RICE GRAIN QUALITY AND MARKETING

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FOREWORD

As more Asian countries become self-sufficient in rice and look toward export markets for selling surpluses, grain quality becomes increasingly important. Although production, harvesting, and postharvest operations affect quality of milled rice, variety remains the most important determinant of market quality. Consumers favor certain varieties and value specific appearances and tastes of milled rice for home cooking.

Recognizing that markets are most responsive to high quality rice, planners of the 1985 International Rice Research Conference, 1-5 June at IRRI, included a half-day session on grain quality and marketing. Presentations covered the status of rice quality in world and domestic markets, consumer demand for rices with certain physical and chemical characteristics, effects of environment and variety on milling quality, and breeding for rices of excellent processing, cooking, and eating qualities.

Participants also discussed priority problem areas in rice breeding for market quality. Recommendations stress research needs in milling quality and consumer preferences. National programs should undertake market quality studies to determine milled rice properties prized by consumers in the local market, as benchmark information for their breeding programs. There should be no conflict between breeding for better appearance, milling and cooking qualities, and breeding for yield.

This publication presents the plenary session papers and recommendations of the discussion session. IRRI staff responsible for the conference and publication include: B.S. Vergara, IRRC coordinator; B.O. Juliano and L.J. Unnevehr, coplanners of the grain quality and marketing session, with G.S. Khush; and L.R. Bostian, editor.

M. S. Swaminathan
Director General

RICE QUALITY
IN WORLD MARKETS

J. N. EFFERSON
Chancellor-Emeritus, Louisiana State University

ABSTRACT

There are major world markets for rice. They are for special qualities, definite varieties, and specific processing types. These markets are highly competitive.

World markets demand six basic rice types: 1) high-quality long-grain rice, 2) medium-quality long-grain rice, 3) short-grain rice, 4) parboiled rice, 5) aromatic or fragrant rice, and 6) glutinous (waxy) rice.

Each is demanded by different markets. The long-grain, higher quality rice is sold mostly in Europe and the Middle East, the medium-quality long-grain in the deficit countries of Asia, the short-grain product in various special-demand areas, the high-quality parboiled in the Middle East and Africa, and the lower quality parboiled in special markets in Asia and Africa. Aromatic rice is demanded mostly in the Middle East, and glutinous rice meets the needs in Laos with smaller volumes to other countries.

Improvement in rice quality worldwide is essential to meet the increasingly discriminating demands of consumers everywhere. Quality improvements will require major adjustments in variety selection, grading, milling, price-support programs, and the like.

Rice is many things to many people. The quality of rice demanded by one community may be completely unacceptable to another. A given quality that brings a premium price in one market may be sold only at a major discount in another. The Japanese consumer prefers a well-milled, very recently processed, short-grain japonica rice; he comments that it sticks together and tastes better. The Thailand consumer prefers a well-milled, aged, long-grain indica rice; he reports that it separates freely and tastes better. Both give the same reasons for widely different qualities.

The Middle East consumer prefers a long-grain, well-milled rice with strong aroma; he feels that rice without a distinctive aroma is like food without salt. The European consumer generally prefers a long-grain rice with no scent; to him, any scent signals spoilage and contamination. He will do without rice rather than buy the scented type.

The American consumer will pay only half as much for milled rice with a trace of red or striped grains, despite no difference in nutritive value. Some West African consumers will pay a premium for milled rice with most grains showing red color. The Bangladesh consumer insists on parboiled rice; he states that it cooks better and tastes better. The Latin American consumer demands raw-milled rice; he reports that parboiled rice tastes like just so much rubber. And so it goes around the world. What is quality rice?

To answer this question, one must understand the world rice market. The basic principles follow:

1. *The world rice market is very thin.* Although rice is the most important basic food in the world and nearly 2 billion people depend on it for more than 80% of their calories, rice is relatively unimportant in world commerce. Most rice is consumed where it is grown. Less than 5% of world total production moves into international markets. Much larger volumes of other food grains, such as wheat and maize, are traded abroad.

This small international market has relatively few buyers and sellers, and its demand and supply is relatively unpredictable and rapidly changing. A small change in a given country can have a major impact on supply and/or demand, and on prices. Because countries differ in consumer preferences, the overall price structure may change rapidly, as may the relative demand for various quality types. The thin market results in wider and more rapid price changes than is common with most world-traded commodities.

2. *Rice is not just rice.* Six basic types of rice are traded in world markets. These are 1) predominantly indica, high-quality, long-grain, raw-milled rice, 2) predominantly indica, medium-quality, long-grain, raw-milled rice, 3) japonica short or medium-grain, raw-milled rice, 4) parboiled rice, with any length grain, and two speciality types, 5) aromatic (fragrant) rice, and 6) glutinous (waxy) rice.

These groups may be subdivided into two or more types, each with distinct differences as to consumer preferences. Each type has different markets and within each type are special quality demands for specific uses. This further dilutes a given market to the point where the low volume adds uncertainty. Also, demand may vary enough that market trends for major types move in opposite directions.

3. *Quality varies markedly within each basic type.* Wheat and maize, the other major food grains, are usually processed before the consumer purchases them for final cooking and eating. But the consumer views rice in the uncooked or unprocessed state and makes judgments about its quality. The consumer has certain rules of thumb in judging rice quality, and he is the boss if rice is to be sold.

First, consumers prefer as few broken grains as possible. A mixture of broken grains and whole grains cooks unevenly and is unattractive. Obviously, quality rice lacks foreign materials such as weed seed, chaff, unmilled grains, dust, dirt, and stones. The grains preferably are of similar size and shape with no mixed varieties. The product must be well-milled and pearly white, preferably translucent. Only the aromatic varieties should have odor. These characteristics affect relative consumer demand and determine grades.

To meet these market standards, major exporters and importers have established official grades based on the relative quality of different lots. Some, such as shippers from the United States, Australia, and Thailand, have established sophisticated separation machinery to segregate and then remix to meet an order for any specific grade. In the United States, paddy (rough rice) marketed by growers is tested for milling quality potential and foreign matter content, and the producer is paid according to grade. In Thailand, paddy from different regions and of specific varieties is generally purchased by millers to meet specific quality orders, and growers receive prices according to the type of paddy bought. Australia and Italy also grade paddy according to potential milling yields and other quality factors. Exporting nations Surinam and Guyana follow similar practices.

Most rice shipped from Asia is sold based on visual examination of samples pulled by a reputable agency. Samples are airmailed to potential buyers before final purchase agreements are approved. In the countries with reputable grading systems, sales and purchases are made by grade, with the grade certified by a nonpartial port authority. This is a fast, dependable approach.

4. *Consumer quality preferences vary widely from country to country.* Generally, the higher the level of living and the lower the per-capita consumption of rice, the wider is the range of prices consumers will pay for different rice qualities.

The high per-capita rice consumption areas are in developing countries where people have low levels of living. Where per capita consumption is 100-150 kg annually, a very small difference in price means a large change in family income for the year. As a result, consumers usually buy the lowest priced rice, other conditions being equal. In world rice markets, these areas want volume at reasonable prices and pay little for quality differences. However, in the domestic production and marketing of many rice-deficit countries, prices vary somewhat according to quality,

Recent rice importers in this group include Bangladesh, Indonesia, Sri Lanka, and several nations of West Africa. However, shortage of foreign exchange has caused some West African nations to shop for the lowest priced imported rice. Some have shifted to buying 100% broken rice for direct consumption, whereas it was traditionally used to manufacture beer and animal feed. This new demand has caused a shortage of broken rice and increased its price from 50% of the price for high-quality milled rice to about 75%. In some countries, consumers have eaten enough broken rice to prefer it, and domestic mills have shifted to breaking the product to meet consumer demand.

In recent years, some countries shifting from a deficit or a self-sufficient position to that of exporter have encountered serious quality problems. Producers, millers, and government leaders have frequently failed to understand the differences between traditional domestic demand and export demand. They have suddenly found they cannot market what they have considered as reasonably good quality rice. Their own consumers have not objected to it, but the rest of the world does not want it, or will buy it only at a very low price, usually much lower than the domestic support price.

In high-income, relatively low per-capita consumption areas, the consumer will pay, and pay well, for the highest quality possible, and will not buy lower quality rice at any price. The United States, Canada, Western Europe, the Middle East, and some consumer groups in Singapore, Hongkong, and urban Malaysia are in this group.

The world market for high-quality, long-grain, raw milled rice

The highest-priced large-volume world market is for the traditional high-quality indica, long-grain, raw milled rice. This market handles about one-fourth of all export-traded rice and generates an even higher percentage of income because of lucrative prices. The major importers of this rice are in Western Europe, the Middle East, Caribbean nations, and certain Asian population centers such as Hongkong, Singapore, and urban Malaysia. This is a quality market; quality is demanded and good prices are paid.

The major suppliers of this market are Thailand and the United States. Smaller volumes are sold from Uruguay, Argentina, and Surinam. Brazil, once a supplier, has been only self-sufficient in recent years.

Table 1 shows prices paid for different qualities, summarizing average wholesale prices for rices of different grades in Rotterdam, Holland, the major center for rice trade in Western Europe. Three price periods are presented: September 1981, a relatively high-price period; July 1982, a low-price period; and June 1984, a period of slightly higher prices. Also summarized in Table 1 are export prices at Bangkok, Thailand, for the major qualities of milled rice commonly shipped abroad from that country, the world's largest exporter.

For many years, the standard for quality milled rice in world markets has been U.S. grade No. 2 with 4% or less broken grains. This is a long-grain rice, white and translucent, with uniform size grains, no foreign material, no dust, no odor, no chalky grains, no red or striped grains, and with a content by weight of no more than 4% broken grains, none smaller than one-fourth grain. In September 1981, this quality was selling in Rotterdam for US$600/t. In July 1982, the price was $509/t and in June 1984, $529/t. In early 1985 this price varied between $460 and $500/t.

Based on this standard, in September 1981, U.S. No. 3, with 10% broken grains, sold for 97% of the standard, U.S. No. 3 with 15% brokens for 94%, and U.S. No. 2 brown rice for 77%. In the same market at the same time, Thailand 100% Grade A, the top export quality from that country, sold for 96% of the standard, Grade B for 92%, and Thai brown rice for 61%. Recently, the spread

Table 1. Variations in rice prices by grades in recent selected periods (1, 2).

