steam loss in the rice cooker method (Oñate and del Mundo, 1963; Juliano et al, 1965; del Mundo, 1979).

V. AGING OR STORAGE CHANGES

Aspects of aging or storage changes of rice grain, brown rice, milled rice, and rice starch have been reviewed (Barber, 1969, 1972; Juliano, 1971a; Moritaka and Yasumatsu, 1972b; Villareal et al, 1976; Yasumatsu and Moritaka, 1979; Shibuya, 1980) or studied recently (Baldi et al, 1977; Bolling et al, 1977, 1978; Indudhara Swamy et al, 1978; Lin et al, 1979; Pushpamma and Reddy, 1979). The exact mechanism of rice aging is not yet fully understood, despite the many studies on the subject. Appreciation of the storage changes is important in the evaluation of milling quality and the cooking and eating quality of rice grain, since the texture of raw and cooked rice is affected by aging.

Emphasis in this section is on changes in grains properly stored and still suitable for human consumption.

A. Physicochemical Changes

Sanjiva Rao (1938) proposed that the aging phenomenon may be the result of a sol-gel transformation of colloidal starch and protein deposited during ripening and transformation into a more stable, water-insoluble physical form during storage. This theory contends that the changes are purely physical in nature.

Many of the physicochemical changes during storage seem to be temperature dependent and are minimized by cold storage at $15 \pm 2^\circ\text{C}$ (Tani et al., 1964; Okabe, 1979). These changes probably start in the field when the crop is progressively drying before harvest and continue during drying of the threshed crop. The phenomenon is sometimes called "after-ripening." In fact, Kester et al (1963) reported that increases in water uptake at 77 and 82°C and in amylo-graphic peak viscosity with delay in harvest of California rices were indicative of aging.

Tensile strength of the grain increases during storage (Kunze and Choudhury, 1972). For example, Bluebelle brown rice improved in tensile strength from 76.0 kg/cm^2 at one month after harvest to 84.2 kg/cm^2 at two months and 85.6 kg/cm^2 at three months. Milled Bluebelle rice improved in tensile strength by 35 kg/cm^2 during four months of storage. Crushing and breaking hardness of brown rice increases during aging (Kondo and Okamura, 1937). The increased hardness is reflected in greater resistance to milling and higher total and head-rice yields of rices aged for three to six months and also resistance to grinding in a Wig-L-Bug amalgamator (Villareal et al., 1976; Perez and Juliano, 1982) (Table XI). Waxy rice does not improve in resistance to grinding in an amalgamator during six months of storage.

Changes in cooking quality during aging are also observed. Increases in volume expansion and water absorption during cooking result from aging of freshly harvested rice regardless of storage form—rough, brown, or milled (Sreenivasan, 1939; Tani et al., 1964; Barber, 1972; Shibuya et al., 1974; Villareal et al., 1976; Indudhara Swamy et al., 1978; Pushpamma and Reddy, 1979). Most studies also report a decrease in extractable solids in the cooking water, except that Shibuya et al (1974) reported increases in total solids and in the iodine-blue value of the cooking liquid of stored Japanese rice. Indudhara Swamy et al (1978) reported an increase in water uptake for up to one year on storage, after which water uptake decreased. Bolling et al (1977, 1978) did not observe any trend in

TABLE XI
Changes in Milling Properties^a of IR36 and IR42 Rough Rice Stored at 25°C for Four Months^b

| Property | Variety and Storage Period | | | | | |
|-----------------------------------|----------------------------|------|------|------|------|------|
| | IR36 | | IR42 | | | |
| | 2 wk | 2 mo | 4 mo | 2 wk | 2 mo | 4 mo |
| Bran-polish removal, % | 8 | 9 | 9 | 8 | 8 | 8 |
| Head rice, % brown rice | 20 | 22 | 21 | 46 | 47 | 51 |
| Total milled rice, % | 92 | 91 | 92 | 92 | 92 | 92 |
| Instron hardness, ^c kg | 12 | 13 | 13 | 9 | 10 | 10 |

^aWith a McGill miller.

^bSource: Perez and Juliano (1982); used by permission.

^cMean of at least 25 grains of brown rice.

volume expansion by the cooking method of Borasio (1962) during storage for up to six years, but Pushpamma and Reddy (1979) reported a progressive increase in swelling number and water absorption during one year of storage. Boiling-water soluble amylose from 45-mesh flour also decreased during rice storage (Indudhara Swamy et al, 1978).

The elongating property of Basmati type rices also improves during storage and accompanies increases in volume expansion and water absorption during cooking of milled rice (Desikachar and Subrahmanyam, 1959; Pushpamma and Reddy, 1979). Increases in cooking time are also reported (Pushpamma and Reddy, 1979) but no change in starch GT (Barber, 1972). Indudhara Swamy et al (1978) reported a slightly rising trend of GT with storage period, particularly from 1.5 years to 3.5 years. Aged rice grains are more resistant to disintegration during cooking, and the cell walls seem more resistant to disruption during grain swelling (Desikachar and Subrahmanyam, 1959).

Cooking tests done below boiling water temperature also showed that changes take place during storage. Water uptake at 80°C generally increased during the first year but dropped steadily, as did the water uptake at 96°C (Indudhara Swamy et al, 1978). Loss of solids during cooking at 80°C also decreased steadily during storage. The level of water-soluble amylose at 65°C also decreased during storage (Indudhara Swamy et al, 1978). Bolling et al (1977, 1978) reported that the swelling number of rice decreased during storage of milled rice; Hogan (1963) also reported that aged rice absorbed less water at 70°C than did freshly harvested rice. These results probably reflect the increased water-insolubility of rice starch and protein during aging, resulting in a slower rate of cooking, even when the starch GT does not increase appreciably. Pushpamma and Reddy (1979) reported that the optimum cooking time for milled rice was 4–6 min longer after six months of storage than it was at harvest.

Similarly, water absorption values below starch GT tended to decrease with grain aging. The water absorbing and swelling capacity of rice after soaking 48 hr at 25–28°C decreased between one and two years of storage (Kondo and Okamura, 1937). The capacity of rice flour to absorb water from water vapor and the equilibrium water content of rough rice, milled rice, and rice flour tended also to be higher for freshly harvested rice than for a previous (one-year-old) crop of the same variety (Desikachar, 1956).

Cooked aged rice is harder and less sticky than cooked freshly harvested rice, as measured by organoleptic means (Moritaka et al, 1971a) and with the texturometer (Shibuya et al, 1974; Hwangbo and Lee, 1976; Okabe, 1979). It has greater consistency with the Haake consistometer (Manohar Kumar et al, 1976; Bolling et al, 1977, 1978), greater Instron hardness (Lisch and Luanay, 1975; Perez and Juliano, 1981), and greater beam-balance stickiness for nonwaxy rice (Manohar Kumar et al, 1976; Villareal et al, 1976). The Instron cooked-rice hardness value of seven milled rices stored at 28–30°C increased from 5.8 to 6.9 kg during three months of storage and then leveled off. Okabe (1979) reports that all Japanese rices are palatable two to three months after harvest but begin to show deterioration (harder texture) after six months of storage.

Juliano et al (1969) observed similar taste panel scores for tenderness, cohesiveness, color, and gloss for cooked waxy milled rices from two successive crops assessed together, suggesting that a difference in storage period of six months did not appreciably change the texture of the resulting cooked rice.

Villareal et al (1976) also reported similar stickiness values for cooked rice of waxy rices stored for six months at 2 and 29°C.

Gel consistency shows a slight hardening effect, particularly for medium-gel samples, during progressive aging for several months (Perez and Juliano, 1981), together with a gel viscosity increase (Villareal et al, 1976). Starch isolated from freshly harvested nonwaxy rices and stored at 29°C for six months also showed harder gels and a higher gel viscosity than those of starches stored at 2°C (Villareal et al, 1976). Limiting or intrinsic viscosity of starch appears also to increase with storage of milled rice (Barber, 1972).

Amylograph pasting viscosity of milled rice flour increases during storage without change in GT (IRRI, 1968; Barber, 1972; Villareal et al, 1976; Perez and Juliano, 1981) and tends to level off after three to four months from the harvest date (IRRI, 1968; Perez and Juliano, 1981) (Table XII). Rough, brown, and milled rices all show the trend of increase in amylograph viscosity for both waxy and nonwaxy rices (Yasumatsu et al, 1964; Shibuya et al, 1974; Villareal et al, 1976; Shoji and Kurasawa, 1981b). Indudhara Swamy et al (1978), however, reported that after an initial increase in amylograph peak viscosity and setback during the first six months of storage, a steady decrease is noted during the subsequent three years of storage of rough and milled rices.

By contrast, starches prepared from Japanese rices stored at ambient temperature (23°C) and at 4°C showed similar amylograph viscosities (Shibuya et al, 1977a), even after one to two years, for waxy and nonwaxy rices (Shoji and Kurasawa, 1981b). The starch granules also showed no difference in surface structure by scanning electron microscopy and in gelatinization characteristics by photopastograms (Shibuya et al, 1977a). Starches from aged and unaged Spanish rices have similar amylograms (Barber, 1972). By contrast, starches from the current two crops of rice in Taiwan had lower peak viscosity than starches prepared from the previous year's two crops (Lin et al, 1979). However, Villareal et al (1976) showed that starch prepared from freshly harvested rice and stored at 2 and 29°C showed increases in amylograph viscosity for both waxy and nonwaxy samples.

Although these physicochemical changes continue even after three to four

TABLE XII
Mean Changes in Cooked Rice Properties During Storage of Milled Rice
of Six Nonwaxy Varieties at 28–30°C*

| Storage Period (mo) | Cooked Rice | | Amylograph Viscosity (BU) | | |
|---------------------|-----------------------|----------------------|---------------------------|---------------|----------------|
| | Instron Hardness (kg) | Gel Consistency (mm) | Peak | Final at 94°C | Cooled to 50°C |
| 0 | 7.4 | 65 | 541 | 359 | 703 |
| 1 | 7.5 | 60 | 592 | 379 | 750 |
| 2 | 8.4 | 54 | 620 | 400 | 793 |
| 3 | 8.8 | 53 | 652 | 440 | 820 |
| 4 | 8.8 | 52 | 649 | 426 | 835 |
| 5 | 8.6 | 50 | 678 | 441 | 851 |
| 6 | 8.4 | 56 | ... | ... | ... |

*Source: Perez and Juliano (1982); used by permission.

months of storage, this minimum aging period would be desirable in a breeding program for screening of milling quality and of cooking and eating quality of rice. Gel consistency is preferably done on freshly milled rice because of the complexing effect of carbonyl compounds on the test in alkaline pH (section III).

B. Chemical Changes

Almost no change in gross chemical composition of the rice grain occurs during storage. Starch and amylose content and protein content of the rice grain remain practically unchanged (Kondo and Okamura, 1937; Yasumatsu et al., 1965a; Barber, 1972; Villareal et al., 1976; Indudhara Swamy et al., 1978). Some hydrolysis or degradation probably occurs, such as an increase in reducing sugars (Tani et al., 1964; Barber, 1972; Pushpamma and Reddy, 1979), a decrease in nonreducing sugars and starch (Barber, 1972; Pushpamma and Reddy, 1979), a decrease in free amino acids (Tani et al., 1964; Barber, 1972; Baldi et al., 1977), an increase in free fatty acids (Narayana Rao et al., 1954; Tani et al., 1964; Barber et al., 1972; Villareal et al., 1976; Shibuya et al., 1977b; Bolling et al., 1978; Shoji and Kurasawa, 1981b) and free phenolic acids (Tsugita et al., 1983), and a decrease in pH or increase in acidity of cooking water (Tani et al., 1964; Shoji and Kurasawa, 1981b). Nonstarch lipids also increase in peroxide value (Narayana Rao et al., 1954; Barber, 1972) and carbonyl content (Villareal et al., 1976) and decrease in iodine value during storage (Barber, 1972). The changes are greater in the outer 10% layer (by weight), where nonstarch constituents are concentrated (Barber, 1972). Waxy rice tends to have higher free fatty acids and carbonyl content than nonwaxy rice (Villarcal et al., 1976; Yanase et al., 1981), due to its higher content of nonstarch lipids in the endosperm (Choudhury and Juliano, 1980). Starch lipid (fat-by-hydrolysis) does not undergo oxidation of unsaturated fatty acids during storage, as reflected by its constant fatty acid composition and content (Yasumatsu and Moritaka, 1964).

In addition to the increase in free fatty acids and in peroxide value, carbonyl compounds characteristic of the stale flavor of cooked milled rice increase during storage. In Japan, rice is usually consumed within a month of milling, since off-flavors are noted by two to four weeks of storage (Yasumatsu et al., 1965b; Moritaka et al., 1972). Yasumatsu et al. (1966a) reported acetaldehyde, propanal (or acetone), 2-butanone, pentanal, and hexanal to be the volatile carbonyl compounds of cooked rice. During storage at 40°C, the appearance of stale flavor corresponded to higher levels of propanal (or acetone), pentanal, and hexanal with accompanying decrease in the content of linoleic and linolenic acids (Yasumatsu et al., 1966b) (Table XIII). Recent studies by Tsuzuki et al. (1981) also showed propanal, pentanal, and hexanal as the major carbonyl compounds that increase the most during storage. The results suggest that oxidation of unsaturated fatty acids is the source of the carbonyl compounds. Later Japanese researchers reported butanal (Mitsuda et al., 1972; Endo et al., 1977), 2-methylpropanal (isobutyraldehyde) (Endo et al., 1977), and 3-methylbutanal (isovaleraldehyde) (Shibuya et al., 1974; Endo et al., 1977). Hexanal is considered the major stale flavor constituent of cooked rice, as it more than doubled during 75 days of storage (Shibuya et al., 1974) (Table XIV) and during 60 days at 40°C (Tsugita et al., 1983). Storage of milled rice resulted in discoloration at high temperature (>25°C), high moisture content (>14%), and undermilling (Barber,

1969), resulting in the browning of the endosperm and also the residual germ in milled rice in an airtight container. Endosperm discoloration also may occur if rough rice is stored at high temperature and high moisture (Indudhara Swamy et al., 1971b).

Although starch content does not decrease during storage, the alkali lability number of both waxy and nonwaxy rices increases progressively during storage of up to seven years (Shoji and Kurasawa, 1981b), indicative of some degree of depolymerization. Freshly harvested rice seems to be less digestible than stored rice, which may be due to the more pasty consistency of the cooked rice and its lower volume expansion, which result in higher dry matter intakes that lead to digestion problems (Sreenivasan, 1939).

Protein solubility in water and salt decreases during storage, with the decrease in albumin solubility being greater (Barber, 1972; Iwasaki et al., 1972; Villareal et al., 1976). General solubility of protein is reported to decrease (Barber, 1972;

TABLE XIII
Composition of Volatile Carbonyl Compounds in the Distillate of
Cooked Rice Stored Two Months at 5 and 40°C^a

| Carbonyl Compounds | Carbonyl Content (% of total) ^b | |
|---------------------|--|------|
| | 5°C | 40°C |
| Acetaldehyde | 51 | 25 |
| Propanal or acetone | 31 | 42 |
| 2-Butanone | 11 | 9 |
| Pentanal | trace | 5 |
| Hexanal | 7 | 19 |

^aSource: Yasumatsu et al (1966b); used by permission.

^bCalculated from peak height in the gas chromatograph. Total carbonyl content at 50°C, 1.7 μmol; at 40°C, 3.7 μmol.