	Prices per metric ton (US $)				Index (1st price = 100)			
	Sep 1981	Jul 1982	Jun 1984	Apr 1985	Sep 1981	Jul 1982	Jun 1984	Apr 1985
C. & F. Prices, Rotterdam								
U.S. #2, milled 4% brokens, in bags	600	507	529	496	100	100	100	100
U.S. #3, milled 10% brokens, in bags	584	480	507	463	97	95	96	93
U.S. #3%, milled, 15% brokens, in bags	562	472	490	446	94	93	93	90
U.S. #2, brown, 4% brokens, in bulk	460	365	356	338	77	62	67	68
Thai 100% Grade A, in bags	579	349	363	292	96	69	69	59
Thai 100% Grade B, in bags	575	320	318	256	96	63	60	52
Thai 100% Grade C, in bags	552	317	316	253	92	62	60	51
Thai 100% Grade B, brown, bulk	365	295	288	223	61	58	54	44
Uruguay brown, bulk	460	360	350	N/A	77	71	66	–
Thai A-1 Super, brokens	300	300	274	217	50	59	52	44
FOB Export Prices, Bangkok								
Milled rice, 100% 1st grade	530	330	300	260	100	100	100	100
Milled rice, 100% 2nd grade	510	300	265	230	96	91	88	89
Milled rice, 100% 3rd grade	507	297	260	225	96	90	87	87
Milled rice, super, 5% brokens	505	290	257	222	95	88	86	86
Milled rice, 5% brokens	465	276	255	220	88	89	85	85
Milled rice, 10% brokens	440	268	250	215	83	81	83	82
Milled rice, 15% brokens	420	260	215		79	79	62	82
Glutinous, 10% brokens	470	285	220		78	86	73	71
Brown rice, 100% 2nd grade	232	200	218		44	64	73	87
Milled brokens, A-1 super	285	275	265		54	83	88	69

between top quality and lower grades of U.S. and Thailand grades increased as price declined. The differences between U.S. prices and Thailand prices for specific grades were maintained, with some variations. A wider spread between the price of the highest quality and the lower ones during periods of declining or relatively low average prices is a consistent market phenomenon.

U.S. rice is milled and stored under rigidly controlled government supervision that produces a milled product sufficiently sanitary and clean so food experts recommend it not be further cleaned or washed. Consumers in

U.S. and Europe commonly do not wash rice of this quality before cooking it. Nutrition experts report that washing removes a part of the vitamins, minerals, and protein.

Thailand rice, although not produced under similar regulations, is carefully handled and graded and is considered almost as good as the U.S. product. However, comparisons of market prices show European consumers discount Thai rice somewhat. U.S. and Thai rice sold in Europe is much cleaner and higher in overall quality than practically all rice sold in most developing countries.

FOB price variations for rice grades at Bangkok, Thailand, are given in Table 1. Since prices for higher grades are normally established based on Rotterdam prices minus transportation, handling, import fees, and normal profit margins, the trends are similar but at a lower level. The prices for the lower Thailand grades, however, are determined by export markets in other areas and do not necessarily follow European trends. They do show the same price relationships of high-price periods to low-price periods and of high-quality to low-quality rice.

The changing consumer demand for broken rice is reflected in the European prices and Thailand export prices for Thailand A-1 Super, brokens. This standard widely traded grade of broken rice hovered about 50% of first-quality rice in Europe from 1981 to 1984. In Bangkok, however, this ratio moved from around 50% in the earlier period to 83-88% recently. This indicates relative demand for different qualities in various locations helps determine rice prices. Demand for broken rice in Europe has not materially changed because its major use is for producing beer and feeds, and competing products can replace broken rice if prices move out of line. However, the export demand for broken rice prices in Thailand is almost as high as for medium-quality whole rice, due to rapidly increasing demand for broken rice in West Africa, mentioned earlier. Thailand broken rice is long-grain, clean and reasonably free of foreign materials, and of much higher quality than broken rice in most developing countries.

Content of red or striped grains also affects quality evaluation. One or two red grains per kilo reduces the grade of U.S. rice from 1 to 3 and a few more red grains results in grade 5 or lower. Discriminating consumers in both the U.S. and Europe just do not want red rice in their product. Some markets do not discriminate against red grains. West Africa's outstanding varieties are long-grained with red seedcoats. Some consumers prefer the mixed red-grain product, and there is little price discrimination for red contamination in either whole rice or broken rice in these areas.

Brown rice is sometimes called "Cargo" rice and in Thailand "loonzain" rice. Brown rice is rough rice with hulls removed but with no further milling or polishing. It is imported into European countries for further milling or polishing to make use of partially idle mills and to secure the by-products (rice bran, rice germ, and broken grains) for specialized markets. Most imported brown rice is long-grained and of relatively high quality.

Some countries import brown rice rather than paddy because the hull of paddy makes up 20% or more of total weight and is practically valueless; removing the hull before shipping greatly reduces transportation costs. Brown rices from the United States, Uruguay, and Argentina, originating from high-quality uniform long-grain rice, normally sell for the same price in Europe. Thailand brown rice, frequently of mixed varieties, moves at a lower price.

The world market for medium-quality, long-grain, raw milled rice

Medium-quality, long-grain, raw milled rice makes up more of the internationally traded rice than does the high-quality product. It is exported mostly by Thailand; other exporters include Burma, China, and Pakistan.

Thailand, the world's largest exporter, supplies practically all the different qualities that world markets demand. Table 2 shows that much of Thailand's exports have been medium-quality, long-grain, 5% brokens to 25% brokens Grade B and C rice and A-1 brokens. During 1979-82, one-half of Thailand's exports were of these qualities.

Major markets for these products have recently included several Asian countries (including Indonesia and Malaysia), Europe, and the Middle East, as well as West Africa. Although these qualities are classified as medium-quality, they are cleaner, better milled, and have fewer impurities and broken grains than most domestic supplies sold in many deficit or self-sufficient areas.

Table 2. Average rice exports of Thailand by grade and region.

	100%	5-15%	25%	Par-boiled	A-1 brokens	Glu-tinous	Brown rice	Others	Total	Percent exports by region
Asia										
1975-78	19.20	22.22	26.82	9.49	13.93	7.10	0.05	1.19	100.00	60.3
1979-82	33.07	14.88	21.72	4.99	12.47	12.56	0.10	0.21	100.00	42.2
Africa										
1975-78	1.73	8.76	4.66	54.06	17.96	nil	4.01	8.82	100.00	26.2
1979-82	0.56	16.61	1.95	29.92	45.46	0.06	0.60	4.84	100.00	28.2
Middle East										
1975-78	37.18	13.30	0.39	47.39	0.15	0.02	1.06	0.51	100.00	10.0
1979-82	69.32	11.00	0.06	17.28	0.42	0.36	0.36	1.20	100.00	16.2
Europe and USSR										
1975-78	20.23	21.11	3.75	10.17	23.83	1.18	19.73	–	100.00	1.2
1979-82	19.67	47.71	12.37	2.73	10.32	0.36	6.84		100.00	9.3
W. Hemisphere										
1975-78	1.64	46.20	37.73	2.28	4.42	0.25	0.25	7.23	100.00	1.0
1979-82	2.45	83.56	3.13	3.48	1.71	3.55	0.11	2.01	100.00	4.3
Total										
1975-78	16.42	17.93	17.86	25.26	13.55	4.31	1.51	3.16	100.00	100.00
1979-82	27.26	20.78	11.01	13.68	19.09	5.56	0.91	1.71	100.00	100.00

The world market for medium-grain and short-grain rice

Normal medium-grain and short-grain rices are primarily japonica, adapted to cool-weather areas. Major exporters are Australia, the United States (California), Taiwan, parts of China, and Italy. Traditionally, many countries in cool-weather areas prefer the semisticky cooking qualities of short-grain rice over long-grain types. Short-grain rice has been a major import during rice-shortage years in South Korea, is an important import in the Pacific Islands, and is demanded by some consumer groups in major urban centers in Asia, Africa, and Europe. It is preferred by some European countries for use in desserts such as rice puddings.

There are exceptions to normal quality short-grain rice. Several Asian countries grow short-grain appearing varieties with very small round grains that cook like freely separating long grains. These are highly prized and bring premiums on local markets. Among countries producing small volumes of these types are Bangladesh, Sri Lanka, and China. A very small volume moves into international trade at premium prices in Hongkong and Singapore. Also, Indonesia has a series of varieties that look medium to short-grain but cook and taste differently. Although Indonesia has occasionally imported some medium- and short-grain japonica rice, this was of necessity, because consumers prefer the local bulu or javanica types or indica-type imports.

From 1980 to 1985, the supply of short and medium-grain rice relative to demand has been considerably larger than that of long-grain types, so many countries are attempting to shift production to more long-grain rice. Both California and Australia are shifting some acreage to long-grain varieties. Short- and medium-grain rice continue to have higher field and milling yields than long-grain rice, therefore these types will continue to predominate in most countries with serious food needs.

The world market for parboiled rice

Parboiled rice developed early in history as a way to salvage very low quality paddy; boiling it before milling hardens the grains so fewer will break. Important by-products soon developed. Consumers preferred the product's distinct taste and noted it would keep longer without refrigeration after cooking. Later, research indicated it was more nutritious than raw milled rice because the water-soluble vitamins diffuse inward during parboiling and remain in the grains after milling.

Parboiling has some major disadvantages. It produces an off-color milled grain which varies from light to dark yellow. The product usually has a distinct odor. These disadvantages have been partially eliminated by improvements in the process. The paddy is soaked to soften it and then steamed to stimulate gelatinization. A recent refinement uses a patented procedure to produce a product almost completely white and odorless.

Parboiled rice is consumed by at least 90% of the population of Bangladesh, a large part of the population of India and Sri Lanka, and large groups of consumers in Pakistan, South Africa, West Africa, Saudi Arabia, Nigeria and other countries of West Africa, and more recently in the United States and Europe. It is a major item in international rice trade.

There are two distinct subtypes of parboiled rice, based on quality, and several grade differences within each group. In volume, the most important is the relatively low-grade medium- and short-grain parboiled rice involving paddy parboiled by relatively primitive methods to salvage it. This is produced in large volume in Thailand, Burma, and Pakistan for export mostly in Bangladesh, Sri Lanka, and some West African countries. In this process, paddy is usually soaked for 1 or 2 d in cool to warm water and then placed in shallow pans, on metal plates, or in shallow vats where heat and moisture are applied to steam the product for a few minutes. It is then dried on open-air concrete or hard-soil patios before milling. Occasionally enclosed steam vats are used for the final process. The water source is usually a nearby stream and due to shortages, water may be used over and over.

The milled product is usually medium to dark yellow to brown, with a characteristic odor. Milling yield is usually only 15-25% broken grains as compared with 40-60% if the same low-quality paddy had been milled raw. There are generally only two or three grades, depending on the depth of color, the proportion of broken grains, and the degree of impurities. Usually the product sells for not much more than standard raw-milled broken rice. It is generally the lowest priced milled rice moving in international trade.

The second subtype of parboiled rice is high quality. A high-quality clean paddy is treated with very hot water for a few hours in clean enclosed vats or tanks. Steam is then forced through each batch for about 30 min. The paddy is then dried in mechanical dryers under sanitary conditions. Clean sterile water is used only once. The milled product is only slightly off-color from milled raw rice; when cooked it is completely white, fluffy, and odorless, and the yield of whole-grain rice is very high — 96-98% or more. It is a very attractive product with a slight nutty taste. It is very popular in many restaurants and for airline meals because it cooks the same every time and stays soft for hours after cooking. It generally sells for 20-50% more than the price of high-quality raw milled rice.