TABLE XIV
Composition of Head Space Vapor of Cooked Milled Rice^a
After 75 Days of Storage^b as Brown or Milled Rice

| Flavor Components | Carbonyl Content (% of total) of Milled Rice Stored as | | |
|----------------------|---|--------------------------|------------------------|
| | Brown Rice (30°C) | Milled Rice (30°C) | Brown Rice (4°C) |
| Acetaldehyde | 6 | 6 | 12 |
| Propanal | 3 | 2 | 7 |
| Pentanal | 4 | 4 | 2 |
| 3-Methylbutanal | 2 | 2 | 1 |
| Hexanal | 57 | 54 | 31 |
| Acetone | 4 | 4 | 6 |
| Total ^c | 95 | 144 | 100 |
| Hexanal ^c | 210 | 300 | 100 |

^a10% bran-polish removal.

^bSource: Shibuya et al (1974); used by permission.

^cBased on milled rice from brown rice control stored at 4°C as 100.

Baldi et al, 1977) but may be related to flour size due to the increase in hardness of the grain during storage. Baldi et al (1977) reported little change in salt-soluble proteins (albumin and globulin) in extractable proteins, but with the reported decrease in percent extraction, a decrease in protein solubility is also implied. Bolling et al (1977, 1978) also reported a decrease in acetic acid-soluble proteins of milled rice during storage for up to seven years. Moritaka and Yasumatsu (1972a) reported that freshly harvested rice has a higher sulphydryl content than stored or aged rice and that its content ranged from 0.8 to 1.5 $\mu\text{eq/g}$ of rice, as against 1.4–2.4 μeq for disulfide. Oxidation of cysteine to cystine by crosslinking may explain the reduced solubility of protein during storage. Similar changes are reported by Barber (1969, 1972). Carbonyl condensation with protein was demonstrated by Barber (1969, 1972), but formaldehyde vapor treatment of low-protein milled rices for 72 hr revealed decreases in amylograph viscosity that are greater than those for the high-protein sample (IRRI, 1970; Juliano, 1971a).

Enzyme levels follow the drop in soluble protein in rice grain: α -amylase, β -amylase, protease, lipase, peroxidase, and catalase (Kondo and Okamura, 1937; Tani et al, 1964; Barber, 1972; Matsuda and Hirayama, 1973; Shibuya et al, 1975; Pushpamma and Reddy, 1979) and glutamic acid decarboxylase (Bautista et al, 1964).

The relatively high α -amylase activity in freshly harvested grain, which decreases during storage, has been considered a possible mechanism for the pastiness of cooked freshly harvested rice (Sreenivasan, 1939; Desikachar and Subrahmanyam 1960). However, α -amylase is concentrated in the bran fraction, and residual α -amylase activity in milled rice is low and readily inactivated during cooking (Desikachar and Subrahmanyam, 1960). Similarly, α -amylase has been advanced as the cause of low amylograph viscosity of waxy milled rice flour, based on the improvement of viscosity by the addition of 5% copper sulfate (Horiuchi, 1967). However, α -amylase activity is low, and the suppression of peak viscosity was shown to be mainly due to nonstarch lipids of waxy milled rice flour (Merca and Juliano, 1981). Recently Shibuya et al (1983) reported that the addition of $10^{-3} M$ mercuric chloride resulted in the maximum increase in amylograph viscosity of waxy milled rice, which they attributed to inactivation of endogenous α -amylase. Cupric acid also increased viscosity but calcium decreased it, with the effect greater for waxy than nonwaxy flour.

Obata and Tanaka (1965) reported that the photolysis of cysteine or cystine in the presence of riboflavin produced hydrogen sulfide, ammonia, and acetaldehyde, which resembled the flavor of cooked rice. Moritaka and Yasumatsu (1972b) showed that hydrogen sulfide was lower in volatiles of cooked rice from rice stored at 40°C than in that from rice stored at 5°C. In addition, Sato et al (1976) found methyl mercaptan, dimethyl sulfide, dimethyl disulfide, and sulfur dioxide in milled rice volatiles in addition to hydrogen sulfide; the level of hydrogen sulfide and dimethyl sulfide (plus sulfur dioxide) was lower in stored rice, whereas that of methyl mercaptan remained high. By contrast, dimethyl sulfide was the off-flavor compound in sake prepared from stored rice above 15°C (Takahashi et al, 1979).

Among the B vitamins, loss of thiamine during storage was much faster than loss of niacin and riboflavin (Kondo and Okamura, 1937; Kik and Williams, 1945; Narayana Rao et al, 1954; Pushpamma and Reddy, 1979).

C. Accelerated Aging and Proposed Mechanisms

Accelerated aging may be accomplished by heating rough or milled rice up to 110°C in sealed containers without loss of moisture to avoid grain cracking (Bhattacharya et al., 1964; Normand et al., 1964). The cured rice resembles naturally aged rice in cooked behavior and taste panel scores, but differs from parboiled rice in that starch granules are not gelatinized. Similar results are obtained with brown rice, where heating has also increased reducing sugars and amylograph viscosity but reduced the acidity of the water extract (due to volatilization), without change in the fat acidity (Iwasaki and Tani, 1967a).

Hot-air (150–260°C) blast toasting of milled rice for several seconds and heating milled rice immersed in safflower oil overnight at 60°C reduced cooked rice Instron stickiness, but plasma treatment in oxygen or hydrogen at 13.56 MHz for 2 or 10 min increased stickiness (Fellers et al., 1983). Short-time steaming of rough rice is also effective in reducing the stickiness of cooked, treated, and milled rice (Desikachar and Subrahmanyam, 1957; Fellers and Deissinger, 1983).

"Stack burning," wherein the temperature of moist, freshly harvested rice rises over 60°C due to microbial respiration, is also a form of aging (IRRI, 1981, 1983a). The yellow grains are not gelatinized or parboiled but are more resistant to grinding in a Wig-L-Bug amalgamator and have higher head-rice recovery and higher starch GT than white grains in the same sample (IRRI, 1981).

Moritaka and Yasumatsu (1972b) proposed a mechanism of aging involving lipids, protein, and starch (Table XV). Lipids form free fatty acids, which can complex with amylose and carbonyl compounds, and hydroperoxides, which can accelerate protein oxidation and condensation plus accumulation of volatile carbonyl compounds. Protein oxidation, together with an increase in the strength of micelle binding of starch, inhibits swelling of starch granules and affects cooked rice texture. Protein oxidation also reduces the level of volatile sulfur compounds. Barber (1972) showed that formaldehyde vapor treatment reduces protein solubility in milled rice but reduces the amylograph peak viscosity of nonwaxy rice (Juliano, 1971a). Oxidation of ferulate esters of the hemicellulose fraction of the cell wall during storage may also contribute to the greater resistance of the grain to disintegration during cooking, as has been demonstrated for ferulate esters of wheat pentosans (Fausch et al., 1963).

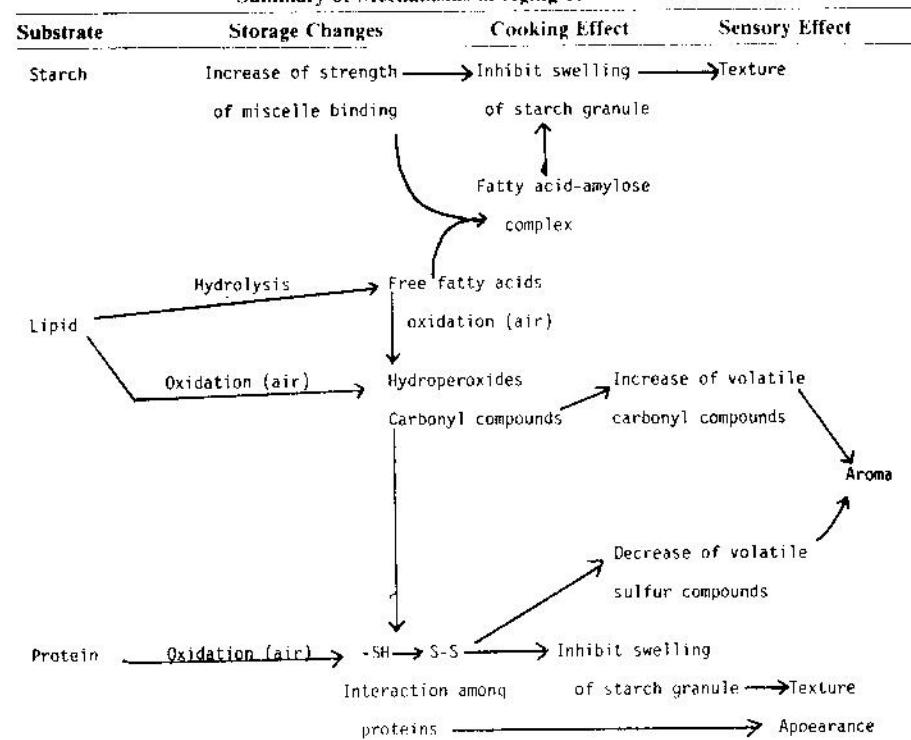
Defatting experiments on milled rice and rice flour have been undertaken to elucidate the role of lipids in storage changes. Hexane defatting of milled rice that removed 72–74% of nonpolar lipids (crude fat) did not affect its cooking quality (Moritaka et al., 1971a) but improved cooked rice flavor over that of undefatted milled rice of two varieties during storage for two and four weeks (Moritaka et al., 1972). The fat extraction reduced the level of unsaturated fatty acids that oxidizes into stale flavor of rice. Petroleum-ether defatting of two freshly harvested nonwaxy milled rices (82–88% defatting) improved raw rice whiteness, lowered gel consistency, increased amylograph viscosity, and retarded increase in raw rice hardness, free fatty acids, and carbonyl compounds during storage at 29°C. However, it had little effect on the following storage changes: increase in water-uptake ratio and reduction of extractable solids during cooking, lower stickiness of cooked rice, increase in amylograph peak viscosity, and decrease of gel consistency values (Villareal et al., 1976). Defatting milled rice with a

nonpolar organic solvent has no effect on the content of starch lipids (fat-by-hydrolysis) (Moritaka et al, 1971a). The nonstarch lipid content from hexane defatting affected texturometer hardness and adhesiveness of aged cooked rice (Moritaka et al, 1971b).

Defatting milled rice flour with diethyl ether also increased amylograph viscosity of the flour on aging (Barber, 1972). The aging effect is least with methanol-extracted, diethyl-ether defatted rice, but some increase was still observed. Diethyl-ether defatting of aged and unaged milled samples does not decrease the difference in amylograph pasting viscosity of the milled rices, although free fatty acids are extracted together with triglycerides and diglycerides (Shibuya et al, 1977b). Milled rices defatted with petroleum ether and hexane also increase in amylograph viscosity on storage (Moritaka et al, 1971a; Villareal et al, 1976). Ether-defatting of milled rice flours increases the amylograph viscosity of waxy rice flours more than that of nonwaxy rice flours (Shoji and Kurasawa, 1981a).

Defatting flours from milled rices stored for six months at 9°C and at room temperature with refluxing 85% methanol changed the shape of the amylogram and removed the difference due to storage temperature (Yasumatsu et al, 1964).

TABLE XV
Summary of Mechanisms of Aging of Rice Grain^a



^aSource: Moritaka and Yasumatsu (1972b); used by permission.

The increase in amylograph viscosity occurred 12°C earlier, and peak viscosity was similar to that of flour from rice stored at 9°C. Adding back the extracted lipid or its free fatty acid fraction restored the amylograph to its original shape. The neutral lipid fraction had no effect. Addition of palmitic, oleic, and linoleic acids to defatted rice powder up to a level of 0.7% of the defatted rice powder increased peak viscosity, above which little additional effect occurred. Corresponding analysis of fat-by-hydrolysis showed rapid increases up to 0.7% with the addition of the fatty acid mixture, above which there was little increase. Ohashi et al (1980) also reported that addition of 0.75% fatty acid to 95% methanol-defatted Japanese rice starch corresponds to maximum amylograph peak viscosity. Defatting freshly harvested milled rice with refluxing 85% methanol reduced the amylograph peak viscosity of the high-amyllose rice only but increased the peak viscosity of waxy rice and low-amyllose nonwaxy rice (Juliano, 1971a).

The contrasting results of defatting with petroleum or diethyl ether or hexane or with a more polar solvent such as 85% methanol (reflux) look surprising. However, the nonpolar solvents extract mainly nonstarch lipids, which explains the lack of effect on amylograph viscosity. Starch lipids are mainly free fatty acids, lysophosphatidylcholine, and lysophosphatidylethanolamine (Chapter 3) and are complexed with amylose. Removal of these lipids by refluxing 85% methanol affected the amylogram. Yasumatsu et al (1964) concluded that the increase in amylograph viscosity during storage is due mainly to the increase in free fatty acids complexed with amylose. However, the level of starch lipids as indexed by fat-by-hydrolysis does not increase during grain storage (Yasumatsu and Moritaka, 1964). Fat-by-hydrolysis is 0.53–0.55% at 13% moisture (0.61–0.63% db) for two varieties, with nonstarch lipids at 0.34–0.36% (0.39–0.41% db). Besides, waxy rice (1% amylose) also increases in amylograph viscosity during storage (Villareal et al, 1976; Shoji and Kurasawa, 1981b).

To verify the importance of oxygen in the aging mechanisms, storage experiments have been performed in an anaerobic atmosphere. Rice stored one year in nitrogen or carbon dioxide had lower acidity in water extract but still increased in fat acidity, peroxide content, and reducing sugars. Its ethanol content increased relative to that of storage in air (Iwasaki and Tani, 1967b). Overall organoleptic evaluation (palatability) of rice stored in nitrogen is similar to that in air at 20–25°C for two years, reflecting an aging effect (Yanai et al, 1979a). However, nitrogen is superior to air in preserving palatability of cooked rice during brown rice storage at 10°C for two years. No remarkable difference in quality was found between the brown rices stored in nitrogen or carbon dioxide. Storage in nitrogen had little effect on the texture changes of rice on cooking relative to storage in air (Perez and Juliano, 1981). Hermetic storage of milled rice at 30°C for three months under vacuum or the gases nitrogen, carbon dioxide, and air had little effect on reducing sugars, fat acidity, texturometer hardness, and adhesiveness of cooked rice at ≤14.7% storage moisture (Yanai et al, 1979b). At 15.7% moisture storage, vacuum packing showed the least changes, followed by gas package and then air package.

Degradation of cell wall of milled rice flour from brown rice stored for 10 months at 4 and 23°C by suspension in 0.1M acetate buffer with 1.5% *Trichoderma viride* cellulase and 0.75% *Aspergillus niger* pectinase in 0.6M sucrose for 25 hr at 36°C followed by washing removed the difference in

amylograph pasting viscosity of the two flours (Shibuya and Iwasaki, 1982). Microscopic examination confirmed the removal of a large portion of the cell walls and more ready separation of protein and starch granules during amylography in the treated flour. The results cannot be considered conclusive proof of the role of the cell wall in the increase in amylograph viscosity, since the cell wall is no longer a "structure-maintaining" component in the rice flour, and the commercial enzymes used are probably contaminated with carbohydrases and proteases. The reduction in protein content from 8.0 to 7.7% on enzymatic treatment may be due to albumin-globulin extraction plus proteolytic degradation. Oxidation of ferulate esters of hemicellulose may contribute to crosslinking and increased strength of cell walls during storage (Mod et al., 1983), as has been shown for wheat flour pentosans (Fausch et al., 1963).

Results to date indicate that starch granules and protein bodies in the endosperm undergo physicochemical changes during aging, making the endosperm harder and more resistant to disintegration during cooking. The role of lipids in these changes is still not very clear, but lipids definitely are involved in flavor deterioration of rice due to the oxidation of unsaturated fatty acids. The complexing of free fatty acids with amylose probably occurs after starch gelatinization, as demonstrated by differential scanning calorimetry (Kugumiya and Donovan, 1981); otherwise, aged rice should have a higher content of starch lipids (fat-by-hydrolysis) and the amylograph should have been affected by hexane or ether defatting. Ghiasi et al (1982) reported that monoglycerides enter the wheat starch granule to form an amylose complex even at 60°C, however. Rice starch stored at 70–90°C readily forms amylose-fatty acid particles because of its 0.8% fat content (Davies et al., 1980).