The company with the patented process to improve quality and appearance has a major share of the United States and export markets for high-quality parboiled rice. Some consumers who have traditionally consumed raw milled rice do not like the taste and texture. To others who consume rice only occasionally, it is completely acceptable. The United States market is growing as are those in Europe and the Middle East.

A recent market development is parboiled brown rice export. Increasing shipments have been moving from the United States and Thailand to South Africa, Canada, and Western Europe. The demand is growing because of market acceptance of high-quality parboiled rice and the improved keeping quality of parboiled brown rice over raw brown rice. Heretofore, the relatively poor keeping quality of brown rice under high temperature has restricted exports. Also, higher quality by-products are being recovered in milling.

The production of high-quality parboiled rice has some limitations. It requires very uniform and clean paddy with no impurities. Poorly dried paddy or paddy with a mixture of immature grains will not produce good-quality parboiled rice. More important, any damage from sucking insects, mostly the stink bug, shows up in parboiled rice as black grains. This is unacceptable for export market. Most countries produce very little “parboil class” paddy and the supply is limited even in the United States and Thailand. Also, once paddy is parboiled, it can never be returned to the original raw state. Since this is a thin, luxury market, sudden economic changes that retard demand can rapidly create a surplus and lower price.

The world market for aromatic rice

Aromatic rice has a special place in world rice markets. It is generally the highest priced rice and, in terms of quality, the most difficult to mill, store, and maintain.

The leading aromatic rice in world trade is Basmati, produced in the Punjab area along both sides of the Indus River in Pakistan and India. Pakistan exports 200,000-300,000t yearly, mostly to Middle East countries, with some to special markets in Europe. India exports 30,000-50,000t annually, mostly to the Soviet Union.

Basmati has a distinct aroma in the field, in harvesting, in storage, during milling, and during cooking and eating. When cooked, Basmati almost doubles its length, compared with about 50% elongation for most varieties. Its yields are low, production costs high, and it is used mostly for special occasions such as festivals and weddings.

When grown outside the Punjab region, Basmati is not aromatic. For example, standard varieties of Basmati grown in the Sind of Pakistan mature without aroma. The aroma is apparently a result of environment, the Punjab climate and/or soil, as well as genetic factors. As a result, Pakistan and India have a monopoly on export markets for Basmati.

Because Basmati usually yields low, paddy prices to farmers must be higher than for other types. Pakistan has controlled production by variable price supports to farmers and through a monopoly government agency exporting only a volume the market can absorb. At this level, Basmati milled rice brings a price about double the export price of normal good quality long-grain milled rice. The government’s storage facility at Karachi holds up to a year’s supply for export. The rice may be reprocessed to enable delivery of a uniform 10% broken, fairly well-milled, export product.

Other aromatic rices are important in world trade. Thailand produces several aromatic varieties. These mostly fill local demands at good prices, but in small volume have special markets in Hongkong and Singapore at relatively high prices.

An aromatic variety grown commercially in the United States is Della, developed by the Louisiana Rice Experiment Station 15 yr ago. It is marketed under several trade names, including Texmati, Pecan Rice, and Della Aromatic. A very small volume, in consumer-size packages, is sold abroad. In small volume, prices are about double those of conventional varieties, but field yield is low and production costs are high. Also, it is processed in separate mills, because the aroma would linger in the machinery and transfer to other rices. Because most U.S. consumers would judge any rice with an aroma to be contaminated, larger mills will not accept Della.

The world market for glutinous rice

Glutinous rice has a different starch composition than normal rice. The milled grains are dead-white and completely chalky. When cooked, glutinous rice becomes a gelatinous mass with grains indistinguishable. Glutinous varieties are grown in many countries in low volume for use in special dishes, primarily desserts.

In Northeast Thailand, and in parts of Laos and Kampuchea, glutinous rice is the staple food. Consumers greatly prefer it, reporting that “it tastes better and sticks to the stomach.” Food scientists have confirmed this belief. When cooked, glutinous rice absorbs about half as much water as normal rice; it provides greater bulk density in the digestive system, and the starch is slower to digest. Thus, consuming the same volume of the product provides the feeling of a full stomach and delays hunger. Northeast Thailand and neighboring Laos-Kampuchea have low incomes and limited food supplies, thus demand for a food that appeases the feeling of hunger is logical.

Thailand is the major exporter of glutinous rice, but the volume is only about 100,000 t a year, and most goes to Laos. It is produced mostly in the northeast, an area with climatic extremes from year to year. A good weather year produces a surplus; bad weather means local famines.

Prices presented in Table 1 reflect the impact of production changes in northeast Thailand. In mid-1981, after a good season in 1980, the export price of glutinous rice was 78% of the price of high-quality regular rice. In mid-1982, after a bad weather year, the price of glutinous rice increased to 86% of the price of good quality raw milled rice.

Normally only two grades of milled glutinous rice are exported from Thailand. These are 10% brokens long-grain glutinous, and 10% brokens short-grain glutinous. Most exports are long-grain rices.

Implications of world market rice quality to the developing world

1. *There are major world markets for rice.* Some markets provide excellent prices for high quality rice; others provide lower prices for less desirable qualities. The most important high-priced markets for good quality rice are Western Europe, the Middle East, and some urban centers in Latin America and Asia. The higher volume, lower quality markets are Indonesia, Sri Lanka, Bangladesh, and some nations of West Africa. A few deficit markets, such as Malaysia, require modest supplies of both types.

2. *World markets for rice are specialized.* The export markets are for a specific variety, a definite quality, a special processing type, or a rice that fits the unusual demands of a discriminating customer. Expertise and analysis are required for a new producer to enter the export market.

3. *For a country to move from self-sufficiency, to exporting, major changes in production, processing, and marketing are required.* The rice qualities acceptable to domestic consumers are frequently not acceptable in world markets. To produce export quality, improvements must be made in variety selection, weed and insect control, drying and storage practices, harvesting, milling, support price programs, transportation, and selling.

4. *Some world markets demand high-quality raw-milled rice.* Other markets require large volumes of lower quality, lower priced milled rice. Others handle only certain types of parboiled, aromatic, or glutinous rice. A country deciding to move into any of these world markets must be efficient and competitive.

5. *Quality is essential in domestic and export markets.* Even in rice-deficit nations, as domestic consumers see improved quality types appear from imports or other sources, pressures will increase for similar quality. However, as some nations reach self-sufficiency, consumers might be forced to consume lower quality domestic rice rather than the higher quality imports received in the past; this should be avoided.

6. *Improved quality starts with better paddy.* A mill may misuse paddy and reduce its potential, but it cannot produce milled rice that is better than the paddy used. Programs to improve quality must provide farmers with technical advice and incentives.

7. *Paddy grades with appropriate prices are needed to encourage high-quality production for export.* In all rice-exporting countries, milled rice grades are an essential part of marketing. The only way the farmer, the dealer, the miller, and the exporter can know and react to market demands is through quality evaluations throughout the marketing chain.

8. *The private sector should continue to handle most of the world rice trade.* In Thailand, private traders handle all sales, payments, grading, and shipping. In the United States, the same is true. In Australia, all international negotiations are handled by a cooperative owned and operated by the rice growers. Rice markets are extremely sensitive to minor changes in climate or economics, and the competitive private sector can react much more rapidly and accurately than can the public sector. Where government handles marketing, action usually comes too little or too late, to the detriment of the welfare of growers and the nation. Government should act as the umpire or referee but should not play the game.

9. *Because of rigid standards in world rice markets, some countries approaching self-sufficiency may wish to consider alternatives to exporting.* Competing for world markets is costly. For many countries lacking the comparative advantages of high yields and low production costs, exports may not be the way to go. Such nations might wish to consider shifting some of their lower-yield areas from rice into more profitable enterprises. Farming systems research may suggest appropriate alternatives.

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CONSUMER DEMAND FOR RICE GRAIN QUALITY IN SOUTHEAST ASIA

L. J. UNNEVEHR, B. O. JULIANO, and C. M. PEREZ
International Rice Research Institute
Los Baños, Laguna, Philippines

ABSTRACT

Abundant world rice supply has led to renewed interest in improving quality of modern rice varieties. The implicit values that consumers pay for grain quality characteristics are estimated for Thailand, Indonesia, and the Philippines. Consumers in all three countries significantly prefer better milling quality (fewer brokens and more polish) and aroma. Preferences for shape and chemical attributes vary, but consumers generally prefer intermediate amylose. International rice research should maintain good potential head rice recovery and reduce amylose content of future MVs. This study drew samples from urban centers. National programs might wish to study regional variation in preferences.

Modern rice varieties released by IRRI and national research programs in tropical Asia during the 1960s had a reputation for poor market and cooking quality. Hard texture of cooked rice and white belly endosperm were common to semidwarf parents. Selecting translucent grain improved market quality but most IR varieties, including IR36 and IR42, still have hard texture of cooked rice. Sacrificing cooking and eating quality for high yields and pest resistance was necessary to meet the growing demand for food in Asia. Asian rice production grew faster than population from 1965 to 1980 as a result of MVs, irrigation, and fertilizer. The real price of rice has declined in world markets and in several Asian countries since 1975, and this has increased demand for quality (4). Improved cooking and eating quality through intermediate amylose content is one of the main goals of IRRI's breeding program for irrigated environments in the 1980s (8).

Consumer taste panel acceptance and characteristics of rice varieties in ASEAN countries were recently reviewed (6). In this article, an economic model of consumer demand for characteristics of goods is used to estimate the implicit values of rice grain quality characteristics in Thailand, Indonesia, and the Philippines. In contrast to consumer panels, market price data provide information about the average preferences of many consumers who make their quality choices under a budget constraint. The estimates of implicit values of quality test how observed consumer preferences correspond to the measures of quality used to screen material in breeding programs. Furthermore, they reveal whether Southeast Asia consumers have similar preferences for rice grain quality and thus whether quality improvement should be undertaken by national or international breeding programs.

METHODOLOGY AND DATA

The methodology is drawn from a model of consumer demand for characteristics of goods developed by Ladd and Suvannunt (10). The model assumes that consumer demand is based on product utility, which is a function of product characteristics. As Unnevehr et al (14) have shown:

$$P_R = \sum_{j=1}^{m} X_{Rj} P_{Rj}$$

where P_R = the market price of rice,

X_{Rj} = the amount of characteristic j in one unit of rice, and

P_{Rj} = the implicit value of characteristic j.

The rice price the consumer pays equals the sum of the values of rice's characteristics.

If the characteristics that define grain quality can be measured, then the implicit value of these characteristics can be estimated. An ordinary least squares regression of commodity price on measures of quality will provide such estimates. Adding a random error term to the above model completes the estimation equation:

$$P_R = \sum_{j=1}^{m} X_{Rj} P_{Rj} + u$$

where u = random error.