Starch probably undergoes physical change, since heat-moisture treatment can improve its amylograph characteristics also. Protein shows increased disulfide bonding (oxidation) during storage and probably also condensation with carbonyl compounds. The direct involvement of cell wall constituents still has to be demonstrated, since the increased insolubility of cell contents can also explain the reduced rupture of cell walls during cooking. Besides, milled rice cell wall extracts tend to reduce, rather than increase, gel viscosity of rice amylopectin (see Chapter 3). Based on amylograph peak viscosity changes, accelerated storage at 40°C increases the viscosity of all amylose types, although waxy rice gave anomalous behavior to palmitic acid addition and nonwaxy rices gave the wrong response to formaldehyde vapor treatment (Juliano, 1971a) (Fig. 18). Based on amylograph values and gel consistency, deterioration and aging are faster for milled rice than for rice stored as rough rice (Perez and Juliano, 1981) (Table XVI).

VI. QUALITY PREFERENCES IN VARIOUS COUNTRIES

Quality preferences in various rice-producing countries and even in regions in the same country are so diverse that no one variety is universally accepted. Such diversity is reflected in the quality evaluation of milled rices from various rice-producing countries in terms of protein and amylose contents, alkali spreading value, gel consistency, and amylograph consistency (Juliano and Pascual, 1980). For example, aging is considered a desired phenomenon in tropical Asia, but it lowers the eating quality in many countries consuming

TABLE XVI
Texture Changes in IR42 Stored as Milled and Rough Rice^a

| Property | Freshly Harvested | Milled Rice Stored for | | Rough Rice Stored for 14 mo |
|---------------------------|----------------------|------------------------|-------|-----------------------------------|
| | | 5 mo | 14 mo | |
| Gel consistency (mm) | 92 | 44 | 46 | 81 |
| Amylograph viscosity (BU) | | | | |
| Peak | 430 | 590 | 565 | 460 |
| Final at 95°C | 295 | 390 | 400 | 360 |
| Cooled to 50°C | 625 | 800 | 885 | 775 |
| Consistency | 330 | 410 | 485 | 415 |

^aData from Perez and Juliano (1981, 1982).

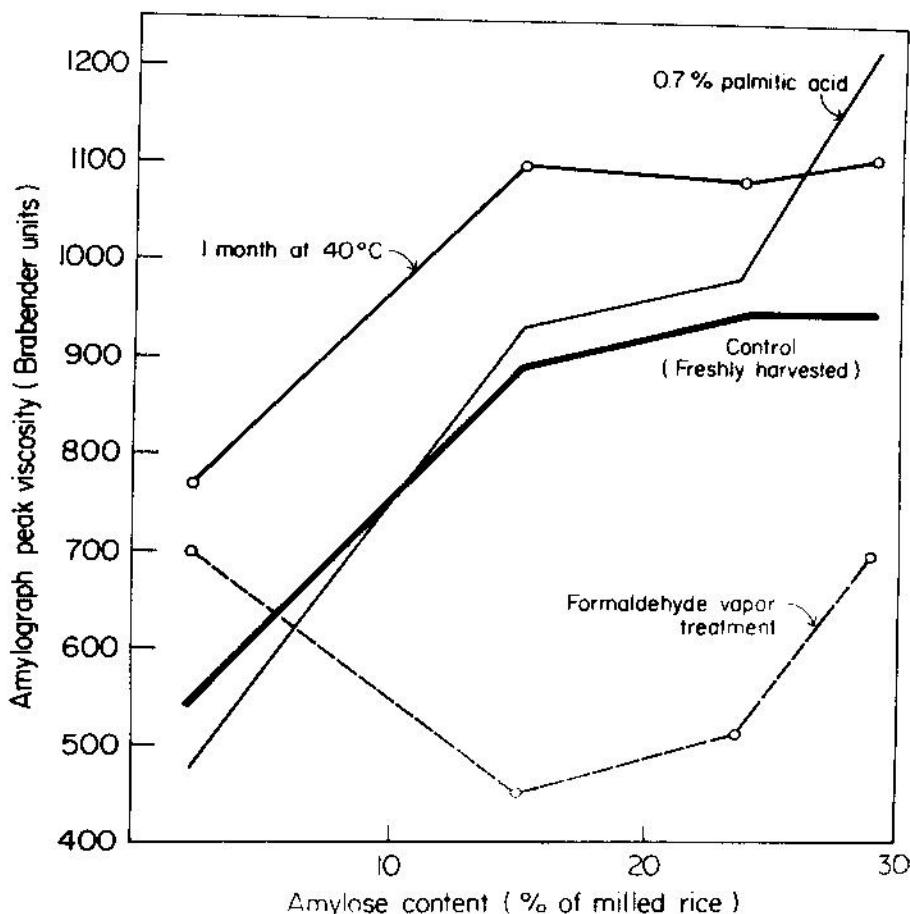


Fig. 18. Changes in the amylograph peak viscosity of milled rice of four freshly-harvested samples differing in amylose content resulting from simulated aging. (Reprinted, with permission, from Juliano, 1971a)

japonica rices. Because a brief review of quality preferences may not do full justice to all aspects of quality in various countries and because of the problem of getting representative rices in these countries, readers are requested to refer to references on specific countries for further details. The following discussion concerns *Oryza sativa*; *O. glaberrima* is discussed separately. Samples were obtained through the rice breeding programs of the appropriate government agency in each country.

Country samples (grown in the country of origin) differed widely in properties (Pascual and Juliano, 1980) (Table XVII). Linear correlation coefficients among milled rice properties confirmed that amylose content has the best correlation with other properties. It correlates negatively with alkali spreading value, gel consistency, and stickiness of cooked rice and positively with amylograph peak, setback, and consistency viscosity values and with hardness of cooked rice. The negative correlation of amylose with gel consistency is probably because hard gel types are mainly high-amyllose rices. The higher correlation coefficient of amylose content with cooked rice stickiness than of amylose content with hardness supports the fact that other factors such as gel consistency and protein content affect cooked rice hardness (Perez and Juliano, 1979). Physicochemical measurements, such as gel consistency and amylograph viscosity, also correlate better with hardness than with stickiness of cooked rice. Thus, hardness of cooked rice is the preferred property to measure in screening programs—rather than stickiness, which is predictable from amylose content.

A. Asia

The preference in Bangladesh is for high-amyllose rices, preferably parboiled, which are cooked in excess water (Choudhury, 1979) (Table XVIII). They have either low or intermediate GT, either long or medium slender grain, and predominantly soft gel consistency. Burmese rices have predominantly high amylose, intermediate or low GT, and medium gel consistency. The elongating variety Nga Kywe (D25-4) has short grain but shows more than double elongation on cooking of presoaked milled rice. Upland rices are also popular and have intermediate and low amylose content.

The rices of China are predominantly japonica in the north and indica in the south (IRRI, 1979b) (Table XVIII). In the Central region, indica rice is normally grown as the first rice crop and japonica rice as the second. Both types are also grown in Taiwan, China, together with waxy rices. Indica rices have generally higher amylose content than japonica rices, predominantly intermediate GT, and hard gel consistency. The source of the dwarfing gene in IR varieties is three Taiwan varieties with high amylose content, low GT, and hard gel consistency (Suzuki and Juliano, 1975). Hybrid rices from China have composition and quality similar to those of self-pollinated varieties. A recent study on Chinese rice varieties indicates that most of the *hsien* or indica rices have high amylose content, intermediate GT, and hard gel consistency; most of the *keng* (japonica) rices have low amylose content, low GT, and soft to medium gel consistency (Zhang and Tang, 1981). Similarly, in Taiwan, China, the native *sen* or indica rices have high amylose content and hard gel consistency and the *keng* or japonica rices have low amylose content (Chang and Li, 1981; Hsieh and Kuo, 1982).

TABLE XVII
Range and Mean Values and Simple Linear Correlation Coefficients Among Physicochemical Properties of Milled Rice from Various Countries^a

| Property | Protein (% at 14% H ₂ O) | Amylose (% db) | Alkali Spreading Value | Gel Consistency (mm) | Amylograph Viscosity (BU) | | Cooked-Rice Instron Hardness (kg) | Stickiness (g/cm) |
|---------------------------------------|---|--------------------|------------------------------|----------------------------|---------------------------|------------------|---|----------------------|
| | | | | | Peak | Setback | | |
| Observations (no.) | 1,079 | 1,090 | 1,082 | 761 | 553 | 553 | 266 | 268 |
| Range | 4.1-14.3 | 0-32.8 | 2.0-7.0 | 26-100 | 405-1,175 | 25-1,090 | 3.0-10.1 | 31-895 |
| Mean | 7.65 | 22.9 | 5.76 | 69.3 | 767 | 76 | 6.20 | 116 |
| Correlation coefficients ^b | | | | | | | | |
| Protein content | -0.03 (1.079) | -0.10** (1.074) | -0.22** (755) | -0.15** (551) | 0.11** (551) | 0.06 | 0.18** (266) | 0.04 (268) |
| Amylose content | | 0.18** (1.082) | -0.43** (755) | 0.29** (547) | 0.63** (547) | 0.72** (547) | 0.59** (266) | -0.82** (268) |
| Alkali spreading value | | | -0.06 (755) | -0.22** (547) | 0.02 (547) | 0.13** (547) | -0.14** (266) | 0.05 (268) |
| Gel consistency | | | | -0.16** (302) | -0.58** (302) | -0.60** (302) | -0.63** (266) | 0.40** (268) |
| Amylograph peak viscosity | | | | | 0.02 (553) | 0.40** (553) | 0.34** (266) | -0.42** (268) |
| Amylograph setback | | | | | | 0.89** (553) | 0.73** (236) | -0.38** (236) |
| Amylograph consistency | | | | | | | 0.75** (236) | -0.48** (236) |
| Cooked-rice hardness | | | | | | | | -0.54** (266) |

^aSource: Juliano and Pascoal (1980), used by permission.

^bNumber of samples correlated shown in parenthesis. * = $P < 0.05$. ** = $P < 0.01$.

India is a vast country with wide differences in preferred quality attributes (Bhattacharya, 1979a; Bhattacharya et al., 1982). The typical Indian rice cooks nonsticky but has soft, long and medium, slender grains; intermediate GT; high amylose content; and soft gel consistency (Table XVIII). However, many South Indian varieties have high amylose, medium gel consistency, and intermediate GT, giving a harder cooked rice. Several samples from North India are scented, fine grains with intermediate amylose content, low GT, and medium gel consistency (Juliano, 1979a; Sood and Siddiq, 1980; Bhattacharya et al., 1982). Several high-amylase intermediate-GT rices from Gujarat and Maharashtra are tiny (<12 mg), whereas those of Kerala are generally coarse and heavy (Bhattacharya et al., 1982). In contrast, the dryland varieties of the northeast and northwest regions of India are coarse and have big grains, intermediate or low amylose, low GT, and soft gel consistency; some are waxy. None of the

TABLE XVIII
Classification of Nonwaxy Milled Rice in Asian Countries Based on Amylose Content,
Starch Final Gelatinization Temperature (GT) and Gel Consistency*

| Country | Subspecies or Type | Samples (no.) | Protein Content (%) | Amylose Type ^b | Starch GT Type ^b | Gel Type ^c |
|--------------|--------------------|---------------|---------------------|---------------------------|-----------------------------|-----------------------|
| Bangladesh | Indica | 48 | 5-11 | H>I>L | I>I>HI | S>M, H |
| Burma | Indica | 33 | 5-10 | H>I>L | I, I>HI | M>S, H |
| China | Indica | 13 | 7-12 | H>I | I>I | H>M |
| | Japonica | 11 | 7-10 | I>I | I>I>HI | S>M |
| China-Taiwan | Indica | 13 | 5-11 | H>I>L | I>I | H>M, S |
| | Japonica | 24 | 4-9 | I>I | I>I | S |
| India | Indica | 61 | 5-11 | H>I>L | I>I>HI | S>H>M |
| Indonesia | Indica | 30 | 5-11 | I>H | I>L>HI | S>M>H |
| | Bulu | 23 | 5-11 | I>H | I>I, H | S, M>H |
| Iran | Indica | 23 | 5-12 | I, I>H | I>I | M>S |
| Japan | Japonica | 31 | 5-11 | I>I | I | S |
| Kampuchea | Indica | 15 | 4-9 | H>I, I | HI, I>I | H>S |
| Korea, South | Indica × | | | | | |
| | japonica | 54 | 7-11 | I | I>I | S>M |
| | Japonica | 72 | 6-9 | I>I | I>I | S>M |
| Laos | Indica | 3 | 6-7 | I>I | I>II | S |
| Malaysia | | | | | | |
| Sabah | Indica | 10 | 6-8 | H>I | I>I, HI | M>S |
| Sarawak | Indica | 27 | 5-9 | H>I, I | I>I>H | S>M>H |
| West | Indica | 26 | 6-9 | H>I | I>I>HI | S>M>H |
| Nepal | Indica | 46 | 5-9 | I>I, I | I>I>HI | S, H>M |
| Pakistan | Fine | 37 | 6-12 | I>H>L | I>I>H | H>M>S |
| | Coarse | 46 | 6-11 | I, H>I | I>I>H | H>S, M |
| Philippines | Wet-land | 82 | 6-13 | H>I>L | I, I | S>M>H |
| | Dry-land | 10 | 6-9 | I>I, H | I>I | S>M, H |
| Sri Lanka | Samba | 13 | 7-14 | H | I>I, HI | S>M |
| | Coarse | 44 | 6-12 | H | I>I>HI | S>H>M |
| Thailand | Wet-land | 35 | 5-12 | H>I>L | I>I>HI | S, H>M |
| | Floating | 14 | 6-11 | H | I>I | H>M, S |
| | Dry-land | 2 | 8 | I, H | I | M, H |
| Vietnam | Indica | 46 | 5-11 | H>I | I>I>HI | S>M>H |

*Data from Juliano and Pascual (1980) and IRRI, unpublished data.

^bI = low, I = intermediate, HI = intermediate-high, H = high.

^cS = soft, M = medium, H = hard.

Samples of Kampuchean (Cambodian) rices obtained in 1964 and 1972 are represented by all amylose and GT types, but high amylose and intermediate and high-intermediate GT predominate (Juliano and Pascual, 1980) (Table XVIII). Similarly, samples of Laotian rices obtained in 1965 consisted of five waxy, low-GT samples, one low-amylase high-GT sample, and two intermediate-amylase intermediate-GT samples (Juliano and Pascual, 1980) (Table XVIII). The Laotians are similar to Thais in north and northeast Thailand, with waxy rice as the staple food.

South Korean rices are traditionally japonica, but indica-japonica crosses are replacing the traditional varieties; the japonica rices are coarse short-grain, mainly low-amylase, and low-GT and have soft gel consistency (Juliano and Pascual, 1980) (Table XVIII). The indica \times japonica rices have properties similar to those of japonica rices, but the early varieties such as Tongil were more flaky than japonica rices such as Jinheung (Hwangbo et al., 1975; Perez and Juliano, 1979). Newer varieties analyzed in 1978 approached japonica rice in quality (IRRI, 1979c) but were about 1 mm longer than japonica milled rices (4.9–6.4 mm vs. 3.6–5.5 mm) (IRRI, 1984). Comparison of properties of selected Korean rices revealed higher amylograph viscosity and lower Instron stickiness of cooked rice for indica-japonica rice, intermediate between those of indica and japonica rices. Verification on the 1982 Korean crop showed amylograph peak viscosity of 740–1,330 BU (mean, 888 BU) for 11 japonica rices and 970–1,215 BU (mean, 1,129 BU) for 13 indica-japonica rices. However, cooked rice Instron values were similar for 43 japonica rices from the 1981 and 1982 crops at hardness values of 3.6–5.8 kg and stickiness of 0.8–4.0 g/cm and for 46 indica-japonica rices at hardness values of 3.6–5.9 kg and stickiness of 1.0–5.0 g/cm. Chung et al (1982) also found Milyang 23 starch to have higher amylograph peak viscosity than Akibare (japonica) starch. Consumers can still differentiate milled rice from each type, probably because the new semidwarf varieties still have a longer grain than the traditional japonica rice.