The dependent variable, PR, will vary for different grades of rice. The independent variables, the X_{Rj}'s, should explain variance in the rice price and the parameter estimates (P_{Rj}'s) give the implicit values of grain characteristics.

The usual assumptions regarding u are made, i.e., mean equal to zero, constant variance, and independence.

The data were obtained from rice samples collected in retail markets in the Philippines, Indonesia, and Thailand. Samples were taken of each grade of rice offered by randomly chosen retailers; the price and advertised variety name were recorded for each sample. The retail markets were chosen to reflect the full range of preferences displayed by different income classes. To minimize price variance other than due to quality, all samples were collected within 1 wk.

The samples were analyzed for physical and chemical characteristics at the IRRI Cereal Chemistry laboratory. The expected relationship of characteristics to rice price (Table 1) is based on observed world market demand and consumer taste panel tests. IRRI screens rice varieties for quality based on these expected preferences.

Physical characteristics include whiteness, broken grains, shape, and chalkiness. Whiteness (polish) and brokens indicate milling quality. Shape, the ratio of grain length to width, and chalky areas in the grain are varietal characteristics. Consumers should prefer white, long slender rice with few brokens and little chalkiness. Whiteness is measured by a Kett whiteness meter, an optical instrument. The scale is from 0 to 100, with 100 indicating pure white magnesium oxide powder. Chalkiness was measured at the Rice Quality laboratory using a visual rating of the chalky proportion of the grain. The scale is 1 (less than 10% chalkiness), 5 (10 to 20%), and 9 (more than 20%) (10). Percentage of brokens is determined by grain sizing and weighing broken grains in a 100-g subsample. Length and width, in millimetres, are measured for 10 grains.

The chemical characteristics — amylose content, gelatinization temperature, gel consistency, and aroma — affect cooking and eating quality. Amylose content is the most important chemical characteristic and determines the hardness of cooked rice. The percentage of amylose content is evaluated by

Table 1. Rice grain quality characteristics.

Gram characteristic (measure)	Expected relationship to price
Physical	
Whiteness (% of pure white)	+
Brokens (% of grains)	-
Shape (ratio length/width)	+
Chalkiness (proportion of grain)	-
Chemical	
Amylose (%)	-
Gel consistency (mm)	+
Alkali spreading value (gelatinization temperature index)	-
Aroma (0-1 dummy)	+

the simplified iodine colorimetric procedure (7): low (10-20%), intermediate (20-25%), and high (25-33%). Many traditional varieties (TVs) have intermediate amylose content and cook moist and tender, while most MVs have high amylose content and harden after cooling. Because a soft texture is preferred, price should relate inversely to amylose content. Gel consistency, another measure of cooked rice texture, is measured by the length of cold milled rice paste in a test tube in a horizontal position (unreplicated 90 and 100 mg/2 m10.2 N KOH) (3). A higher number indicates a softer consistency: soft, 61-100 mm; medium, 41-60 mm; and hard, 25-40 mm. Mean of 90 and 100mg rice data is presented. Price should correlate positively with gel consistency. Gelatinization temperature (GT) determines the time required for cooking. Gelatinization temperature is measured by the alkali spreading value (11). It is the extent of disintegration of milled rice soaked in a 1.7% potassium hydroxide solution for 23 h at 30° C using a 1-7 score. A high rating indicates more disintegration and a low gelatinization temperature. Rices with intermediate GT (alkali spreading value of 4-5) are expected to be preferred over those with low GT (alkali spreading value of 6-71, because most TVs have intermediate GT. Because the alkali spread measure is inversely correlated with GT, this variable should have a negative implicit price. Aroma is a special characteristic of some TVs and it usually commands a price premium. Its presence or absence is indicated by a 0-1 dummy variable.

RESULTS

The range of choice of characteristic values available to consumers in each country depends on the rice varieties grown there. In the Philippines, MVs were planted on 85% of the rice area in 1982 (13). These are primarily IRRI MVs that have high (>25%) amylose content. The Philippine samples reflect national statistics; they were 91% MVs and had a high average amylose content of 28% (Table 2).

MVs are also widely adopted in Indonesia, where they covered 60% of the rice area in 1980 (5). Many of the MVs grown are locally developed varieties which have intermediate amylose content, rather than the high amylose content of IRRI varieties. The samples collected in Indonesia were about half MVs and half TVs. The MV samples had intermediate amylose so the sample average amylose content of 23% is much lower than in the Philippines (Table 2). Many of the TV samples were local bulu varieties which have short, chalky grains. Thus, Indonesian samples were bolder and more chalky than Philippine samples (Table 2).

Thailand is the world's largest rice exporter, and world market preferences for long translucent grains and good milling quality strongly influence the domestic market. Because IRRI varieties have grain shorter than 7.0 mm, they are not released directly in Thailand. Rather, Thai scientists have used IRRI varieties as parents in crosses to develop semidwarf varieties with the physical grain quality demanded by the world market. MVs released in Thailand were planted on only about 10% of the cultivated area in the late 1970s (5) because

Table 2. Average characteristics of rice samples (standard deviation in parentheses).

	Philippines	Indonesia	Thailand
Price (US¢/kg)	31.1	43.5	34.7
	(4.3)	(7.1)	(5.0)
Whiteness (%)	42.4	39.4	40.5
	(2.7)	(2.5)	(2.7)
Chalkiness score	42.5	37.7	16.3
	(10.7)	(11.3)	(15.4)
Shape (L/W)	3.9	8.0	4.1
	(2.0)	(1.8)	(2.2)
Amylose (%)	3.2	2.5	3.5
	(0.2)	(0.3)	(0.3)
Gel Consistency (mm)	27.8	23.4	23.6
	(2.4)	(2.3)	(4.2)
Alkali spreading value	41.1	46.8	56.6
	(10.2)	(8.3)	(14.6)
% Aromatic	5.7	5.5	5.1
	(0.6)	(0.7)	(0.8)
No. of samples	5.6	11.9	31.4
	107	118	86

they are not suited to the rainfed conditions there. The samples collected in Thai markets had a lower percentage of brokens and longer grains than in the other two countries (Table 2). The samples were all TVs, having the preferred characteristic of intermediate amylose content. Many Thai samples were aromatic.

Estimates of implicit prices of grain quality characteristics for the three countries are presented in Table 3. The implicit price represents the change in the rice price for a one unit change in the characteristic. The quality attributes included explain a large proportion of price variation in all three countries, indicating that laboratory measures provide good indicators of consumer preferences. The signs and significance of characteristics vary among countries, however.

In the Philippines, all grain quality characteristics, except gel consistency and shape (Table 3, regression 1), are significant. The Philippine data did not have enough aromatic samples (6 out of 107) to accurately measure an implicit price for aroma. Consumers show the expected preferences for physical quality and amylose content, but the implicit price of GT has an unexpected sign, probably because of low GT of prized upland rices and fine-grained IR42. In this sample of predominantly high-amylose rices, amylose content alone explained more than 50% of price variation. This result supports the hypothesis that high amylose content is the most important negative attribute of IRRI MVs.

Indonesian consumers also significantly prefer better milling quality, in particular a white (well-milled) rice. Other physical quality preferences differ. Because Indonesian consumers prefer their local TVs with short, chalky grains, there is a negative implicit price for shape and no significant negative price for chalkiness. As in the Philippines, the positive implicit price for GT in

Table 3. Regression estimates of implicit prices for grain quality characteristicsin three southeast Asian countries (dependent variable is price in US¢/kg; t-statistics in parentheses).

Country/ regression	No. of samples	Inter- cept	White (%)	Brokens (%)	Chalki- ness score	Shape (L/W)	Amylose (%)	Gel consist- ency (mm)	Alkali spreading value	Aroma	R^2	Durbin Watson
Philippines												
	107	35.16	0.34	–0.12	–0.38	2.85	–1.12	–0.01	1.94		.71	1.55
		(4.38)	(3.18)	(–5.10)	(–3.17)	(1.68)	(–9.49)	(–0.35)	(4.20)			
Indonesia	118											
		–0.19	1.14	–0.18	0.00	–4.68	0.14	0.05	1.92	9.07	.64	1.77
		(–0.02)	(5.39)	(–4.58)	(0.00)	(–2.31)	(0.51)	(0.96)	(2.26)	(6.71)		
Thailand	86	14.71	0.30	0.15	0.15	2.47	0.02	0.02	0.04	5.89	.89	1.80
		(2.62)	(3.47)	(10.57)	(1.10)	(2.29)	(0.22)	(1.14)	(0.12)	(0.00)		

Indonesia indicates an unexpected preference for low GT, probably because of the low GT of bulu rices. The implicit price of amylose content in Indonesia is not as large or significant as in the Philippines, perhaps because most Indonesian samples (101 out of 118) already have the preferred intermediate level of amylose. Therefore, consumers do not place any value on further reduction in amylose. These results generally agree with Mears' (12) qualitative survey of Indonesian consumer preferences.

The significance of milling quality characteristics and shape in Thailand reflects the importance of export demand. Aroma is the only significant chemical characteristic. The aromatic variety Khao Hawn Mali has low amylose content and low GT. There is no significant price for lower GT in Thailand, although the Thai samples have a lower average alkali spreading value (higher average GT) than samples from other countries. Thus, only Thai consumers show the expected preference for intermediate GT.

In summary, preferences for good milling quality and aroma are similar and have the expected sign in all countries, but preferences for shape and chemical attributes vary. Chalkiness and gel consistency do not seem to be particularly significant determinants of price in any country. The hypothesis concerning consumer preference for intermediate GT needs further study, because Philippine and Indonesian results indicate a significant preference for low GT. However, C4 and Cisadane have intermediate GT.

The hypothesis that consumers prefer intermediate amylose is generally supported. The high amylose content of IRRI MVs in the Philippines is clearly not preferred. In Indonesia and Thailand most samples already have the preferred intermediate amylose content so no significant value is observed for further reductions. The importance of intermediate amylose to Indonesian consumers is revealed indirectly by the efforts of local plant breeders to breed MVs with this characteristic. Cisadane, an intermediate-amylose MV released in 1981, was so widely adopted in 1984 that very few high-amylose rices were found in the market samples.

There are few other studies of the relationship between rice price and rice grain quality, and other studies have considered only physical quality characteristics. Head rice recovery was found to be a major determinant of quality price differentials in United States paddy markets (2). In the 1960s, Philippine rice prices varied mainly with percentage of brokens and presence of foreign matter (1). These results agree with the findings here that milling quality is a consistently important price determinant. This study is the first to measure the implicit values of chemical characteristics, however, and further study is needed to verify our results.