Rices from Sabah, East Malaysia, obtained in 1982 had mainly high amylose, low GT, and medium gel consistency (IRRI, 1983b) (Table XVIII). Corresponding samples from Sarawak, East Malaysia, showed mainly high amylose, intermediate GT, and soft gel consistency (Juliano and Pascual, 1980; Juliano, 1983b) (Table XVIII). Dryland varieties with intermediate and low amylose content, intermediate GT, and soft gel consistency have more popular eating qualities than the recommended varieties with high amylose content (Juliano, 1983b). One such interesting variety is Adan Buda, with 11% amylose, high GT, and medium gel consistency, which is used for preparation of rice sweets, probably in place of waxy rice.

West Malaysian rices are also mainly the high-amylase type, with intermediate GT, and soft gel consistency (Juliano and Pascual, 1980; Juliano, 1983b) (Table XVIII). However, intermediate-amylase and waxy rices are also present. Mahsuri, an indica-japonica variety, is quite popular in Malaysia and has high amylose content, intermediate GT, and medium gel consistency (Juliano, 1983b). It gave one of the softest cooked rices among the six Malaysian rices tested. Waxy rice is used for rice cakes, desserts, and sweets (IRRI, 1983a).

High-amylase rices predominate in samples from Nepal, with corresponding low GT and soft or hard gel consistency (Juliano and Pascual, 1980) (Table XVIII). A survey of dryland rices revealed predominantly low-amylase types.

Varieties for preparing popped rice such as Handiphool have high amylose content and intermediate GT.

Pakistani rices are broadly classified into fine scented rices such as Basmati and the coarse types represented by Mehran 59 (IR6-156-2) (Azeez and Shafi, 1966; IRR1, 1983a). The Basmati rices have intermediate amylose content, low GT, and medium gel consistency, which correlate to extreme elongation during cooking and soft texture of cooked rice (Juliano and Pascual, 1980) (Table XVIII). The grains are somewhat chalky in appearance. Basmati rices are affected by growing location; the best quality is claimed in the Punjab area of India and Pakistan, and rices grown there have low GT (Juliano, 1972b). The coarse varieties have high amylose content, low GT, and hard gel consistency. However, Mehran 59 is preferred over IR8 in terms of eating quality, and it has softer gel than IR8 at 80 mg/2 ml of 0.2N KOH and lower amylograph consistency than IR8 (IRR1, 1983a). Dwarf Red Gunja, used for *chapatis*, has properties similar to those of Mehran 59 but has a red pericarp.

All amylose types are represented in the Philippines, but the general preference is for intermediate- to low-amylose rices (Juliano et al 1964c; Merca et al, 1979; del Mundo and Juliano, 1981). Although C4-63G (with intermediate amylose, intermediate GT, and soft gel consistency) is a popular variety, consumer panel tests showed a preference for the texture of cooked low-amylose rices (del Mundo and Juliano, 1981). Dryland rices such as Azucena, Dinalaga, Mangarez, and Palawan have 18–22% amylose and are highly prized; some are aromatic (Juliano et al, 1964c). Among intermediate-amylose rices, cooked rice of C4-63G with intermediate-high GT is about 1 kg softer in cooked rice Instron hardness than BPI-121-407 with low GT (Perez and Juliano, 1979). High-amylose rices with intermediate GT and soft gel consistency, such as IR5 and IR32, are preferred over hard gel types, such as IR8 and IR42 (Juliano, 1983b). However, IR42 milled rice is higher priced, because of high milling recovery, translucency, and similar fine-grain characteristics, than the traditional variety Wagwag, and has a low percentage of immature grains. The variety IR36, with medium gel consistency, has a texture of cooked rice intermediate between those of IR32 (soft gel) and IR42 (hard gel). Scented rices such as Milagrosa and Azucena also bring high prices. The traditional waxy variety, Malagkit Sungsong, also has aroma and is still considered superior for the preparation of rice cakes and desserts to new varieties that also have low GT but no aroma.

All Sri Lankan varieties are high-amylose and have either small round grains (*samba*), 10–15 mg grains, or long, coarse grains (Breckenridge, 1979). Many varieties are red pericarped and processed either as parboiled or raw undermilled rice. Both types are mainly of intermediate GT and soft gel consistency (Juliano and Pascual, 1980). (Table XVIII). A consumer preference study in the Kandy district showed preference for red-pericarped, parboiled, medium-grain, undermilled rice (Breckenridge, 1979). The other combinations that are likely to be preferred are red-pericarped, raw, undermilled rice, especially in the southern coastal regions, and parboiled, white, well-milled *samba* rices in the urban areas. *Samba* rices have greater resistance to grain splitting during cooking and have cooked rice Instron hardness values of 6–7 kg (IRR1, 1980). Samples with soft gel consistency have lower amylograph peak viscosity and consistency, and parboiling further reduces amylograph viscosity.

In Thailand, good quality rice is defined as long (>7 mm), slender, translucent

grain that produces a fluffy, tender cooked product (Kongseree, 1979a). Many varieties have high amylose content, low GT, and variable gel consistency (Juliano and Pascual, 1980; Juliano, 1983b) (Table XVIII). Taste panel tests indicate that intermediate-amylase varieties with soft gel consistency are preferred over high-amylase rice, such as RD7 and Khao Pakh Maw 148, with intermediate to high-intermediate GT (Juliano et al, 1964c; Kongseree, 1979a). Many wetland Thai varieties have low GT (Juliano et al, 1964c). A popular low-amylase wetland variety, Khao Dawk Mali 105, may owe its popularity to its aroma, but its popularity in the northeast may be due to its cooked texture intermediate between those of waxy and intermediate- to high-amylase rices. Waxy rices, such as Niaw San Pahtawng, are a staple food in north and northeast Thailand. These are presoaked and steamed instead of boiled and are predominantly low GT (Kongseree, 1979b). The waxy variety RD4, with high GT, has poor eating quality. Deepwater or floating rices predominantly have high amylase, intermediate GT, and soft gel consistency (Kongseree, 1979a). Resistance to grain cracking is a desired property of floating rice.

Vietnamese varieties have high or intermediate amylase, intermediate GT, and soft gel consistency. Intermediate-amylase rices are preferred for their soft cooked rice, particularly aromatic traditional varieties such as Nang Thóm and Tau Huóng (Juliano et al, 1964c). Thus, the preference for intermediate-amylase rices is similar to that of Filipinos, Indonesians, and Thais. However, all the current recommended varieties have high amylase, low or intermediate GT, and hard to medium gel consistency (IRRI, 1983b).

B. Other Regions

Relatively less work has been done on African rices. High-amylase rices predominate in Ghana, Liberia, Nigeria, Senegal, and Sierra Leone, but low-amylase rices are important in Egypt and, of two samples from Ivory Coast, one had high amylase content and the other intermediate (Juliano and Pascual, 1980) (Table XIX). Traditional Egyptian rices with low and intermediate amylase, low GT, and soft gel consistency are short- to medium-grain, but high-amylase, long-grain, semidwarf varieties have been introduced recently. Dry-land African varieties such as OS4 and OS6 have intermediate to low amylase, variable GT, and soft gel consistency.

North American samples were derived from only four countries. IR8-type rices are common in Cuba, which explains the presence of more high-amylase rices with low GT than other types (Castillo et al, 1978) (Table XIX). IR8 splits more during cooking than two other high-amylase varieties, IR880-C9 and Naylamp, and the low-amylase variety IR1529 (IRRI, 1980). Mexican rices were mainly high- and intermediate-amylase rices (Table XIX), except for the low-amylase variety Joachin A74 analyzed in 1978. Both amylase types have either low or intermediate GT. Soft gel consistency predominates among Mexican rices. Samples from El Salvador are mainly intermediate-amylase with low GT and soft or medium gel consistency (Table XIX).

U.S. rices are divided into short- and medium-grain and long-grain types with distinct cooking properties (Webb et al, 1979) (Table XIX). The long-grain varieties cook dry and fluffy, and the cooked grains tend to remain separate. They are mainly intermediate-amylase, intermediate-GT, and soft-gel

consistency rices (Webb et al., 1979). Cooked grains of typical medium- and short-grain varieties are more moist and chewy than those of long-grain types, and the grains tend to clump together; they have low amylose, low GT, and soft to medium gel consistency. U.S. rices are discussed in Chapter 11.

Rices with intermediate amylose content, low GT, and soft gel consistency are common to Argentina and Chile, but both low- and intermediate-amyllose rices with low and intermediate GT are popular in Brazil (Juliano and Pascual, 1980) (Table XIX). Dryland varieties are popular in Brazil, and the U.S. variety Bluebell is included in the 1976 samples.

In the other South American countries, Colombia, Peru, and Surinam, high-amylose rices predominate, with low GT in Colombia and Peru and intermediate

TABLE XIX
Classification of Nonwaxy Milled Rice in Countries Outside of Asia Based on Amylose Content, Starch Gelatinization Temperature (GT), and Gel Consistency^a

| Country | Samples (no.) | Protein Content (%) | Amylose Type ^b | Starch GT Type ^b | Gel Type ^c |
|--------------------------|---------------|---------------------|---------------------------|-----------------------------|-----------------------|
| Africa | | | | | |
| Egypt | 36 | 5-9 | I>I, II | I>I | S>H, M |
| Ghana | 6 | 8-9 | H>I | I | S |
| Ivory Coast | 2 | 8-9 | I, I | I, II | S |
| Liberia | 4 | 6-9 | H>I | I, I | M>S, H |
| Nigeria | 43 | 6-11 | H>I>II | I>I>H | H>S>M |
| Senegal | 3 | 5-7 | H | I | S>M |
| Sierra Leone | 24 | 5-10 | H>I, I | I>I | S>M |
| North America | | | | | |
| Cuba | 10 | 6-8 | H>I, I | I>I | M>S, H |
| Mexico | 28 | 5-10 | H, I>I | I, I>H | S>M>H |
| El Salvador | 7 | 7-11 | I>H | I>I | S, M |
| USA | | | | | |
| Long | 11 | 6-8 | I, H | I | S |
| Short/medium | 16 | 5-7 | I | I | S>M |
| South America | | | | | |
| Argentina | 20 | 6-9 | I>I>H | I>I | S>M |
| Brazil | 16 | 5-12 | I, I | I, I>H | S>M>H |
| Chile | 4 | 8-10 | I | I | S |
| Colombia | 16 | 6-11 | H>I | I>I | S, M>H |
| Peru | 22 | 5-11 | H>I, I | I>I>H | H, S>M |
| Surinam | 20 | 6-9 | H>I, I | I>I, H, II | S>M, H |
| Europe | | | | | |
| Bulgaria | 16 | 6-10 | I, I | I | S |
| France | 24 | 5-12 | I>I | I | S>M |
| Hungary | 16 | 6-8 | I | I | M, S |
| Italy | 37 | 5-8 | I>I | I | S>M>H |
| Portugal | 21 | 5-8 | I>I | I | S |
| Spain | 7 | 6-13 | I, I | I | S |
| Oceania-Australia | | | | | |
| Long | 10 | 6-8 | I, I | I | S |
| Short | 6 | 6-8 | I, I | I | S |
| USSR | 15 | 5-8 | I>I | I>I | S |

^aData from Juliano and Pascual (1980) and IRRI, unpublished data.

^bI = low, I+ = intermediate, HI = intermediate-high, H = high.

^cS = soft, M = medium, and H = hard.

GT in Surinam (Juliano and Pascual, 1980) (Table XIX). Most of the Colombian varieties from the Centro Internacional de Agricultura Tropical and Instituto Colombiano Agropecuario have low GT. High-amylase rices with low GT and hard gel consistency are common in Colombia and Peru. The varieties from Stichting Machinale Landbouw in Surinam have characteristic big, coarse, long grains.

The European rices are mainly short- and medium-grain japonica varieties with low to intermediate amylose content, low GT, and soft gel consistency, as represented by samples from Bulgaria, France, Hungary, Italy, Portugal, and Spain (Juliano and Pascual, 1980) (Table XIX). Among the French rices, only the variety Arlésienne (21–24% amylose) has medium gel consistency and is considered to have excellent cooking quality, being preferred over the other rices with low amylose content and soft gel consistency (Feillet and Marie, 1979). Arlésienne has firmer cooked rice than the other French rices (Juliano et al., 1981a). Hungarian rices have mainly intermediate amylose and soft to medium gel consistency. Most of the Italian rices also have soft to medium gel consistency, except Raffaello (24–25% amylose) with hard gel consistency. Rice is prepared mainly as risotto with added vegetables, such as mushrooms, spices, or meats, and is served just like pasta. Among the Portuguese rices, the highest-amylase rice is Ponta Rubra (23–25% amylose), which gives positive amylograph setback but soft to medium gel consistency. The Spanish variety Babia (24% amylose) accounts for over 65% of the national rice production (Barber and Tortosa, 1979). This may explain the ready preference in Spain for aged rice (Barber, 1972), in contrast to Japan and Korea, which prefer lower-amylase japonica varieties.

Australians are traditional eaters of short- or medium-grain rice but have been changing to predominantly long-grain rice over the past decade (Blakeney, 1979b). The two main varieties grown are Calrose, a medium-grain rice (19% amylose), and Inga, a long-grain rice (22% amylose). Inga rice samples were analyzed as low-amylase at IRRI (Juliano and Pascual, 1980; Juliano et al., 1981a). Australian long-grain rices have low to intermediate amylose content, intermediate GT, and soft gel consistency; short- and medium-grain rices have starch properties similar to these except for low GT (Blakeney, 1979b; Juliano and Pascual, 1980) (Table XIX). Inga (17% amylose) has softer cooked rice than the U.S. long-grain variety Labelle (23% amylose) when cooked in excess water for optimum cooking time and by the rice cooker method (Juliano et al., 1981a). Inga has been replaced by Pelde.

Samples from the USSR are also mainly intermediate-amylase rices with low GT and soft gel consistency (Juliano and Pascual, 1980) (Table XIX). A few (four) low-amylase rices (18–20%) also are present; these have intermediate GT and are probably not japonica rices, since the japonica rice has low GT.

C. *Oryza glaberrima* and Other Samples

Most *O. glaberrima* samples analyzed have red pericarp and starch properties similar to those of *O. sativa*. Most of 182 traditional *O. glaberrima* accessions from the International Institute of Tropical Agriculture have red pericarp, but six were not pigmented (IRRI, 1983a). Milled rice amylose content ranged from 21.7 to 30.0%, db; 130 were high-amylase and the rest, intermediate-amylase. All

were mainly of low starch GT, ranging in alkali spreading value from 4.8 to 7.0. One hundred had soft gel consistency, 68 had medium gel consistency, and 14 had hard gel consistency. Nine of those with hard gel consistency had intermediate amylose content. Earlier, 15 samples of *O. glaberrima* analyzed at IRRI had 18.9–29.2% amylose and intermediate GT (IRRI, 1966; Ignacio and Juliano, 1968).

Analysis of 11 wild species and two interspecific hybrid samples showed endosperm starch properties similar to those of *O. sativa* (Ignacio and Juliano, 1968). Amylose content ranged from 16.8 to 23.9% for nonwaxy brown rices, and starch GT ranged from low to high (60–78°C). The high-GT samples were mainly low-amylose types. Eight samples of *O. brevilegulata* A. Chev. et Roehr. had 25.4–30.4% amylose and intermediate GT (IRRI, 1966). *O. nivara* was used in the breeding program as a source of resistance to grassy stunt in IR30, IR32, IR38, and IR40, without any adverse effect on grain quality.

Milled-rice samples of four rice-sorghum hybrids showed 14.9–23.9% amylose (mean, 18.2%), soft gel consistency (84–100 mm), alkali values of 3.9–7.0 (low>intermediate>high), and protein content ($N \times 5.95$) of 9.0–10.7% (IRRI, 1980). The lysine content of the protein ranged from 3.1 to 3.6 g/16.8 g of N, which is closer to that of rice protein than to that of sorghum protein (1–2% lysine).

Seeds of a rice-wheat hybrid from China have incompletely covered hull and are somewhat curved; some have slight grooves at the dorsal and ventral surfaces (IRRI, 1983a). The milled grain has 25% amylose, an alkali spreading value of 4.3 (intermediate GT), and medium (56 mm) gel consistency. Cracking hardness is lower than for milled rice, probably due to its higher moisture content. It has 10.8% protein and 4.1 g of lysine per 16.8 g of N. Sodium dodecyl sulfate (SDS)-polyacrylamide gel electrophoresis of proteins soluble in 0.5% SDS-0.6% β -mercaptoethanol showed the characteristic subunits of rice protein.

World germ-plasm bank entries showed 11.6% waxy (0–2% amylose), 2.9% very low-amylose (3–9%), 15.6% low-amylose (10–19%), 39.5% intermediate-amylose (20–24%), and 30.4% high-amylose (>24%) brown rice, dry weight basis (IRRI, 1979c). The amylose content of defatted brown rice is one percentage point lower than that of milled rice, mainly because of its lower starch content

TABLE XX
Linear Correlation Coefficients Among Amylose Content,
Alkali Digestibility, and Protein Content of
14,583 Germ-Plasm Bank Brown-Rice Entries^a

| Property | Simple Correlation Coefficient ^b with | | |
|----------------------|--|-----------------|-----------------|
| | Alkali Digestibility | Protein Content | |
| | | Dry Season | Wet Season |
| Amylose content | -0.35** (14,583) | -0.13** (8,807) | -0.14** (5,955) |
| Alkali digestibility | | -0.21** (8,969) | 0.16** (5,994) |
| Protein, dry season | | | 0.36** (747) |

^aData from IRRI (unpublished, 1981).

^bNumber of samples correlated shown in parenthesis. ** = $P < 0.01$.

(Perez and Juliano, 1978). Amylose content correlated negatively with alkali digestibility scores and with protein content (IRRI, 1979c, 1981, unpublished data) (Table XX), which confirmed the partial data on 10,517 germ-plasm bank entries.

High amylose content is incompletely dominant to low and is controlled by a major gene and several modifiers (Chang and Somrith, 1979; Chang and Li, 1981). Progenies having intermediate amylose content are readily recovered from crosses between high-amylase semidwarf varieties and intermediate-amylase upland rices. The waxy condition of the endosperm is under control of a single recessive gene (Chang and Somrith, 1979). Hard gel consistency is conditioned by a single dominant gene and is closely associated with high amylose content in F₂ populations (Chang and Li, 1981).

Crosses between intermediate-GT and high-GT varieties have only intermediate- and high-GT types (Chang and Somrith, 1979). High-GT types such as Century Patna 231 have been obtained from crosses between intermediate-GT and low-GT varieties. Some crosses between high-GT and low-GT parents give high, intermediate, and low segregants, but the intermediate GT type is deficient and fails to breed true. The dominance of high GT in such cross combinations is common in several F₂ populations.

VII. SUMMARY

Market quality is affected by grain size and shape, milling quality, degree of milling, and grain appearance—brokens, chalkiness, translucency, and whiteness. Unfortunately, these physical properties do not predict cooking and eating qualities, which have to be determined by actual cooking and by physicochemical methods such as amylose content, starch GT, or gel consistency. Nutritional quality is also not visually apparent and requires at least protein analysis. Lysine content is fortunately predictable from protein content, together with nutritional value, because of the low levels of antinutritional factors in milled rice. These qualities are influenced by aging or storage changes, which rice technologists should be aware of. Lastly, a brief review is presented on quality characteristics of rices from rice-producing countries and world collection samples, on other *Oryza* species, and on other rice hybrids.

Simple, rapid tests for these quality characteristics are needed in rice-breeding programs; such tests must be readily run by nonchemists but without loss of accuracy. A priority area is milling quality.

LITERATURE CITED

- AL-BAYATI, S. H., and LORENZ, K. 1975. Physico-chemical properties of starches isolated from Iraqi rice varieties. *Lebensm. Wiss. Technol.* 8:163-167.
- ALI, S. Z., and BHATTACHARYA, K. R. 1972. An alkali reaction test for parboiled rice. *Lebensm. Wiss. Technol.* 5:216-218.
- ANTONIO, A. A., and JULIANO, B. O. 1974. Physicochemical properties of glutinous rices in relation to pinipig quality. *Philipp. Agric.* 58:17-23.
- ANTONIO, A. A., JULIANO, B. O., and DEL MUNDO, A. M. 1975. Physicochemical properties of glutinous rice in relation to "suman" quality. *Philipp. Agric.* 58:351-355.
- AZEEZ, M. A., and SHAFI, M. 1966. Quality in Rice. Dep. Agric. Gov. West Pakistan Tech. Bull. 13. 50 pp.
- BALDI, G., FOSSATI, G., RANGHINO, F., and FANTONE, G. C. 1977. Conservazione

- del riso: Variazioni in contenuto proteico, frazioni proteiche, composizione amminocidica. Riso 26:253-265.
- BARBER, S.** 1969. Basic studies on aging of milled rice and application to discriminating quality factors. Inst. Agroquim. Tecnol. Aliment., Valencia, Spain. Project E025-AMS-(9), final report. U.S. Dep. Agric., ARS, Foreign Res. Tech. Program Div. 189 pp.
- BARBER, S.** 1972. Milled rice and changes during aging. Pages 215-263 in: Rice: Chemistry and Technology, 1st ed. D. F. Houston, ed. Am. Assoc. Cereal Chem., St. Paul, MN.
- BARBER, S., and BENEDITO DE BARBER, C.** 1979. Outlook for rice milling quality evaluation systems. Pages 209-221 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BARBER, S., and JULIANO, B. O.** 1971. Optimizing technologies of rice processing and utilization. Pages 5-12 in: Proc. World Cereal Bread Congress 5th, Dresden. Vol. 4. VEB Fachbuchverlag, Leipzig.
- BARBER, S., and TORTOSA, E.** 1979. Rice grain quality evaluation in Spain. Pages 167-173 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BARBER, S., BHATTACHARYA, K. R., FEILLET, P., IKEHASHI, H., DEL MUNDO, A. M., MURTY, V. V. S., and SIVASUBRAMANIAN, V.** 1979. Priority research problem areas for assessment of grain quality in rice-breeding programs—Workshop committee report. Pages 377-379 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BATCHER, O. M., HELMINTOLLER, K. F., and DAWSON, E. H.** 1956. Development and application of methods for evaluating cooking and eating quality of rice. Rice J. 59(13):4-8, 32.
- BATCHER, O. M., DEARY, P. A., and DAWSON, E. H.** 1957. Cooking quality of 26 varieties of milled white rice. Cereal Chem. 34:277-285.
- BATCHER, O. M., STALEY, M. G., and DEARY, P. A.** 1963a. Palatability characteristics of foreign and domestic rices cooked by different methods. I. Rice J. 66(9):19-24.
- BATCHER, O. M., STALEY, M. G., and DEARY, P. A.** 1963b. Palatability characteristics of foreign and domestic rices cooked by different methods. II. Rice J. 66(10):13-16.
- BAUTISTA, G. M., LUGAY, J. C., CRUZ, L. J., and JULIANO, B. O.** 1964. Glutamic acid decarboxylase activity as a viability index of artificially dried and stored rice. Cereal Chem. 41:188-191.
- BEACHELL, H. M., KHUSH, G. S., and JULIANO, B. O.** 1972. Breeding for high protein content in rice. Pages 419-428 in: Rice Breeding. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BHASHYAM, M. K., RAJU, G. M., SRINIVAS, T., and NAIDU, B. S.** 1985. Physico-chemical studies in relation to cracking properties in rice using isogenic lines. J. Food Sci. Technol. 21:272-277.
- BHATTACHARYA, K. R.** 1979a. Status of rice breeding for grain quality in India. Pages 135-148 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BHATTACHARYA, K. R.** 1979b. Gelatinization temperature of rice starch and its determination. Pages 231-249 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BHATTACHARYA, K. R.** 1979c. Tests for parboiled rice. Pages 363-373 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BHATTACHARYA, K. R., and SOWBHAGYA, C. M.** 1971. Water uptake by rice during cooking. Cereal Sci. Today 16:420-424.
- BHATTACHARYA, K. R., and SOWBHAGYA, C. M.** 1972a. A colorimetric bran pigment method for determining the degree of milling of rice. J. Sci. Food Agric. 23:161-169.
- BHATTACHARYA, K. R., and SOWBHAGYA, C. M.** 1972b. An improved alkali reaction test for rice quality. J. Food Technol. 7:323-331.
- BHATTACHARYA, K. R., and SOWBHAGYA, C. M.** 1979. Pasting behavior of rice: A new method of viscometry. J. Food Sci. 44:797-800, 804.
- BHATTACHARYA, K. R., and SOWBHAGYA, C. M.** 1980. On the alkali degradation type of rice kernels. J. Sci. Food Agric. 31:615-618.
- BHATTACHARYA, K. R., and SOWBHAGYA, C. M.** 1981. An abridged Brabender viscomograph test. Lebensm. Wiss. Technol. 14:79-81.
- BHATTACHARYA, K. R., DESIKACHAR, H. S. R., and SUBRAHMANYAN, V.** 1964. Curing of freshly harvested rice by heat treatment. Indian J. Technol. 2:378-380.
- BHATTACHARYA, K. R., SOWBHAGYA, C. M., and INDUDHARA SWAMY, Y. M.**

1972. Interrelationship between certain physicochemical properties of rice. *J. Food Sci.* 37:733-735.
- BHATTACHARYA, K. R., SOWBHAGYA, C. M., and INDUDHARA SWAMY, Y. M.** 1978. Importance of insoluble amylose as a determinant of rice quality. *J. Sci. Food Agric.* 29:359-364.
- BHATTACHARYA, K. R., SOWBHAGYA, C. M., and INDUDHARA SWAMY, Y. M.** 1982. Quality profiles of rice: A tentative scheme for classification. *J. Food Sci.* 47:564-569.
- BLAKENEY, A. B.** 1979a. Rice grain quality evaluation in Australia. Pages 115-121 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BLAKENEY, A. B.** 1979b. Instron measurement of cooked-rice texture. Pages 343-353 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- BOLLING, H., and EL BAYĀ, A. W.** 1975. Einfluss der Lipide auf die Bestimmung des Amylosegehaltes in Reis und Weizen. *Chem. Mikrobiol. Technol. Lebensm.* 3:161-163.
- BOLLING, H., HAMPEL, G., and EL BAYĀ, A. W.** 1977. Changes in physical and chemical characteristics of rice during prolonged storage. *Riso* 26:65-69.
- BOLLING, H., HAMPEL, G., and EL BAYĀ, A. W.** 1978. Studies on storage of milled rice for a long period. *Food Chem.* 3:17-22.
- BORASIO, L.** 1962. Qualité et évaluation des paddy et des riz usines. Méthodes d'analyse et d'appréciation des caractéristiques physico-organoleptiques. *Agron. Trop.* 17:979-1010.
- BORASIO, L.** 1965. Aspect actual de l'analyse et de l'appréciation des riz. *Riso* 14:41-65.
- BOURNE, M. C.** 1978. Texture profile analysis. *Food Technol.* 32(7):62-66, 72.
- BRECKENRIDGE, C.** 1979. Rice grain evaluation in Sri Lanka. Pages 175-181 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- CAGAMPANG, G. B., PEREZ, C. M., and JULIANO, B. O.** 1973. A gel consistency test for eating quality of rice. *J. Sci. Food Agric.* 24:1589-1594.
- CASTILLO T., D., HENRIQUEZ R., D., HERNANDEZ L., A., MOSÉS W., A., and CASTILLO S., D.** 1978. Estudio fisico-químico de almidones de 38 variedades de arroz (*Oryza sativa*) cultivadas en temporada seca. *Cienc. Tec. Agric. Arroz* 1(1):45-68.
- CHANDLER, R. F., Jr.** 1979. *Rice in the Tropics: A Guide to the Development of National Programs*. Westview Press, Inc., Boulder, CO. 256 pp.
- CHANG, T. T., and SOMRITH, B.** 1979. Genetic studies on the grain quality of rice. Pages 49-58 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- CHANG, W.-L., and LI, W.-Y.** 1981. Inheritance of amylose content and gel consistency in rice. *Bot. Bull. Acad. Sinica* 22:35-47.
- CHEIGH, H.-S., KIM, S.-K., PYUN, Y.-R., and KWON, T.-W.** 1978. Kinetic studies on cooking of rice of various polishing degrees. *Korean J. Food Sci. Technol.* 10:52-56.
- CHIKUBU, S.** 1975. Quality of rice in South-East Asia. Pages 537-549 in: *Rice in Asia*. Assoc. Jpn. Agric. Sci. Soc. Univ. Tokyo Press, Tokyo.
- CHIKUBU, S., ENDO, I., and TANI, T.** 1964. Studies on cooking and eating qualities of white rice. II. Measurement of viscoelastic behavior of cooked rice by the parallel plate plastometer. *Eijo To Shokuryo* 16:407-410.
- CHOUDHURY, N. H.** 1979. Studies on quality of rice in Bangladesh. Pages 123-127 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- CHOUDHURY, N. H., and JULIANO, B. O.** 1980. Effect of amylose content on the lipids of mature rice grain. *Phytochemistry* 19:1385-1389.
- CHUNG, H.-M., AHN, S.-Y., and KIM, S.-K.** 1982. Comparison of physico-chemical properties of Akibare and Milyang 23 rice starch. *J. Korean Agric. Chem. Soc.* 25:67-74. (In Korean)
- COFFMAN, W. R., and JULIANO, B. O.** 1979. Seed protein improvement in rice. Pages 261-277 in: *Seed Protein Improvement in Cereals and Grain Legumes*, Vol. II. Int. Atomic Energy Agency, Vienna.
- DAMARDJATI, D. S.** 1983. Physical and chemical properties and protein characteristics of some Indonesian rice varieties. D. Agric. Sc. dissertation, Bogor Agric. Univ., Bogor, Indonesia. 294 pp.
- DAVIES, T., MILLER, D. C., and PROCTER, A. A.** 1980. Inclusion complexes of free fatty acids with amylose. *Stärke* 32:149-158.
- DEL MUNDO, A. M.** 1979. Sensory assessment of cooked milled rice. Pages 313-325 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- DEL MUNDO, A. M., and JULIANO, B. O.** 1981. Consumer preference and properties of raw and cooked milled rice. *J. Texture Stud.* 12:107-120.
- DESHIPANDE, S. S., and BHATTACHARYA,**