DISCUSSION AND CONCLUSIONS

This paper has demonstrated a simple methodology for testing consumer preferences. Laboratory measures of physical and chemical quality characteristics of rice can be regressed on rice price to explain observed differences in market prices. The regression parameter estimates show the implicit value of characteristics to consumers, and the significance of parameter estimates indicates the importance of characteristics. Such estimates are useful to identify the grain characteristics that plant breeding programs should focus on to improve quality.

Only some of the characteristics measured here can be substantially improved through plant breeding. In addition to inherited traits, grain quality is determined by cultivation environment and postharvest handling. Breeders can manipulate potential head rice recovery, chalkiness, shape, and the chemical variables. Improvements in handling and milling will depend on consumers' willingness to pay for better quality and on economies in processing.

Improvements in quality without reductions in yield will generally benefit rice consumers by lowering the cost of better quality rice. If higher quality varieties were widely adopted, producers would not receive a price premium but would benefit in two other ways. First, they would retain better quality rice for home consumption. Second, they would have a wider domestic market for their rice. Similarly, rice-exporting countries would benefit from quality improvement that would expand their potential export markets.

The market samples used here were drawn only from one main urban center in each country. Analysis of samples from other markets is needed to test the extent of regional variation in consumer preferences. Nevertheless, the results suggest that two types of quality improvement in modem rice varieties benefit consumers throughout Southeast Asia. Improving potential head rice (whole grain) recovery has widespread benefits because consumers in all three countries prefer fewer broken grains. Such improvement came in 1970 with IR20, a variety with potential head rice recovery of more than 60% of paddy. The earlier MVs, IR5 and IR8, have head rice recovery of only 36 to 40% of paddy. It will be important to maintain good potential head rice recovery in future MVs.

Development of intermediate-amylose rice varieties that have a wide range of acceptability in different agroclimatic environments would also benefit Southeast Asian consumers. C4, an intermediate-amylose MV released in the 1960s, was abandoned by farmers when it proved highly susceptible to insect pests. Cisadane, the intermediate-amylose MV developed in Indonesia, is resistant to an important insect pest, brown planthopper, but is not suitable for the Philippines because it is not resistant to a common rice disease, tungro, there. Since 1981, IRRI has tested some intermediate-amylose lines with intermediate or low GT and multiple insect and disease resistance.

Because consumer preferences for other characteristics vary, national programs have substantial room to tailor varieties to local preferences. International rice research could provide national programs with plant materials having a diversity of grain characteristics. National programs should further study consumer preferences to focus on quality objectives important to most consumers.

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UTILIZATION CHARACTERISTICS AND QUALITIES OF UNITED STATES RICE

B. D. WEBB
C. N. BOLLICH
Agricultural Research Service, USDA,
H. L. CARNAHAN
California Cooperative Rice Research Foundation, Inc.,
K. A. KUENZEL
University of Arkansas Rice Experiment Station,
and
K. S. McKENZIE
Louisiana Agricultural Experiment Station,
Louisiana State University Agricultural Center

SUMMARY

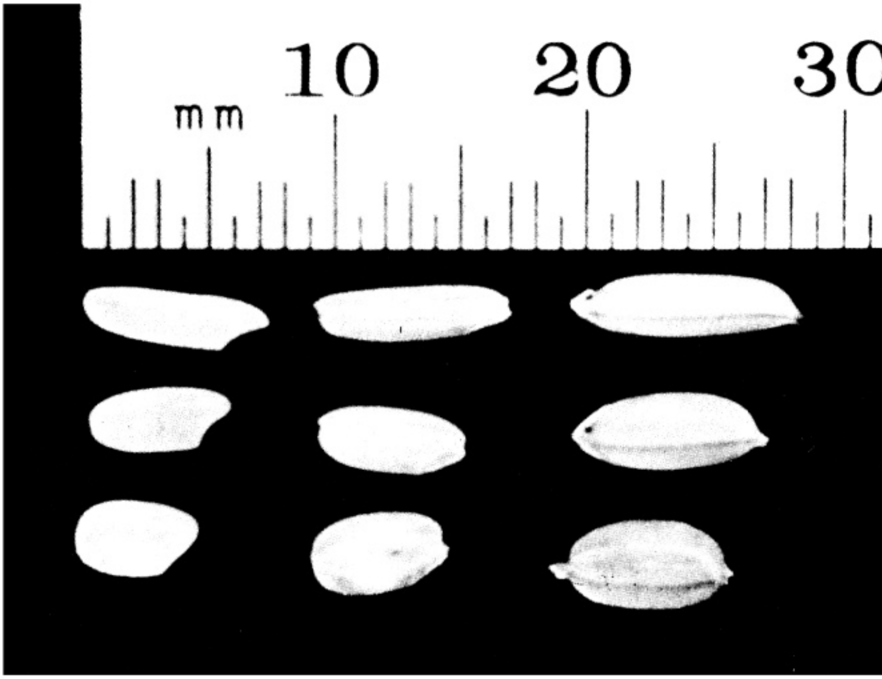
The United States rice industry is highly diverse and innovative in production, utilization, consumption, and export, and in cooking, eating, and processing qualities. The U.S. produces and markets three grain types classed as long-grain, medium-grain, and short-grain rices.

Present day long-grain varieties include the widely produced traditional mild-tasting types that cook dry and fluffy and are preferred for prepared products such as parboiled, quick-cooked, canned, frozen, and other manufactured products. Such varieties have intermediate amylose content, slight to moderate alkali-spreading reaction, and intermediate gelatinization temperature.

In contrast, traditional medium- and short-grain varieties cook moist and clingy, and are preferred for dry breakfast cereals, baby foods, and brewing. Such varieties have low amylose content, extensive alkali-spreading reaction, and low gelatinization temperature.

Dual-purpose and specialty rices produced on a limited scale include: 1) long-grain, superior-cooking-and-processing varieties for both table and manufactured products, with high amylose content, intermediate gelatinization temperature, low amylographic breakdown and high setback viscosities, and low solids loss in processing; 2) traditional long-grain varieties combined with aromatic (Basmati) type flavor; 3) short-grain waxy (sweet) rices with low gelatinization temperature and virtually 100% amylopectin starch; and 4) both long- and medium-grain rices for ethnic and industrial uses.

Rice produced and marketed in the U.S. is of three grain (kernel) sizes and shapes (Fig. 1) classed as long-, medium-, and short-grain types (Table 1). Historically, and now through planned breeding, each type is associated with



1. Typical United States long, medium-, and short-grain rice types. Top (l to r): rough (paddy rice): long-, medium-, and short-grain. Middle (l to r): Brown rice long-, medium-, and short-grain. Bottom (l to r): milled (head) rice long-, medium-, and short-grain.

specific cooking, eating, and processing characteristics and product uses (1,19).

For example, grains of traditional mild-tasting southern long-grain varieties cook dry, fluffy, and separate when boiled or steamed. They are preferred for parboiled rice, quick-cooking rice, canned rice, canned soups, dry soup mixes, frozen dishes, and other convenience products.

On the other hand, traditional medium- and short-grain varieties cook moist, chewy, and clingy, and are preferred in such products as dry breakfast cereals, baby foods, and brewing.

Among the dual-purpose and specialty rices are: 1) varieties with aromatic (nutty) flavor, 2) superior cooking and processing rice for table and

Table 1. Range of average grain size and shape measurements among traditional U.S. commercial long-, medium-, and short-grain types.[a]

Grain type	Grain form	Length (mm)	Width (mm)	Length-width ratio	Thickness (mm)	1,000-grain wt (g)
Long		6.7-7.0	1.9-2.0	3.4:1 to 3.6:1	1.5-1.7	15-18
Medium	Milled	5.5-5.8	2.4-2.7	2.1:1 to 2.3:1	1.7-1.8	17-21
Short		5.2-5.4	2.7-3.1	1.7:1 to 2.0:1	1.9-2.0	20-23

[a]Adapted in part from (19).

manufacturing, 3) waxy (glutinous) rices called sweet rice, and 4) rices developed for ethnic and industrial uses.

The U.S. rice industry is highly diverse, complex, and innovative in production, utilization, domestic consumption, export, and in cooking, eating, and processing qualities. Rice varieties of each grain type and quality must be available to meet these various needs, and suitable cooking, eating, and processing qualities are prerequisites for all new rice varieties. Previously, breeders emphasized grain yield, grain appearance, milling yield, plant type and maturity, nitrogen responsiveness, and resistance to insects and diseases. Now rice breeding programs give high priority to cooking and processing qualities, and these attributes are assessed at the United States Department of Agriculture National Rice Quality Laboratory at Beaumont, Texas, serving the cooperative rice improvement program in Arkansas, California, Louisiana, Mississippi, and Texas. More than 97% of the U.S. crop is produced from varieties developed and released by these cooperative (federal-state-industry) rice research centers and experiment stations.

VARIETIES AND TYPES OF U.S. RICE

New varieties are continually developed and released for commercial production. Current varieties, their grain types, broad cooking and processing classifications, and general production areas are given in Table 2. Currently, long-grain types account for about two-thirds of total production, medium-grain less than 30%, and short-grain and special-purpose rices about 5% (11).

Almost all long-grain production is in the southern states of Arkansas, Texas, Louisiana, and Mississippi, with some in Missouri and Florida. California produced its first commercial-scale long-grain crop in 1982 (7) and this production is steadily increasing. California produces mainly medium-grain rices, and most of the U.S. short-grain rice. In the southern area, Louisiana and Arkansas are the leading medium-grain producing states.

Five varieties — Labelle, Starbonnet, Lemont, Newbonnet, and Lebonnet — account for more than 90% of U.S. long-grain production. Four varieties — Mars and Saturn in the southern states, and M201 and M9 in California — account for most U.S. medium-grain production. In short-grain production, the California variety S201 predominates.

U.S. production of dual-purpose and specialty rices is limited but their production is very important to specific segments of the rice industry. Interest in these type rices appears to be increasing among broader segments of the rice industry.

PHYSICOCHEMICAL, COOKING, AND PROCESSING CHARACTERISTICS

Long-grain rices

Some chemical and physical endosperm characteristics of U.S. rices are shown in Table 3. For many years, breeding programs have successfully used physicochemical characteristics as indirect indices of rice cooking, eating, and

Table 2. Variety, grain type, cooking and processing quality type, and production area of U.S. rices.