- K. R. 1982. The texture of cooked rice. *J. Texture Stud.* 13:31-42.
- DESIKACHAR, H. S. R. 1956. Changes leading to improved culinary properties of rice on storage. *Cereal Chem.* 33:324-328.
- DESIKACHAR, H. S. R., and SUBRAHMANYAN, V. 1957. The curing of freshly harvested paddy. Parts I and II. *J. Sci. Ind. Res. India* 16A:365-370.
- DESIKACHAR, H. S. R., and SUBRAHMANYAN, V. 1959. Expansion of new and old rice during cooking. *Cereal Chem.* 36:385-391.
- DESIKACHAR, H. S. R., and SUBRAHMANYAN, V. 1960. The relative effects of enzymatic and physical changes during storage on the culinary properties of rice. *Cereal Chem.* 37:1-8.
- DESIKACHAR, H. S. R., and SUBRAHMANYAN, V. 1961. The formation of cracks in rice during wetting and its effect on the cooking characteristics of the cereal. *Cereal Chem.* 38:356-364.
- EBATA, M. 1968. Studies on the alkali decomposition of rice kernel. III. A new alkali test using rice flour. *Nippon Sakumotsu Gakkai Kiji* 37:510-515.
- EBATA, M. 1978. Studies on diagnosis of rice grains by photometric method. IV. Estimation of milling degree and quality evaluation of milled rice. *Nippon Sakumotsu Gakkai Kiji* 47:400-407.
- EBATA, M., and HIRASAWA, K. 1982. Studies on the texture of cooked rice. I. Textural parameters in relation to palatability. *Nippon Sakumotsu Gakkai Kiji* 51:235-241.
- EGGUM, B. O. 1973. A study of certain factors influencing protein utilization in rats and pigs. *Publ. 406. Natl. Inst. Anim. Sci.*, Copenhagen. 173 pp.
- EGGUM, B. O., JULIANO, B. O., and MANINGAT, C. C. 1982. Protein and energy utilization of rice milling fractions by rats. *Qual. Plant. Plant Foods Human Nutr.* 31:371-376.
- ELLIS, J. R., VILLAREAL, C. P., and JULIANO, B. O. 1985. Protein content, distribution and retention during milling of brown rice. *Qual. Plant. Plant Foods Hum. Nutr.* 35. In press.
- ENDO, I., CHIKUBU, S., SUZUKI, M., KOBAYASHI, K., and NAKA, M. 1976. Palatability evaluation of cooked milled rice by physicochemical measurement. *Shokuhin Sogo Kenkyusho Kenkyu Hokoku* 31:1-11.
- ENDO, I., CHIKUBU, S., and TANI, T. 1977. Measurement of volatile carbonyl compounds in the vapor of cooked rice. *J. Jpn. Soc. Food Sci. Technol.* 24:142-144. (In Japanese)
- ENDO, I., YANASE, H., ISHIMA, T., and CHIKUBU, S. 1980. Texture measurement of a very small amount of cooked rice by Textrometer. I. Investigation of measurement conditions and application to main rice varieties. *Shokuhin Sogo Kenkyusho Kenkyu Hokoku* 37:1-8.
- FAUSCH, H., KÜNDIG, W., and NEUKOM, H. 1963. Fericlic acid as a component of a glycoprotein from wheat flour. *Nature* 199:287.
- FEILLET, P., and MARIE, R. 1979. Rice breeding for grain quality in France. Pages 129-133 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- FELIFRS, D. A., and DEISSINGER, A. E. 1983. Preliminary study on the effect of steam treatment of rice paddy on milling properties and rice stickiness. *J. Cereal Sci.* 1:147-157.
- FELIFRS, D. A., MOSSMAN, A. P., and SUZUKI, H. 1983. Rice stickiness. II. Application of an Instron method to make some varietal comparisons and to study modification of milled rice by hot-air treatment. *Cereal Chem.* 60:292-295.
- FERREL, R. E., and PENCE, J. W. 1964. Use of the amylograph to determine extent of cooking in steamed rice. *Cereal Chem.* 41:1-9.
- FRIEDMAN, H. H., WHITNEY, J. E., and SZCZESNIAK, A. S. 1963. The texturometer - A new instrument for objective texture measurement. *J. Food Sci.* 28:390-396.
- GHIASI, K., VARRIANO-MARSTON, E., and HOSENEY, R. C. 1982. Gelatinization of wheat starch. II. Starch-surfactant interaction. *Cereal Chem.* 59:86-88.
- GHOSH, B. P., and SARKAR, N. 1959. Effect of some inorganic salts on water absorption by rice during cooking. *Ann. Biochem. Exp. Med.* 19:83-86.
- HALICK, J. V., and KELLY, V. J. 1959. Gelatinization and pasting characteristics of rice varieties as related to cooking behavior. *Cereal Chem.* 36:91-98.
- HALICK, J. V., and KENEASTER, K. K. 1956. The use of a starch-iodine-blue test as a quality indicator of white milled rice. *Cereal Chem.* 33:315-319.
- HALICK, J. V., BEACHELL, H. M., STANSEL, J. W., and KRAMER, H. H. 1960. A note on the determination of gelatinization temperatures of rice varieties. *Cereal Chem.* 37:670-672.
- HALL, V. L., and JOHNSON, J. R. 1966. A revised starch-iodine blue test for raw milled rice. *Cereal Chem.* 43:297-302.
- HAMPEL, G. 1968. Quality tests on rice for world trade. *Cereal Sci. Today* 13:64-70.
- HOGAN, J. T. 1963. Rice research at Southern Laboratory. *Rice J.* 66(7):38-41.

- HOGAN, J. T., and DEOBALD, H. J. 1965. Measurement of the degree of milling of rice. *Rice J.* 68(10):10, 12-13.
- HOKI, M. 1979. Mechanical properties of selected indica rice as compared with japonica. *Bull. Fac. Agric. Mie Univ.* 58:143-146.
- HORIUCHI, H. 1967. Studies on the cereal starches. VII. Correlations among the amylograph characteristics of rice starch and flour. *Agric. Biol. Chem.* 31:1003-1009.
- HSIEH, S.-C., and KUO, Y.-C. 1982. Evaluation and genetical studies on grain quality characters in rice. Pages 99-112 in: *Proc. Symp. on Plant Breeding*. S. C. Hsieh and D. J. Lu, eds. Agric. Assoc. China and Regional Soc. of SABRAO, Taipei.
- HURRELL, R. F., LERMAN, P., and CARPENTER, K. J. 1979. Reactive lysine in foodstuffs as measured by a rapid dye-binding procedure. *J. Food Sci.* 44:1221-1227.
- HWANGBO, J.-S., and LEE, S.-R. 1976. Changes in eating quality and lipid components of Tongil rice variety in storage. *Korean J. Food Sci. Technol.* 8:74-79. (In Korean)
- HWANGBO, J.-S., LEE, K.-Y., CHUNG, D.-H., and LEE, S.-R. 1975. Cooking and eating qualities of Tongil (indica type) and Jinheung (japonica type) rice varieties. *Korean J. Food Sci. Technol.* 7:212-219. (in Korean)
- IAEA. 1977. Nutritional Evaluation of Cereal Mutants. Proc. Advisory Group Meeting. Int. Atomic Energy Agency, Vienna, 1976. Vienna, 187 pp.
- IGNACIO, C. C., and JULIANO, B. O. 1968. Physicochemical properties of brown rice from *Oryza* species and hybrids. *J. Agric. Food Chem.* 16:125-127.
- IKEHASHI, H., and KHUSH, G. S. 1979. Methodology of assessing appearance of the rice grain, including chalkiness and whiteness. Pages 223-229 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- INDUDHARA SWAMY, Y. M., and BHATTACHARYA, K. R. 1982. Breakage of rice during milling. I. Types of cracked and immature grains. *J. Food Sci. Technol.* 19:106-110.
- INDUDHARA SWAMY, Y. M., ALI, S. Z., and BHATTACHARYA, K. R. 1971a. Hydration of raw and parboiled rice and paddy at room temperature. *J. Food Sci. Technol.* 8:20-22.
- INDUDHARA SWAMY, Y. M., ALI, S. Z., and BHATTACHARYA, K. R. 1971b. Relationship of moisture content and temperature to discoloration of rice during storage. *J. Food Sci. Technol.* 8:150-152.
- INDUDHARA SWAMY, Y. M., SOWBHA GYA, C. M., and BHATTACHARYA, K. R. 1978. Changes in the physicochemical properties of rice with aging. *J. Sci. Food Agric.* 29:627-639.
- IRRI. 1964. 1963 Annual Report. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1966. Annual Report for 1965. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1968. Annual Report for 1967. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1970. Annual Report for 1969. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1971. Annual Report for 1970. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1974. Annual Report for 1973. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1976. Annual Report for 1975. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1978. Annual Report for 1977. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1979a. Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines. 390 pp.
- IRRI. 1979b. Rice Research and Production in China: An IRRI Team's View. Int. Rice Res. Inst., Los Baños, Laguna, Philippines. 119 pp.
- IRRI. 1979c. Annual Report for 1978. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1980. Annual Report for 1979. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1981. Annual Report for 1980. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1983a. Annual Report for 1981. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1983b. Annual Report for 1982. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- IRRI. 1984. Annual Report for 1983. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- ISHIMA, T., TAIRA, H., TAIRA, H., and MIKOSHIBA, K. 1974. Effect of nitrogenous fertilizer application and protein content in milled rice on organoleptic quality of cooked rice. *Shokuhin Sogo Kenkyusho Kenkyu Hokoku* 29:9-15.
- IWASAKI, T., and TANI, T. 1967a. Effect of heating on brown rice composition and quality. *Cereal Chem.* 44:204-210.
- IWASAKI, T., and TANI, T. 1967b. Effect of oxygen concentration on deteriorative mechanisms of rice during storage. *Cereal Chem.* 44:233-237.
- IWASAKI, T., SHIBUYA, N., and CHIKUBU, S. 1972. Studies on rice protein. I. Albumin and globulin in rice endosperm; their heterogeneity and difference in subunit composition among stored, heated, and fresh rice. *J. Jpn. Soc. Food Sci. Technol.* 19:70-75. (in Japanese)

- JENNINGS, P. R., COFFMAN, W. R., and KAUFFMAN, H. E. 1979. Rice Improvement. Int. Rice Res. Inst., Los Baños, Laguna, Philippines. 186 pp.
- JULIANO, B. O. 1971a. Relation of physicochemical properties to processing characteristics of rice. Pages 21-27 in: Proc. World Cereal Bread Congr., 5th, Dresden, Vol. 4. VEB Fachbuchverlag, Leipzig.
- JULIANO, B. O. 1971b. A simplified assay for milled-rice amylose. *Cereal Sci. Today* 16:334-338, 340, 360.
- JULIANO, B. O. 1972a. Quality vital in rice marketing. *Ricemill News* 9(5):23-24.
- JULIANO, B. O. 1972b. Physicochemical properties of starch and protein and their relation to grain quality and nutritional value of rice. Pages 389-405 in: Rice Breeding. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- JULIANO, B. O. 1972c. Chemical basis of differences in milling, cooking and eating quality of rice varieties. Pages 88-107 in: Proc. Symposium Toward More Progressive Barrios. Univ. Philippines Los Baños, Philippines.
- JULIANO, B. O. 1973. Quality of milled rice. *Riso* 22:171-184.
- JULIANO, B. O. 1978. Metabolic evaluation of rice protein. *Food Chem.* 3:251-263.
- JULIANO, B. O. 1979a. The chemical basis of rice grain quality. Pages 69-90 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- JULIANO, B. O. 1979b. Amylose analysis in rice—A review. Pages 251-260 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- JULIANO, B. O., compiler. 1982a. An international survey of methods used for evaluation of the cooking and eating qualities of milled rice. IRRI Res. Paper Ser. 77. Int. Rice Res. Inst., Los Baños, Laguna, Philippines. 28 pp.
- JULIANO, B. O. 1982b. Properties of rice starch in relation to varietal differences in processing characteristics of rice grain. *J. Jpn. Soc. Starch Sci.* 29:305-317.
- JULIANO, B. O. 1983a. Rapid simple testing for nutrients as an aid to plant breeding. Pages 515-525 in: Chemistry and World Food Supplies. CHEMRAWN II, Manila 1982. L. W. Shemilt, ed. Pergamon Press, Oxford.
- JULIANO, B. O. 1983b. Consumer acceptance and processing characteristics of rice varieties. Pages 227-233 in: Proc. Food Conference 1982, Singapore. T. C. Yam, K. W. Lu, and F. C. Yoon, eds. Singapore Inst. Food Sci. Technol., Singapore.
- JULIANO, B. O., and BEACHELL, H. M. 1975. Status of rice protein improvement. Pages 457-469 in: High-quality Protein Maize. Proc. CIMMYT/Purdue Symp. on Protein Quality in Maize, CIMMYT, 1972. Dowden, Hutchinson and Ross, Inc., Stroudsburg, PA.
- JULIANO, B. O., and PASCUAL, C. G. 1980. Quality characteristics of milled rice grown in different countries. IRRI Res. Paper Ser. 48. Int. Rice Res. Inst., Los Baños, Laguna, Philippines. 25 pp.
- JULIANO, B. O., and PERDON, A. A. 1975. Gel and molecular properties of nonwaxy rice starch. *Stärke* 27:115-120.
- JULIANO, B. O., and PEREZ, C. M. 1983. Major factors affecting cooked milled rice hardness and cooking time. *J. Texture Stud.* 14:235-243.
- JULIANO, B. O., and PEREZ, C. M. 1984. Results of a collaborative test on the measurement of grain elongation of milled rice during cooking. *J. Cereal Sci.* 2:281-292.
- JULIANO, B. O., ALBANO, E. L., and CAGAMPANG, G. B. 1964a. Variability in protein content, amylose content and alkali digestibility of rice varieties in Asia. *Philipp. Agric.* 48:234-241.
- JULIANO, B. O., BAUTISTA, G. M., LUGAY, J. C., and REYES, A. C. 1964b. Studies on the physicochemical properties of rice. *J. Agric. Food Chem.* 12:131-138.
- JULIANO, B. O., CAGAMPANG, G. B., CRUZ, I. J., and SANTIAGO, R. G. 1964c. Some physicochemical properties of rice in Southeast Asia. *Cereal Chem.* 41:275-286.
- JULIANO, B. O., OÑATE, I. U., and DEL MUNDO, A. M. 1965. Relation of starch composition, protein content, and gelatinization temperature to cooking and eating qualities of milled rice. *Food Technol.* 19:1006-1011.
- JULIANO, B. O., CARTAÑO, A. V., and VIDAL, A. J. 1968a. Note on a limitation of the starch-iodine blue test for milled rice amylose. *Cereal Chem.* 45:63-65.
- JULIANO, B. O., IGNACIO, C. C., PANGANIBAN, V. M., and PEREZ, C. M. 1968b. Screening for high protein rice varieties. *Cereal Sci. Today* 13:299-301, 313.
- JULIANO, B. O., NAZARENO, M. B., and RAMOS, N. B. 1969. Properties of waxy and isogenic nonwaxy rices differing in starch gelatinization temperature. *J. Agric. Food Chem.* 17:1364-1369.
- JULIANO, B. O., OÑATE, I. U., and DEL MUNDO, A. M. 1972a. Note: Amylose and protein contents of milled rice as eating quality factors. *Philipp. Agric.* 56:44-47.