Variety and grain type	Type of cooking, eating, and processing quality for which the variety was developed	Production area
Long-grain		
Labelle		
Labonnet		
Lemont		
Newbonnet		
Starbonnet	Traditional southern long-grain quality	Southern U.S. (major production)
Bellemont		
Bond		
Leah		
Skybonnet		
Tebonnet		
L201		
L202	California long-grain type quality	Western U.S. (limited production)
Calbelle		
Newrex	Improved southern long-grain type quality combined with superior processing quality	Southern U.S. (limited production)
Della (Aromatic)	Specialty flavored rice quality	Southern U.S. (limited production)
Toro II	Special quality for special groups	Southern U.S. (limited production)
Medium-grain		
M201		
M9		
M101	Traditional California medium-grain quality	Western U.S. (major production)
M302		
M7		
Mars		
Nato	Traditional southern medium-grain quality	Southern U.S. (major production)
Saturn		
M401	Premium California medium-grain quality	Western U.S. (limited production)
Kokuhorose		
Brazos	Traditional Southern medium-grain quality combined with specific brewing quality	Southern U.S. (limited production)
Short-grain		
S201	Traditional California short-grain quality	Western U.S.
Nortai	Southern short-grain quality	Southern U.S. (limited production)
Waxy Mochi Gome	Specialty “Sweet Rice” quality	Western U.S. (limited production)
Waxy Calmochi 202		

processing behavior (14,19). These indices and their test procedures are: amylose content [(21) as modified by (8) or (13)]; alkali-spreading value of whole milled grains in contact with dilute alkali — an indicator of gelatinization temperature type (10); amylographic gelatinization temperature (5); amylographic gelatinization and paste viscosity characteristics (6); protein content (2); and parboil-canning stability (15).

As shown in Table 3, traditional southem U.S. long-grain varieties which cook dry and fluffy are characterized by intermediate amylose content, a slight to moderate alkali-spreading reaction indicative of an intermediate gelatinization temperature, and an intermediate to high-intermediate amylographic gelatinization temperature. Amylographic paste viscosity charac-

Table 3. Average physicochemical, cooking, and processing characteristics of traditional and specialty U.S. long-grain rice varieties when grown in their area of origin.[a]

Long-grain variety	Quality type	Amylose (%)[b]	Alkali spreading value (av no.)	Gelatnization temperature type	Amylographic gelatinization temperature (° C)	Amylographic viscosity (Brafender units)					Protein (%)[e]	Parboil canning stability (% loss)
						Peak	15 min at 95°C	Cooled to 50°C	Breakdown[c]	Setback[d]		
Labelle		23.8	3.3	Intermediate	73	830	400	840	−430	+10	6.6	20
Lebonnet		24.6	3.7	Intermediate	73	820	400	850	−420	+30	6.8	18
Lemont		24.2	3.8	Intermediate	74	860	440	860	−420	0	7.0	I8
Newbonnet	Traditional	24.1	3.4	Intermediate	72	790	410	780	−380	−10	6.6	18
Starbonnet	southern	24.1	3.2	Intermediate	72	850	410	860	−440	+10	6.9	19
Bellemont	long-grain	23.6	3.6	Intermediate	73	790	390	790	-400	0	7.1	19
Bond		23.4	3.9	Intermediate	75	810	390	820	−420	+10	7.4	20
Leah		23.7	4.0	Intermediate	72	820	400	810	−420	−10	6.8	22
Skybonnet		23.9	3.4	Intermediate	71	790	400	810	−390	+20	6.7	19
Tebonnet		23.8	3.6	Intermediate	74	800	420	790	−380	-10	6.9	19
L201	California	23.4	3.9	Intermediate	71	800	390	810	−410	+10	6.8	23
L202	long-grain	26.2	4.0	Intermediate	70	770	400	850	−370	+80	6.9	21
Calbelle		24.3	4.4	Intermediate	69	760	390	800	−370	+40	7.1	20
Newrex	Superior	26.0	4.2	Intermediate	74	790	680	960	−110	+170	7.0	15
Della	Flavored	22.6	3.9	Intermediate	72	800	410	780	-390	−20	7.1	21
Toro 2	Specialty	16.7	6.8	Low	66	810	420	760	-390	-50	6.7	34

[a]Adapted in part from (18). Milled rice characteristics. [b]Milled rice amylose 12% moisture basis. [c]Breakdown viscosity = peak minus viscosity after 15 min at 95 °C. [d]Setback viscosity = peak - viscosity cooled to 50 ° C. [e]% N × 5.95 dry basis.

teristics usually show an intermediate peak height, relatively high breakdown viscosity, and a slightly positive setback viscosity. Parboil-canning stability in terms of solids loss during processing is relatively low (desirable) and canned grains show relatively little splitting and fraying of edges and ends. Over 95% of the total U.S. long-grain production is from varieties of these traditional southern long-grain types.

California long-grain types have similar characteristics, except L202 which has about 2% higher amylose content than traditional southern types. California types usually show slightly higher alkali-spreading values and slightly lower gelatinization temperatures.

The variety Newrex represents the first major improvement in inherent cooking, eating, and processing quality of southern long-grain varieties. It was developed (4) to satisfy the industry's need for a drier and fluffier table rice combined with much improved canning stability and low washout losses in processing. Newrex (Table 3) differs from traditional southern long-grain varieties in: 1) much lower amylographic breakdown viscosity and higher setback viscosity, 2) significantly lower solids loss in processing, indicating less canned kernel splitting and fraying, and much improved grain stability and integrity in processing, 3) a 2-4% higher amylose content, and 4) a slightly firmer cooked kernel texture (17). Alkali-spreading values, gelatinization temperature, and protein levels are similar to those of traditional southern types. Although production of Newrex is limited, the rice industry is becoming increasingly interested in the development of long-grain varieties with improved processability. Newrex is the forerunner of these improved types.

Della, a scented (aromatic) long-grain variety, is produced in limited amounts as a specialty rice. Its aroma is like that of roasted popcorn or nuts, and the nutty taste resembles that of the much-sought-after Basmati rices of Pakistan and India. Della does not, however, possess the extreme cooked kernel elongation of true Basmatis. Its cooking, eating, and processing characteristics (Table 3) are similar to those of traditional southern long-grain varieties.

Toro 2 is a specialty rice produced in limited amounts for local markets. Its grain size and shape is similar to other U.S. long-grain rices, but it has the cooking and eating qualities of U.S. short- and medium-grain types. Toro consumers like the clingy cooked texture characteristic of short- and medium-grains in a long-grain type. Toro 2 (Table 3) is a low-gelatinizing, low-amylose type like U.S. short- and medium-grain varieties (Table 4).

Producers, processors, and distributors practice extreme caution in keeping these specialty rices separated from traditional types.

Medium- and short-grain rices

Traditional medium- and short-grain rices which cook moist and clingy, in contrast to the traditional dry fluffy cooking long-grain types, are characterized (Table 4) by a comparatively low amylose content and extensive spreading reaction of whole grain rice in contact with dilute alkali, indicative of

Table 4. Average physicochemical, cooking, and processing characteristics of traditional and specialty U.S. medium-, and short-grain rice varieties when grown in their area of origin.[a]

Medium-short-grain variety	Quality type	Amylose (%)[b]	Alkali spreading value (av no.)	Gelatinization temperature type	Amylographic gelatinization temperature (°C)	Amylographic viscosity (Brafender units)					Protein (%)[e]	Parboil canning stability (% loss)
						Peak	15 min at 95°C	Cooled to 50°C	Breakdown[c]	Setback[d]		
Medium-grain												
M201		18.7	7.0	Low	66	740	360	710	–380	–30	6.2	31
M9	Traditional	18.0	7.0	Low	67	730	370	700	–360	–30	6.6	36
M101	California	20.1	6.9	Low	65	800	390	780	–410	–20	5.9	36
M302	medium-grain	19.4	6.6	Low	64	700	330	680	–370	–20	6.4	34
M7		17.6	7.0	Low	66	810	400	800	–410	–10	6.8	33
Mars	Traditional	16.1	6.0	Low	69	910	400	710	–510	–200	6.3	32
Nato	southern	15.8	6.0	Low	68	930	410	720	–520	–210	6.9	32
Saturn	medium-grain	15.4	6.2	Low	67	960	430	740	–530	–220	7.0	34
M401	Premium	18.8	6.9	Low	65	690	310	670	–380	–20	6.2	35
Kokuhorose	California	16.4	6.9	Low	64	780	340	690	–440	–90	6.4	33
Brazos	Dual-purpose	17.2	6.5	Low	66	780	390	760	–390	–20	6.9	30
Short-grain												
S201	Traditional California short-grain	18.0	6.9	Low	64	780	390	710	–390	–70	6.6	33
Nortai	Traditional southern short-grain	17.3	6.2	Low	67	820	390	700	–430	–120	7.4	32
Mochi Gome	Waxy or	1.0	7.0	Low	62	520	210	290	–310	–230	7.3	38
Calmochi 202	"Sweet Rice"	1.0	7.0	Low	60	510	200	270	–310	–240	7.0	37

[a]Adapted in pan from (18). Milled rice characteristics. [b]Milled rice amylose 12% moisture basis. [c]Breakdown viscosity = peak minus viscosity after 15 mm at 95 °C. [d]Setback viscosity = peak – viscosity cooled to 50 °C. [e]% N × 5.95 dry basis.

a low gelatinization temperature. Amylograms of the traditional medium- and short-grain types usually show comparatively lower cooled paste viscosities due, in part, to their lower amylose levels. The parboil-canning characteristics of traditional medium- and short-grain types show high (undesirable) solids loss in canning and the processed kernels show extensive splitting and fraying of edges and ends.

Most traditional California medium-grain varieties have slightly higher amylose levels and lower gelatinization temperatures than traditional southern varieties. For some ethnic and manufactured products, California types are preferred; for others, both California and southern types are used. These differences in preferences are not clearly understood. The traditional California and southern medium-grain varieties account for over 90% of U.S. medium-grain production.

Premium California medium-grain varieties M401 and Kokuhorose possess physicochemical characteristics similar to those of traditional medium-grain types. Their premium status is believed largely due to their larger kernels, appearance, and undefined differences in taste and flavor. Production is limited but increasing.

Brazos was developed as a dual-purpose variety possessing traditional southern medium-grain quality combined with a higher susceptibility to starch liquefaction by malt diastase than other southern medium-grain types. This property is preferred for specific brewing uses. California medium-grain varieties have this characteristic, but southern varieties heretohre have not. Factors responsible for these differences in starch liquefaction rates have not been defined.

The predominant short-grain variety, California S201, has cooking, eating, and processing characteristics (Table 4) similar to those of traditional California medium-grain types, except for grain size and shape. Nortai, a southern short-grain, is dual-purpose, combining traditional quality with specific brewing characteristics.

Specialty waxy varieties (sweet rices) Mochi Gome and Calmochi 202 are produced in limited quantities exclusively in California. They have opaque endosperm of virtually all amylopectin starch, and significantly lower gelatinization temperatures and amylographic peak, hot, and cool paste viscosities than other U.S. varieties. Cooked grains lose their shape and are very glutinous.

Waxy rices go into ethnic uses and specialty products including rice cakes, sauces, gravies, salad dressing, desserts, pizza shells, and batter dips for fried chicken. Mochi Gome is preferred for mochi cake, but reasons for this preference have not been identified.