- JULIANO, B. O., PEREZ, C. M., and GOMEZ, K. A. 1972b. Variability in protein content of rice. *Kalikasan* 1:74-81.
- JULIANO, B. O., ANTONIO, A. A., and ESMAMA, B. V. 1973. Effects of protein content on the distribution and properties of rice protein. *J. Sci. Food Agric.* 24:295-306.
- JULIANO, B. O., PERDON, A. A., PEREZ, C. M., and CAGAMPANG, G. B. 1974. Molecular and gel properties of starch and texture of rice products. Pages 120-126 in: *Proc. Int. Congr. Food Sci. Technol.*, 4th, Madrid, 1974. Vol. I. Agroquím. Técnol. Aliment., Valencia, Spain.
- JULIANO, B. O., PEREZ, C. M., BLAKENEY, A. B., BRECKENRIDGE, C., CASTILLO T., D., CHOUDHURY, N. H., KONGSREE, N., LAIGNELET, B., MERCA, F. E., PAULE, C. M., and WEBB, B. D. 1980. Report of the international cooperative testing on the gel consistency of milled rice. *Riso* 29:233-237.
- JULIANO, B. O., PEREZ, C. M., BARBER, S., BLAKENEY, A. B., IWASAKI, T., SHIBUYA, N., KENEASTER, K. K., CHUNG, S., LAIGNELET, B., LAUNAY, B., DEL MUNDO, A. M., SUZUKI, H., SHIKI, J., TSUJI, S., TOKOYAMA, J., TATSUMI, K., and WEBB, B. D. 1981a. International cooperative comparison of instrument methods for cooked rice texture. *J. Texture Stud.* 12:17-38.
- JULIANO, B. O., PEREZ, C. M., BLAKENEY, A. B., CASTILLO T., D., KONGSREE, N., LAIGNELET, B., LAPIS, E. T., MURTY, V. V. S., PAULE, C. M., and WEBB, B. D. 1981b. International cooperative testing on the amylose content of milled rice. *Staerke* 33:157-162.
- JULIANO, B. O., BLAKENEY, A. B., BUTTA, I., CASTILLO, D. T., CHOUDHURY, N. H., IWASAKI, T., SHIBUYA, N., KONGSREE, N., LAPIS, E. T., MURTY, V. V. S., PAULE, C. M., PEREZ, C. M., and WEBB, B. D. 1982. International cooperative testing of the alkali digestibility values for milled rice. *Staerke* 34:21-26.
- JULIANO, B. O., PEREZ, C. M., ALYOSHIN, E. P., ROMANOV, V. B., BLAKENEY, A. B., WELSH, L. A., CHOUDHURY, N. H., DELGADO, L., IWASAKI, T., SHIBUYA, N., MOSSMAN, A. P., SIWI, B., DAMARDJATI, D. S., SUZUKI, H., and KIMURA, H. 1984. International cooperative test on texture of rice cooked to 75% water content in excess and optimum cooking water. *J. Texture Stud.* 15:357-376.
- JULIANO, B. O., PEREZ, C. M., ALYOSHIN, E. P., ROMANOV, V. B., BEAN, M. M., NISHITA, K. D., BLAKENEY, A. B., WELSH, L. A., DELGADO, L. L., EL BAYÀ, A. W., FOSSATI, G., KONGSREE, N., MENDES, F. P., BRILHANTE, S., SUZUKI, H., TADA, M., and WEBB, B. D. 1985. Cooperative study on amylography of milled rice flour for pasting viscosity and starch gelatinization temperature. *Staerke* 37:40-50.
- KATO, S. 1979. Studies on the rheology of boiled rice. *Kaseigaku Zasshi* 30:121-133.
- KAUL, A. K., DHAR, R. D., and SWAMINATHAN, M. S. 1969. Microscopic screening of rice grains for protein characteristics. *Curr. Sci.* 38:529-531.
- KAUL, A. K., KHAN, M. R., CHOUDHURY, M. H., and SHAIKH, M. A. Q. 1978. Nutritional and cooking quality characters of some local rice cultivars of Bangladesh. Pages 167-179 in: *Seed Protein Improvement by Nuclear Techniques*. Int. Atomic Energy Agency, Vienna.
- KAUL, A. K., KHAN, M. R. I., and MUNIR, K. M. 1982. Rice Quality. A Survey of Bangladesh Germplasm. M. H. R. Talukdar, ed. Publ. No. 64. Bangladesh Rice Res. Inst., Joydebpur, Dhaka, Bangladesh. 178 pp.
- KESTER, E. B., LUKEWS, H. C., FERREL, R. E., MOHAMMAD, A., and FINFROCK, D. C. 1963. Influence of maturity on properties of Western rices. *Cereal Chem.* 40:323-336.
- KHUSH, G. S., PAULE, C. M., and DE LA CRUZ, N. M. 1979. Rice grain quality evaluation and improvement at IRRI. Pages 21-31 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- KIK, M. C., and WILLIAMS, R. R. 1945. The Nutritional Improvement of White Rice. Bull. 112. Natl. Res. Counc., Natl. Acad. Sci., Washington, DC. 76 pp.
- KONDO, M., and OKAMURA, T. 1937. Storage of rice. XVII. Comparative study of unhusked rice and hulled rice in regard to the changes of its qualities during long storage in straw bags. *Ber. Ohara Inst. Agric. Biol. Okayama Univ.* 7:483-490.
- KONGSREE, N. 1979a. Physicochemical properties of Thai rice varieties and methodology used in quality improvement. Pages 183-190 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- KONGSREE, N. 1979b. Quality tests for waxy (glutinous) rice. Pages 303-311 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- KUGIMIYA, M., and DONOVAN, J. W. 1981.

- Calorimetric determination of the amylose content of starches based on formation and melting of the amylose-lysolecithin complex. *J. Food Sci.* 46:765-770, 777.
- KUNZE, O. R., and CHOUDHURY, M. S. U. 1972. Moisture adsorption related to the tensile strength of rice. *Cereal Chem.* 49:684-696.
- KURASAWA, H., IGAUE, I., and HAYAKAWA, T. 1962. Study on the eating quality (especially stickiness) of nonwaxy rice. III. The stickiness indication of rice by a starch-iodine-blue test. *Niigata Norin Kenkyu* 14:93-100.
- KURASAWA, H., KANAUTI, Y., TAKEI, K., OGAWA, S., OKABE, T., HAYAKAWA, T., and IGAUE, I. 1972. Correlation analysis between eating quality, rheological property and amylose content of starch. *Agric. Biol. Chem.* 36:1809-1813.
- KUSHIBUCHI, K., and FUJIMAKI, H. 1975. Relation between rice quality and translucency of brown rice. Applicability of tester for translucency of rice grain. *Agric. Technol. Tokyo* 30(7):16-18. (In Japanese)
- LAIGNELET, B., and FEILLET, P. 1979. Use of the Viscoelastograph for measuring the texture of cooked rice. Pages 355-361 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- LARMOND, E. 1977. Laboratory methods for sensory evaluation of food. Publ. 1637. Res. Branch Canada Dept. Agric., Ottawa, 73 pp.
- LEE, C. Y., KIM, Y. W., HEU, M. H., and BAIK, J. K. 1976. A colorimetric method for the determination of amylose contents in waxy rice. *Seoul Natl. Univ. Coll. Agric. Bull.* 1(1):95-101.
- LIN, W.-M., CHANG, S.-M., and LEE, C.-Y. 1979. Studies on the changes of physicochemical properties of rice during storage. *Bull. Inst. Chem. Acad. Sin.* 26:13-23.
- LISCH, J. M., and LAUNAY, B. 1975. Appréciation instrumentale de la texture de riz appertisés. *Bull. Inf. Rizie, France* 157:15-26.
- LITTLE, R. R., and HILDER, G. B. 1960a. Differential response of rice starch granules to heating in water at 62°C. *Cereal Chem.* 37:456-463.
- LITTLE, R. R., and HILDER, G. B. 1960b. Differential reaction of milled white rice varieties to a Millon reagent containing trichloroacetic acid and mercuric acetate. *Cereal Chem.* 37:475-482.
- LITTLE, R. R., HILDER, G. B., and DAWSON, E. H. 1958. Differential effect of dilute alkali on 25 varieties of milled white rice. *Cereal Chem.* 35:111-126.
- LOWRY, O. H., ROSEBROUGH, N. J., FARR, A. L., and RANDALL, R. J. 1951. Protein measurement with the Folin phenol reagent. *J. Biol. Chem.* 193:265-275.
- MANINGAT, C. C., and JULIANO, B. O. 1978. Alkali digestibility pattern, apparent solubility and gel consistency of milled rice. *Staerke* 30:125-127.
- MANOHAR KUMAR, B., UPADHYAY, J. K., and BHATTACHARYA, K. R. 1976. Objective tests for the stickiness of cooked rice. *J. Texture Stud.* 7:271-278.
- MATSUDA, H., and HIRAYAMA, O. 1973. Changes of lipid components and lipolytic acyl-hydrolase activities in rice grains during their storage. *Nippon Noge Kagaku Kaishi* 47:379-384.
- MAZURS, E. G., SCHOCH, T. J., and KITE, F. E. 1957. Graphical analysis of the Brabender viscosity curves of various starches. *Cereal Chem.* 34:141-152.
- MERCA, F. E., and JULIANO, B. O. 1981. Physicochemical properties of starch of intermediate-amylose and waxy rices differing in grain quality. *Staerke* 33:253-260.
- MERCA, F. E., MASAJO, T. M., and BUSTRILOS, A. D. 1979. Rice grain quality evaluation in the Philippines. Pages 161-165 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- MILLER, B. S., LEE, M. S., POMERANZ, Y., and ROUSSER, R. 1979. A rapid, objective method to measure the degree of milling of rice. *Cereal Chem.* 56:172-180.
- MITSUDA, H., KAWAI, F., and YAMAMOTO, A. 1972. Underwater and underground storage of cereal grains. *Food Technol.* 26(3):50-56.
- MOI, R. R., CONKERTON, E. J., CHAPPA, D. C., and YATSU, I. Y. 1983. Rice phenolic acids and their changes with aging. (Abstr.) *Cereal Foods World* 28:560.
- MOHANDOSS, R., and PILLAIYAR, P. 1980. An extrusion test for determining the palatability of parboiled rices. *J. Food Sci. Technol.* 17:244-246.
- MORITA, S., and YASUMATSU, K. 1972a. Studies on cereals. IX Sulphydryl and disulfide contents of milled rice. *Eijo To Shokuryo* 25:42-45.
- MORITA, S., and YASUMATSU, K. 1972b. Studies on cereals X. The effect of sulphydryl groups on storage deterioration of milled rice. *Eijo To Shokuryo* 25:59-62.
- MORITA, S., SAWADA, K., and YASUMATSU, K. 1971a. Studies on cereals VI. Effect of fat extraction on rice quality and

- storage deterioration of defatted rice. *Eiyo To Shokuryo* 24:457-460.
- MORITAKA, S., SAWADA, K., and YASUMATSU, K. 1971b. Studies on cereals. VII. Relation between lipid content of milled rice and deterioration of rice flavors during storage. *Eiyo To Shokuryo* 24:474-476.
- MORITAKA, S., SAWADA, K., and YASUMATSU, K. 1972. Studies on cereals. VIII. Storage deterioration of defatted rice. *Eiyo To Shokuryo* 25:16-20.
- MORRISON, W. R., and COVENTRY, A. M. 1985. Extraction of lipids from cereal starches with hot aqueous alcohols. *Staerke* 37:83-87.
- MORRISON, W. R., and LAIGNELET, B. 1983. An improved colorimetric procedure for determining apparent and total amylose in cereal and other starches. *J. Cereal Sci.* 1:9-20.
- MOSSBERG, R. 1969. Evaluation of protein quality and quantity by dye-binding capacity: A new tool in plant breeding. Pages 151-160 in: *New Approaches to Breeding for Improved Plant Protein*. Int. Atomic Energy Agency, Vienna.
- MOSSMAN, A. P., FEILLERS, D. A., and SUZUKI, H. 1983. Rice stickiness. I. Determination of rice stickiness with an Instron tester. *Cereal Chem.* 60:286-292.
- MURAYAMA, N., and SUZUKI, H. 1965. Light-scattering-alkali-amylography, a new method for determining the alkali-susceptibility of starch granules by the measurement of scattered light. *Nippon Nogei Kagaku Kaishi* 39:358-363.
- NAGARAJU, M., CHAUDHARY, D., and BALAKRISHNARAO, M. J. 1975. A simple technique to identify scent in rice and inheritance pattern of scent. *Curr. Sci.* 44:599.
- NAGATO, K., and KONO, Y. 1963. Grain texture of rice. I. Relations among hardness distribution, grain shape and structure of endosperm tissue of rice kernel. *Nippon Sakumotsu Gakkai Kiji* 32:181-189.
- NARAYANA RAO, M., VISWANATHA, T., MATHUR, P. B., SWAMINATHAN, M., and SUBRAHMANYAN, V. 1954. Effect of storage on the chemical composition of husked, undermilled and milled rice. *J. Sci. Food Agric.* 5:405-409.
- NGUYEN, C. N., and KUNZE, O. R. 1984. Fissures related to post-drying treatments in rough rice. *Cereal Chem.* 61:63-68.
- NISHITA, K. D., and BEAN, M. M. 1982. Grinding methods: Their impact on rice flour properties. *Cereal Chem.* 59:46-49.
- NORMAND, F. L., HOGAN, J. T., and DEOBALD, H. J. 1964. Improvement of culinary quality of freshly harvested rice by heat treatment. *Rice J.* 67(13):7-10.
- OBATA, Y., and TANAKA, H. 1965. Studies on the photolysis of L-cysteine and L-cystine. Formation of the flavor of cooked rice from L-cysteine and L-cystine. *Agric. Biol. Chem.* 29:191-195.
- OHASHI, K., GOSHIMA, G., KUSADA, H., and TSUGE, H. 1980. Effect of emulsified lipid on the gelatinization of rice starch. *Staerke* 32:54-58.
- OKABE, M. 1979. Texture measurement of cooked rice and its relationship to the eating quality. *J. Texture Stud.* 10:131-152.
- ONATE, L. U., and DEL MUNDO, A. M. 1963. Eating quality of seven varieties of lowland rice. *Philipp. Agric.* 47:208-214.
- ONATE, L. U., and DEL MUNDO, A. M. 1966. Consumer and laboratory panel evaluation of seed board rice varieties. *Philipp. Agric.* 50:301-309.
- ONATE, L. U., DEL MUNDO, A. M., and JULIANO, B. O. 1964. Relationship between protein content and eating quality of milled rice. *Philipp. Agric.* 47:441-444.
- PAG (Protein Advisory Group of the United Nations System). 1975. PAG guideline (No. 16) on protein methods for cereal breeders as related to human nutritional requirements. *PAG Bull.* 5(2):22-48.
- PALTER, R., and KOHLER, G. O. 1969. Survey hydrolysis procedure for lysine analysis. *Cereal Chem.* 46:22-26.
- PARIAL, L. C., ROONEY, L. W., and WEBB, B. D. 1970. Use of dye-binding and biuret techniques for estimating protein in brown and milled rice. *Cereal Chem.* 47:38-43.
- PAULF, C. M., GOMEZ, K. A., JULIANO, B. O., and COFFMAN, W. R. 1979. Variability in amylose content of rice. *Riso* 28:15-22.
- PELLETTI, P. L., and YOUNG, V. R., eds. 1980. *Nutritional Evaluation of Protein Foods*. World Hunger Programme Food Nutr. Bull. Suppl. 4. United Nations Univ., Tokyo. 154 pp.
- PELSHENKE, P. F., and HAMPEL, G. 1958. Untersuchungen an Importreis. *Getreide Mehl* 8(13):17-22.
- PEREZ, C. M. 1979. Gel consistency and viscosity of rice. Pages 293-302 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- PEREZ, C. M., and JULIANO, B. O. 1978. Modification of the simplified amylose test for milled rice. *Staerke* 30:424-426.
- PEREZ, C. M., and JULIANO, B. O. 1979. Indicators of eating quality for non-waxy rices. *Food Chem.* 4:185-195.
- PEREZ, C. M., and JULIANO, B. O. 1982. Physicochemical changes of the rice grain in