ENVIRONMENTAL AND CULTURAL FACTORS AFFECTING PHYSICOCHEMICAL, COOKING, EATING, AND PROCESSING CHARACTERISTICS OF RICE

Environmental and cultural factors affecting physicochemical properties of rice (3, 9, 12, 16, 20) include location and season of growth, date of seeding and

Table 5. Effect of location of growth on some physicochemical, cooking, and processing characteristics (average) of two traditional southern rice varieties [a]

Variety	Location	Amylose (%)[b]	Alkali spreading value (av. no.)	Gelatinization temperature type	Amylographic gelatinization temperature (°C)	Amylographic viscosity: Peak	Amylographic viscosity: 15 min at 95°C	Amylographic viscosity: Cooled to 50°C	Amylographic viscosity: Breakdown[c]	Amylographic viscosity: Setback[d]	Protein (%)[e]
Southern long-grain Labelle	Texas	23.6	3.6	Intermediate	74	850	400	840	–450	–10	6.5
	Lousiana	23.7	3.5	Intermediate	73	820	390	820	–430	0	6.7
	Arkansas	24.3	4.3	Intermediate	70	790	380	790	–410	0	7.2
	Mississippi	24.0	4.0	Intermediate	71	800	400	780	–400	–20	7.0
	California	25.7	6.5	Low	68	590	360	650	–230	+60	5.7
Southern medium-grain Nato	Texas	15.9	6.3	Low	69	940	400	730	–540	–210	7.1
	Louisiana	15.7	6.0	Low	70	950	390	700	–560	–250	7.3
	Arkansas	17.1	6.5	Low	68	860	410	760	–450	–100	7.7
	Mississippi	17.3	6.4	Low	67	840	390	740	–450	–100	7.6
	California	20.8	7.0	Low	64	620	340	670	–280	+50	6.8

[a] Adapted in part from (18). [b] Milled rice amylose 12% moisture basis. [c] Breakdown viscosity = peak minus viscosity after 15 min at 95 °C. [d] Setback viscosity= peak — viscosity cooled to 50° C. [e] % N X 5.95 dry basis.

harvest, ratoon cropping, age of crop (new crop versus old), fertility, and other cultural practices and these studies clearly show the influences on specific physicochemical indices of quality.

However, there is little published research examining the impact of environmental and cultural practices under actual processing conditions, primarily because of manufacturing's proprietary nature. Rice product manufacturers regularly need to adjust processing methods within a crop season (new crop versus old crop) even for the same variety. A better understanding of the impact of environment and cultural practices on physicochemical characteristics and their relation to actual processing conditions could help to explain why interseason and intraseason adjustments are necessary.

The influence of location of growth on physicochemical, cooking, eating, and processing characteristics is illustrated in Table 5. Some characteristics vary greatly by location; others seem unaffected. The effect of location on amylose and alkali spreading values illustrated by the two varieties in Table 5 are consistent for most varieties sampled over several years. These environmental effects suggest, for example, that varieties may be area- and/or environment-specific in quality attributes. The new short-stature California long-grain variety L-202, as a result of conscious effort, contains 2-3% higher amylose than southern long-grain varieties and has the desired intermediate alkali spreading value even when grown in California. Similarly, season of growth, ratoon cropping, and crop age affect characteristics of U.S. rices.

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EFFECT OF ENVIRONMENT AND VARIETY ON MILLING QUALITIES OF RICE

O. R. KUNZE
Texas A&M University
College Station, Texas

ABSTRACT

Fissured rice grains usually break during milling, thereby reducing head rice yield and milling quality. Low-moisture rice grains can fissure when subjected to a moisture-adsorbing environment. At harvest time, field samples of rice are used to determine grain moisture content. This moisture measurement implies that all grains are at the measured moisture, but the paddy may vary from dry grains at nearly storage moisture to wet grains still in the dough stage.

Low-moisture grains may be subjected to high-moisture environments 1) in the field before harvest, 2) in combine hoppers or holding bins before the grain is dried, 3) in deep bed or column dryers where a drying front moves through the bed of grains, and 4) in storage, transport, or milling facilities.

Each rice variety has its own susceptibility to fissuring. Moisture stresses produce fissured grains more in bold varieties than in long-grain or long, slender-grain varieties. Different rice varieties may have similar grain configurations but may not be uniformly susceptible to fissured grains. Chemical compositions of rice varieties with similar grain configurations but with different fissuring susceptibilities need to be studied to determine if fissuring characteristics can be predicted from the chemical composition.

In many countries, milling quality influences the economic value of the grain. Milling quality usually includes total and head rice yields from a rice sample. Milling quality is vital in the rice trade, therefore, quality must be determined and defined so research can improve it.

This paper addresses the engineering and varietal aspects of milling quality. Engineering aspects include harvesting, handling, drying, storage, transport, and milling operations, and can also include physical and mechanical properties of grain.

Different varieties have different grain configurations and grains differ in chemical composition, influencing milling quality. Engineering and varietal aspects are not necessarily independent of each other.

Mechanical equipment can lower rice quality by breaking grain. Therefore, processing-equipment manufacturers must produce machines that protect milling quality. Normally, equipment which mutilates the product it processes cannot stay on the market. Equipment manufacturers must continually upgrade their equipment to remain competitive.

This paper does not discuss machine mechanisms that produce higher milling quality, but centers on other factors that influence quality. Dried rough rice (paddy) is hygroscopic and reacts to every environment to which it is exposed. Rice assumes this hygroscopicity after maturation in the field. The mature grain moves from a condition of plant dependence to one of plant independence. As grain dries, it loses moisture to the environment. When the drying grain drops below approximately 20% moisture content, grain moisture cycles with daily environmental conditions; grain moisture attempts to stay in equilibrium with the ambient temperature and relative humidity. Even during and after harvest, each rough rice grain continually reacts with its environment.

This paper identifies and discusses environmental conditions to which a rough rice grain might be exposed, and discusses how rice varieties may react to these conditions.

LITERATURE REVIEW

Early researchers understood that rice in the field may fissure after it matures and is ripening. Copeland (3), a professor of plant physiology and former dean of the College of Agriculture at the University of the Philippines, wrote: "Sun-cracking, as the word indicates, is a fine crosswise cracking of the grain, typically due to exposure to the sun and rapid drying. The effect is that an excessive portion of the grains break in milling. As the chief element in fixing the value of paddy is the amount of 'head-rice' (whole grains) which can be milled out of it, its value decreases rapidly with the presence of grains which will break. Early rice is much more subject to breaking than late rice. — It may be worthwhile to cap the shocks of early varieties, if not of late rice."

Although Copeland (3) was not completely correct in perceiving what caused the rice grain to sun-crack, he was correct in stating that an excessive portion of sun-cracked grains break during milling. About 6 yr later, Kondo and Okamura (6) published an article containing the information to rectify any misconceptions left by Copeland. They took rough rice (Kibiho) at storage moisture (12.6% moisture content) and exposed it to the ambient environment at 0800 h, leaving it exposed for 24 h. They recorded grain moisture content, the ambient temperature, and relative humidity every 2 h. By 1600 h, grain moisture had dropped to 9.5% and none of the grains had fissured. By 1800 h, grain moisture content had increased to 10.8% and 4.0% of the grains had fissured; by 2000 h, 5% of the grains were fissured; by 2200 h, 19%; by midnight, 46%; and by 0800 the next morning, 72% of the rough rice grains had fissured while the grain moisture content had returned to 12.4%.

Brown rice at 13.9% moisture content was subjected to the same exposure pattern. At 1600 h, its moisture content was 10.8% with no fissured grains. By 1800 h, moisture content had increased to 11.3% and 10.5% of the grains were fissured; by 2000 h, 61.5% of the grains were fissured, and by midnight, 100% of the brown rice kernels had fissured. The next morning at 0800 h, the brown rice had a 13.8% moisture content. Similar experiments with different initial grain moistures were run with Kibiho and Asahishinriki rice varieties.

In other research (6), low-moisture grains on field-dried plants were exposed to rain for several hours. Many grains fissured. Bundles of harvested rice were hung on rods to dry in the ambient environment. More kernels fissured in the outer portions of the bundles than in the interior. Small bundles showed more fissured grains than large bundles. Grains fissured most easily where they were most subject to drying and exposed to rain and dew. Rough rice exposed to a brief rain showed some fissured grains but fissures did not increase when rice was immediately dried. The researchers concluded that "It is without doubt that the moisture adsorption by dry rice is a definite cause for the fissuring of rice grains."

Five years later, Stahel (15) published similar work. He harvested rice with moisture between 20 and 24% and dried it in the sun. At various times during drying, he measured the moisture content in a sample while remaining sample grains were sealed in a flask. Later, the samples at different moisture contents were submerged in water for 1.5 h before being spread on drying frames until moisture content was about 10%. When grain moisture was between 15 and 24%, remoistening did not influence breaking. But when rice was dried to 14 or 15% moisture before rewetting, head rice yield declined. According to Stahel, the percentage of whole grain begins to decline when grain moistures in the field reach 17-20% between 1000 and 1100 h. Moisture of rice standing in the field may be 4-5% lower in the afternoon of a dry sunny day than at 1000 or 1100 h.

Stahel (15) concluded that whenever dry paddy is remoistened, sun cracks develop and cause much more breaking during milling. He further stated that the term 'sun-crack' is a misnomer because cracks are not due to rapid drying in the sun but to an increase in moisture content. The critical point at which remoistening produced sun cracks was about 14% moisture.

Despite Stahel's published work, the sun crack misconception continued. Meanwhile, the wheat industry was confronted with the phenomenon that postrainstorm-harvested wheat never had the density of prerainstorm-harvested wheat (16). Years later, x-ray techniques provided proof of internal spaces in weathered wheat (5,13). Grosh and Milner (5) reported that "although other workers have noted cracking when the endosperm is dried, direct evidence that cracks form in wheat as a result of wetting the endosperm alone has not been offered previously. While it may be reasonable to assume that some fine cracking may exist in sound grain, these results indicate a pronounced increase in cracks, both as to number and dimension, as a result of wetting." Thus, the fissuring response from moisture adsorption was also confirmed for wheat but the information did not move into the literature of postharvest rice technology.

If heated air drying is considered an environmental condition, Ban's work applies (1). He related rice cracking to high drying rates. Fissures (cracks) which developed were related to drying rate and moisture span through which grain was dried. Fissures developed after drying. When rapidly dried rice was stored under airtight conditions, grains fissured for 48 h after drying. Earle and Ceaglske (4) had previously found that a large moisture gradient in macaroni at the end of drying caused macaroni to fail soon after drying.

In 1962, I rediscovered that rapid moisture adsorption caused rice to fissure.

DISCUSSION OF LITERATURE

Early terminology such as sun-cracks, sun-cracking, sun-checks, and sun-checking have been a confusion in the rice industry. Meanings implied are not necessarily wrong nor right. The sun apparently does not directly cause fissured grain but instead causes rice to lose moisture so grains subsequently readsorb moisture from the environment. The sun's drying potential does not appear sufficient in itself to cause the postdrying cracking which Ban (1) observed with heated air drying. Mechanical drying can maintain this drying potential over an extended time. In ambient air, however, this potential increases during morning hours, reaches maximum in the afternoon, and then decreases and finally reverses itself in late afternoon and evening hours of a summer day. In both cases, the process is similar, with time and drying potentials as the significant variables.