- storage: A brief review. Pages 180-190 in: Documentation of the Seminar Paddy Deterioration in the Humid Tropics, Baguio City, Philippines, 1981. German Agency for Tech. Cooperation, Eschborn, Germany.
- PEREZ, C. M., PASCUAL, C. G., and JULIANO, B. O. 1979. Eating quality indicators for waxy rices. *Food Chem.* 4:179-184.
- POMERANZ, Y., STERMER, R. A., and DIKEMAN, E. 1975. NMR-oil content as an index of degree of rice milling. *Cereal Chem.* 52:849-853.
- PRIESTLEY, R. J. 1976. Apparent solubility and alkali degradation patterns of rice varieties. *J. Food Sci.* 41:209-210.
- PRIESTLEY, R. J. 1977. Solubilisation of starch fractions in rice varieties during cooking. Pages 141-151 in: *Developments in Food Carbohydrate*, Vol. I. G. G. Birch and R. S. Shallenberger, eds. Applied Science Publ. Ltd., London.
- PRIESTLEY, R. J., and BIRCH, G. G. 1973. An alternative to the alkali test for assessing the quality of milled rice. *Lebensm. Wiss. Technol.* 6:224-226.
- PRIMO, E., CASAS, A., BARBER, S., and BENEDITO DE BARBER, C. 1962. Factores de calidad del arroz. VI. Influencia de las proteínas sobre la calidad de cocción. Proteínas en la capa externa. *Rev. Agroquím. Tecnol. Alimentos* 2:135-141.
- PUSHPAMMA, P., and REDDY, M. U. 1979. Physico-chemical changes in rice and jowar stored in different agro-climatic regions of Andhra Pradesh. *Bull. Grain Technol.* 17:97-108.
- RAGHAVENDRA RAO, S. N., and JULIANO, B. O. 1970. Effect of parboiling on some physicochemical properties of rice. *J. Agric. Food Chem.* 18:289-294.
- RANGHINO, F. 1966. Valutazione della resistenza del riso alla cottura, in base al tempo di gelatinizzazione dei granelli. *Riso* 15:117-127.
- REFAI, F. Y., and AHMED, S. A. 1958. Entwicklung einer Schnellmethode zur Bestimmung der Kochqualität von Reis. *Getreide Mehl* 8(10):77-78.
- RIVENBURGH, D. V. 1961. Analysis of selected varieties and grades of rice moving in world trade, in terms of U.S. official rice standards. U.S. Dep. Agric., Foreign Agric. Serv. Marketing Res. Rep. 460, 40 pp.
- RUSSELL, P. L., and JULIANO, B. O. 1983. Differential scanning calorimetry of rice starches. *Stärke* 35:382-386.
- SANDSTEDT, R. M., and ABBOTT, R. C. 1964. A comparison of methods for studying the course of starch gelatinization. *Cereal Sci. Today* 9:13-18, 26.
- SANJIVA RAO, B. 1938. Investigations on rice. *Curren. Sci.* 6:446-447.
- SASAKI, T., OSANAI, S.-I., INATSU, O., and EBÉ, Y. 1977. Physicochemical characteristics and tastes of rice varieties in Hokkaido. *Hokkaidoritsu Nogyo Shikenjo Hokoku* 37:1-10.
- SATO, S., TADENUMA, M., OBA, T., TAKAHASHI, Y., and KOIKE, K. 1976. Changes of volatile sulfur compounds in white rice during sake making. *Nippon Jozo Kyokai Zasshi* 71:387-390.
- SCHOCH, T. J., and MAYWALD, E. C. 1956. Microscopic examination of modified starches. *Anal. Chem.* 28:382-387.
- S H A M S - U D - D I N , M . , and BHATTACHARYA, K. R. 1978. On the meaning of the degree of milling of rice. *J. Food Technol.* 13:99-105.
- SHIBUYA, N. 1980. Recent investigations on the deterioration of rice during storage. *Grains J. (Natl. Grains Authority Manila)* 5(2):21-24.
- SHIBUYA, N., and IWASAKI, T. 1982. Effect of the enzymatic removal of endosperm cell wall on the gelatinization properties of aged and unaged rice flours. *Stärke* 34:300-303.
- SHIBUYA, N., IWASAKI, T., YANASE, H., and CHIKUBU, S. 1974. Studies on deterioration of rice during storage. I. Changes of brown rice and milled rice during storage. *J. Jpn. Soc. Food Sci. Technol.* 21:597-603. (In Japanese)
- SHIBUYA, N., IWASAKI, T., and CHIKUBU, S. 1975. Lipase activity in rice kernel. *Shokuhin Sogo Kenkyusho Kenkyu Hokoku* 30:10-13.
- SHIBUYA, N., IWASAKI, T., and CHIKUBU, S. 1977a. Studies on deterioration of rice during storage. III. On the changes of rice starch during storage of rice. *Denpun Kagaku* 24:55-58.
- SHIBUYA, N., IWASAKI, T., and CHIKUBU, S. 1977b. Studies on deterioration of rice during storage. II. Role of the free fatty acids in the changes of rheological properties of cooked rice and its paste during storage of rice. *Denpun Kagaku* 24:67-68.
- SHIBUYA, N., SUZUKI, N., and IWASAKI, T. 1983. Effect of endogenous α -amylase on the amylogram of milled rice flour. *Denpun Kagaku* 30:284-287.
- SHOJI, I., and KURASAWA, H. 1981a. On viscosity characteristics of rice and rice starch against Brabender amylography. II. Effects of protein and fat on viscosity of glutinous and non-glutinous rice starches. *Kaseigaku Zasshi*

- 32:167-171.
- SHOJI, I., and KURASAWA, H. 1981b. On the viscosity of rice and rice starch by Brabender amylogram. III. The viscosity changes of the brown rices (glutinous, non-glutinous rices) stored for some periods in room temperature. *Kaseigaku Zasshi* 32:350-355.
- SHUEY, W. C., and TIPPLES, K. H., ed. 1980, rev. 1982. *The Amylograph Handbook*. Am. Assoc. Cereal Chem., St. Paul, MN. 37 pp.
- SIMPSON, J. E., ADAIR, C. R., KOHLER, G. O., DAWSON, E. H., DEOBALD, H. J., KESTER, E. B., HOGAN, J. T., BATCHELOR, O. M., and HALICK, J. V. 1965. Quality Evaluation Studies of Foreign and Domestic Rices. Tech. Bull. 1331. Agric. Res. Serv., U.S. Dept. Agric., Washington, DC. 186 pp.
- SOOD, B. C., and SIDDIQ, E. A. 1978. A rapid technique for scent determination in rice. *Indian J. Genet. Plant Breed.* 38:268-271.
- SOOD, B. C., and SIDDIQ, E. A. 1980. Studies on component quality attributes of basmati rice, *Oryza sativa* L. Z. *Pflanzenzuecht.* 84:294-301.
- SOWBAGYA, C. M., and BHATTACHARYA, K. R. 1971. A simplified colorimetric method for determination of amylose content in rice. *Staerke* 23:53-56.
- SOWBAGYA, C. M., and BHATTACHARYA, K. R. 1979. Simplified determination of amylose in milled rice. *Staerke* 31:159-163.
- SREENIVASAN, A. 1939. Studies on quality in rice. IV. Storage changes in rice after harvest. *Indian J. Agric. Sci.* 9:208-222.
- SRINIVAS, T., BHASHYAM, M. K., MUNE GOWDA, M. K., and DESIKACHAR, H. S. R. 1978. Factors affecting crack formation in rice varieties during wetting and field stresses. *Indian J. Agric. Sci.* 48:424-432.
- SRINIVAS, T., BHASHYAM, M. K., NARASIMHA REDDY, M. K., and DESIKACHAR, H. S. R. 1981. Development of a modified technique for intra-varietal selection for low crack susceptibility and low milling breakage in rice. *Indian J. Agric. Sci.* 51:228-232.
- STERMER, R. A. 1968. An instrument for objective measurement of degree of milling and color of milled rice. *Cereal Chem.* 45:358-364.
- SUMINO, S., ISHIMURA, Y., KATAOKA, S., and KURASAWA, H. 1979. Studies on the eating and cooking qualities of milled rice in Fukushima prefecture. I. Sensory test and physical property of milled rice produced in 1976. *Koriyama Women's Coll. Bull.* 15:31-40. (In Japanese)
- SUZUKI, H. 1979a. Amylography and alkali viscometry of rice. Pages 261-282 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- SUZUKI, H. 1979b. Use of Texturometer for measuring the texture of cooked rice. Pages 327-341 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- SUZUKI, H., and JULIANO, B. O. 1975. Alkaliviscogram and other properties of starch of tropical rice. *Agric. Biol. Chem.* 39:811-817.
- SUZUKI, H., IKEHASHI, H., and KUSHIBUCHI, K. 1979. Rice grain quality evaluation in Japan. Pages 149-159 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.
- SUZUKI, H., SHIKI, J., and OSUGI, M. 1983. Conditions for measuring hardness and stickiness of cooked rice grains by Texturometer. *Nippon Eiyo Shokuryo Gakkaishi* 36:199-202.
- SUZUKI, K., KUBOTA, K., OMICHI, M., and HOSAKA, H. 1976. Kinetic studies on cooking of rice. *J. Food Sci.* 41:1180-1183.
- SUZUKI, K., AKI, M., KUBOTA, K., and HOSAKA, H. 1977. Studies on the cooking rate equations of rice. *J. Food Sci.* 42:1545-1548.
- TAKAHASHI, K., OHBA, T., TAKAGI, M., SATO, S., and NAMBA, Y. 1979. Identification and determination of an off-flavor compound, dimethyl sulfide, in saké brewed with old rice. *Hakko Kogaku Zasshi* 57:148-157.
- TANI, T. 1958. Rice qualities. *Eiyo To Shokuryo* 11:45-50.
- TANI, T., and KUBO, S. 1962. Tendency of variation of chemical contents of rice grains. *Recent Adv. Breeding* 3:59-65. (In Japanese)
- TANI, T., CHIKUBU, S., and SHIKANO, T. 1952. A new M. G. method of staining for grain. I. Application to pressed barley and milled rice. *Shokuryo Kenkyusho Kenkyu Hokoku* 6:75-78.
- TANI, T., CHIKUBU, S., and IWASAKI, T. 1964. Changes in chemical properties of rice during storage at controlled temperature. I. *Eiyo To Shokuryo* 16:436-441.
- TSAI, C. Y., HANSEL, L. W., and NELSON, O. E. 1972. A colorimetric method of screening maize seeds for lysine content. *Cereal Chem.* 49:572-579.
- TSUGITA, T., OHTA, T., and KATO, H. 1983. Cooking flavor and texture of rice stored under different conditions. *Agric. Biol. Chem.* 47:543-549.

- TSUJI, S. 1981. Texture measurement of cooked rice kernels using the multiple-point mensuration method. *J. Texture Stud.* 12:93-105.
- TSUZUKI, E., TANAKA, K., and SHIDA, S. 1981. Studies on the characteristics of scented rice. VIII. Effect of storage conditions on some fatty acid compositions and flavor components in rice grains. *Kenkyu Hokoku Miyazaki Daigaku Nogakubu* 28:31-37.
- UNNEVEHR, L. J., JULIANO, B. O., PEREZ, C. M., and MARCIANO, E. B. 1985. Consumer demand for grain quality in Thailand, Indonesia and the Philippines. *IRRI Res. Ser. 118. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.* In press.
- VILLAREAL, R. M., RESURRECCION, A. P., SUZUKI, L. B., and JULIANO, B. O. 1976. Changes in physicochemical properties of rice during storage. *Staerke* 28:88-94.
- VILLEGAS, E., and MERTZ, E. T. 1971. Chemical screening methods for maize protein quality at CIMMYT. *Res. Bull. 20. Int. Maize and Wheat Improvement Center (CIMMYT), Mexico City.* 14 pp.
- WEBB, B. D. 1979. Assessing parboil-canning stability of rice in varietal improvement programs. Pages 283-292 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.*
- WEBB, B. D. 1980. Rice quality and grades. Pages 543-565 in: *Rice: Production and Utilization.* B. S. Luh, ed. Avi Publ. Co., Inc., Westport, CT.
- WEBB, B. D., and STERMER, R. A. 1972. Criteria of rice quality. Pages 102-139 in: *Rice: Chemistry and Technology.* 1st ed. D. F. Houston, ed. Am. Assoc. Cereal Chem., St. Paul, MN.
- WEBB, B. D., BEACHELL, H. M., and HALICK, J. V. 1963. Use of the amylograph test in evaluating breeding selections and new varieties of rice for specific uses. (Abstr.) *Cereal Sci. Today* 8:136-137.
- WEBB, B. D., BOLLICH, C. N., JOHNSTON, T. H., and McILRATH, W. O. 1979. Components of rice quality: Their identification, methodology, and stage of application in United States breeding programs. Pages 191-205 in: *Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst., Los Baños, Laguna, Philippines.*
- WILLIAMS, P. C. 1975. Application of near infrared reflectance spectroscopy to the analysis of cereal grains and oilseeds. *Cereal Chem.* 52:561-576.
- WILLIAMS, V. R., WU, W.-T., TSAI, H.-Y., and BATES, H. G. 1958. Varietal differences in amylose content of rice starch. *J. Agric. Food Chem.* 6:47-48.
- YANAI, S., ISHITANI, T., and KAKIUCHI, Y. 1979a. Influence of gaseous environment on hermetic storage of brown rice. *Nippon Shokuhin Kogyo Gakkaishi* 26:25-31.
- YANAI, S., ISHITANI, T., and KOJO, T. 1979b. Influence of gaseous environment on the hermetic storage of milled rice. *Nippon Shokuhin Kogyo Gakkaishi* 26:145-150.
- YANASE, H., ENDO, I., and CHIKUBU, S. 1981. Studies on quality and processing suitability of glutinous rice. I. Milling yields, properties of appearance and storage of glutinous rice. *Shokuhin Sogo Kenkyusho Kenkyu Hokoku* 38:1-9.
- YASUMATSU, K., and MORITAKA, S. 1964. Fatty acid compositions of rice lipid and their changes during storage. *Agric. Biol. Chem.* 28:257-264.
- YASUMATSU, K., and MORITAKA, S. 1979. Progress in methods for evaluating rice quality. *J. Takeda Res. Lab.* 38:62-72.
- YASUMATSU, K., MORITAKA, S., and KAKINUMA, T. 1964. Effect of the change during storage in lipid composition of rice on its amylogram. *Agric. Biol. Chem.* 28:265-272.
- YASUMATSU, K., MORITAKA, S., ISHII, K., SHIMAZONO, H., and FUJITA, E. 1965a. Studies on cereals. I. Changes of chemical characteristics of polished rice during storage. *Eijo To Shokuryo* 18:123-129.
- YASUMATSU, K., MORITAKA, S., BICHIU, S., ISHII, K., SHIMAZONO, H., and FUJITA, E. 1965b. Studies on cereals. II. Flavor deterioration of polished rice during storage. *Eijo To Shokuryo* 18:130-133.
- YASUMATSU, K., MORITAKA, S., and WADA, S. 1966a. Studies on cereals. IV. Volatile carbonyl compounds of cooked rice. *Agric. Biol. Chem.* 30:478-482.
- YASUMATSU, K., MORITAKA, S., and WADA, S. 1966b. Studies on cereals. V. Stale flavor of stored rice. *Agric. Biol. Chem.* 30:483-486.
- YOSHIKAWA, S., ENDO, I., and OKABE, M. 1974. New approaches in Texturometer evaluation of sensory properties. *Proc. Int. Congr. Food Sci. Technol.* 4th, Madrid, 2:144-149.
- ZHANG, W.-X., and TANG, S.-X. 1981. A preliminary study on the cooking qualities of Chinese rice varieties (*O. sativa* L.). *Sci. Agric. Sin.* 5:32-39.