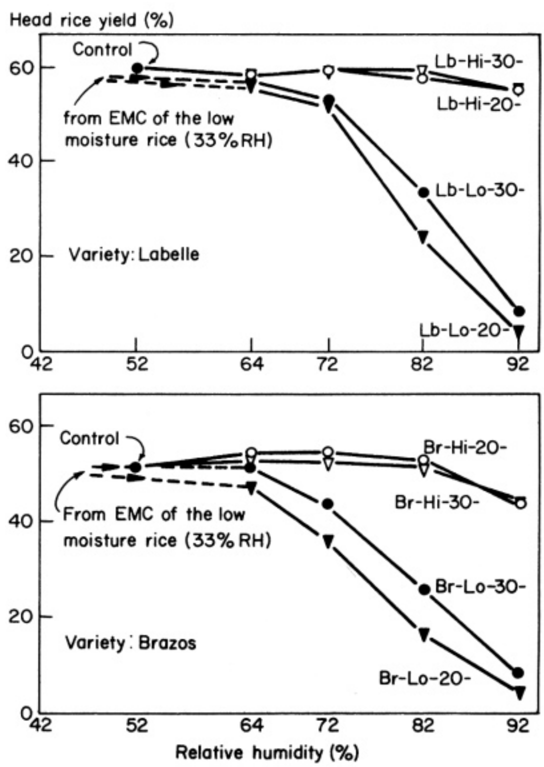
Terminology in the current literature also lacks preciseness. We need to more accurately describe damage to grain. Terms such as cracks, surface cracks, stress cracks, checks, faults, internal faults, splits, fractures, partial fractures, vacuoles, crack rings, fissures, and others are readily found in the literature. Which of these terms convey the same meaning and which convey differences in kernel defects? Perhaps more importantly, what is the source of the defect described? If the type of defect observed would clearly delineate the source of the defect, then research could be more efficiently directed to the critical needs.

ENGINEERING ASPECTS

In studying grain fissuring from moisture adsorption, Chen and Kunze (2) took low-moisture rough rice samples (long-grain Labelle, and medium-grain Brazos) and subjected them to a single relative humidity increase for 4 d. They first observed that mature rough rice from the field or from storage provides a biased sample for moisture adsorption experiments because these samples contain grains fissured from previous environmental exposures. Selecting good grains from such a lot introduces bias because the most susceptible grains have been removed. The remaining good grains would then be less susceptible to fissures and would give the variety a more favorable evaluation than justified.

An unbiased sample for moisture adsorption would be harvested in the field before any fissured grains develop. It would be dried in a carefully controlled environment. Grains most susceptible to fissure would be maintained as sound and whole. Yet the sample might still be biased because of immaturity or high moisture content at harvest. Unbiased samples would be ideal for comparing fissure resistance of varieties in commercial production or for comparing progeny materials used to develop new varieties.

Chen and Kunze (2) found their control samples for Labelle showed 11.1% more total yield than head yield; Brazos showed 20.7% more total yield than head rice yield. These were considered the extent of bias in the original samples. These biased samples were then equilibrated before being subjected to relative humidity increases. A sudden relative humidity increase of 30% or more then further reduced head rice yield (Fig. 1). Experiments were run at temperatures of 20 and 30° C with initial moisture contents of samples at 8.6



1. Effects of relative humidity and temperature on head rice yield of two varieties subjected to the indicated exposure (2).

and 10.7%. After exposure, samples were dried in a controlled environment laboratory (23°C and 52% RH) for at least 3 wk. Thereafter, samples were milled and processed into head rice, large grain fragments, and small grain fragments. Ratio of brokens was the weight ratio of small fragments to large fragments. A high ratio indicated more small particles and fewer large ones. Chen and Kunze (2) concluded that head rice yield was the most sensitive measure of exposure effects and the ratio of brokens was a secondary measure somewhat indicative of environmental exposures to which the grains were subjected.

Kunze and Hall (10, 11) worked with six brown rice varieties and subjected them to increments of relative humidity increases at three temperatures. Thermal gradients produced by a temperature change of 34°C did not produce fissures in rice as long as grains were maintained at constant moisture. Moisture gradients were more effective in producing stress cracks than were temperature gradients. Cracks (fissures) from large and small humidity changes differed. Small humidity changes produced only major cracks. Under large relative humidity changes, minor cracks at grain ends preceded fissures. Grains initially at an equilibrium moisture content of 9% or lower, dry basis, fissured the fastest when the vapor pressure change was the greatest. Grains with an initial moisture content of 13% developed fissures faster from a smaller vapor pressure increase.

The foregoing literature review and discussion show that rice grains at storage moisture will fissure when subjected to an environment from which they can rapidly adsorb moisture. The remainder of this paper attempts to identify moisture adsorption environments to which rice grains may be subjected and to show how grains from different varieties may react to these moisture adsorption environments.

Before harvest

After planting, the rice seedling emerges with a single stem. After developing into a plant with four or five leaves, the seedling produces its first tiller or second stem. Other tillers follow, with stems growing and flowering in sequence. The sequence continues during fruiting and maturation, so that maturing grains in the field can vary widely in moisture content. Grain moisture content may vary considerably from the measured field moisture. When field moisture of rice is between 20 and 25%, there already are some low-moisture grains which will readsorb moisture from the environment during daily fluctuations of temperature and relative humidity. Kunze and Prasad (12) harvested the most mature panicles from a plot. After hand-shelling 60 of the most mature grains, they found 14 were fissured. Field moisture of the rice was 29.4%. The fissured grains apparently had dried to low enough moisture in previous days to develop fissures when they readsorbed moisture at night. **Thus, the first moisture-adsorbing environment to which low-moisture grains may be exposed is in the field before harvest.**

During harvest

Rice is usually harvested at moisture content between 20 and 24%. However, field moisture only represents the average moisture in the sample. The harvested mass is a mixture of high-, low-, and intermediate-moisture grains which together determine field moisture. Kunze and Calderwood (9) cite an example where field rice at 22% moisture may contain low-moisture grains at 15% and high-moisture grains at 45%. Rough rice at 20% moisture and 26.7° C produces an interstice relative humidity of 94.6% according to Wratten and Kendrick (17). Rice at 25% moisture at the same temperature produces an interstice relative humidity of 98.8%. Rice at 14% moisture at the same temperature is in equilibrium with a relative humidity of 75.6%.

Thus, equilibrium relative humidity between low-moisture grains and field-moisture rice can differ 20%. When field moisture of rice is high, the harvested mass has only a few low-moisture grains and much moisture is available to be readsorbed. As field moisture decreases, the sample has more low-moisture grains and less moisture is available for readsorption. The ratio of low-moisture grains to high-moisture grains in the field changes from day to day.

Moisture-adsorbing environments for low-moisture rice grains can be produced in the combine hopper, field holding carts, transport trucks, or holding bins before rice is dried. Kunze and Prasad (12) mixed low-moisture grains (rough, brown, and milled) with high-moisture rough rice. They sealed the mixture in a container for 48 h before inspecting the low-moisture grains for fissures. They concluded that low-moisture rice will fissure when subjected to any environment from which it can rapidly adsorb moisture. Milled rice grains fissured more readily than brown rice and brown rice fissured more readily than rough rice. **These moisture-adsorption environments can be readily produced in a field-harvested rice mass.**

During drying

Rice combined in the field may be transported directly to an on-farm dryer or a commercial installation. Dryers use ambient or heated air, and their volumes and types of airflow vary. Commercial dryers may be mixing or nonmixing.

This section discusses consequences of blowing heated air through a column of freshly harvested rice.

Nonmixing column or deep bed dryers can produce moisture-adsorbing environments that can fissure low-moisture grains in freshly harvested rice. Heated dry air enters the grain bed and rapidly becomes humid warm air by converting sensible heat of the air to latent heat of evaporation. After penetrating the rice bed only a few centimeters, the drying air relative humidity may be 100%. The region of heat and mass exchange is known as the drying front. Before passing through the front, air is considered hot and dry; after passage, air is warm and humid.

What happens to low-moisture grains ahead of the drying front? These grains suddenly find themselves in a moisture-adsorbing environment and adsorb moisture until the drying front reaches them. If moisture is adsorbed for a sufficient time, as in a deep drying bed, low-moisture grains ahead of the drying front will fissure before they start to dry. These fissures will develop during drying but not from drying. This distinction is subtle but essential. When the grain dries, its low-moisture outer surface contracts around a high-moisture interior. The grain interior should then be in compression while the exterior is in tension. This rationale does not justify the development of fissured grains during drying.

Kunze and Prasad (12) mixed low-moisture test grains of milled, brown, and rough rice with larger volumes of high-moisture rough rice. Results showed that milled rice fissures more readily than brown rice, and brown rice fissures more readily than rough rice, when all test grains are subjected to the same moisture-adsorbing environment. In other experiments, Kunze and Prasad (12) placed low-moisture grains on top of a bed of high-moisture rice before the bed of rice was dried. Results showed that whenever the high-moisture grains had only 4-5% more moisture than the low-moisture test grains, moisture readsorption caused some low-moisture test grains to fissure. A moisture content difference of 6-7% caused nearly all brown rice grains to fissure. These experiments simulated freshly harvested rice (with both high- and low-moisture grains) being dried in a bed or a continuous-flow column dryer. **Low-moisture grains near the top of the bed (with airflow up) or on the air exhaust side of the grain column could adsorb moisture and fissure before the drying front reached them.**

After drying

According to Kunze (8): (a) rice grains were not fissured at the end of drying, (b) grains fissured after drying, and (c) time after drying was required before fissures developed. The subsiding moisture gradient after rapid drying was believed to cause the fissures. Grains continued to fissure until the moisture gradient was essentially equalized across the grain. Sharma and Kunze (14) reported that most kernels fissured within 48 h after drying but additional fissures developed at a slower rate for another 72 h thereafter.

Rice grains dried to storage moisture may fissure when exposed to an environment from which they can readsorb moisture. Such readsorption can occur immediately after drying when the hull bas a lower moisture content than the rest of the grain. Other moisture-adsorption environments for rice at storage moisture include the tops of storage bins, aeration air, ambient air during transport, loading and unloading environments, and even milling operations. **The grain is hygroscopic and will readsorb moisture whenever it has the opportunity.**

VARIETAL ASPECTS

Rice varieties have different fissuring characteristics according to Stahel (15). Kunze and Hall (10, 11) worked with brown rice of six varieties. The varieties, in order of increasing resistance to fissure damage, were Fortuna (least resistant), Zenith, Rexoro, Bluebonnet 50, Belle Patna, and Century Patna

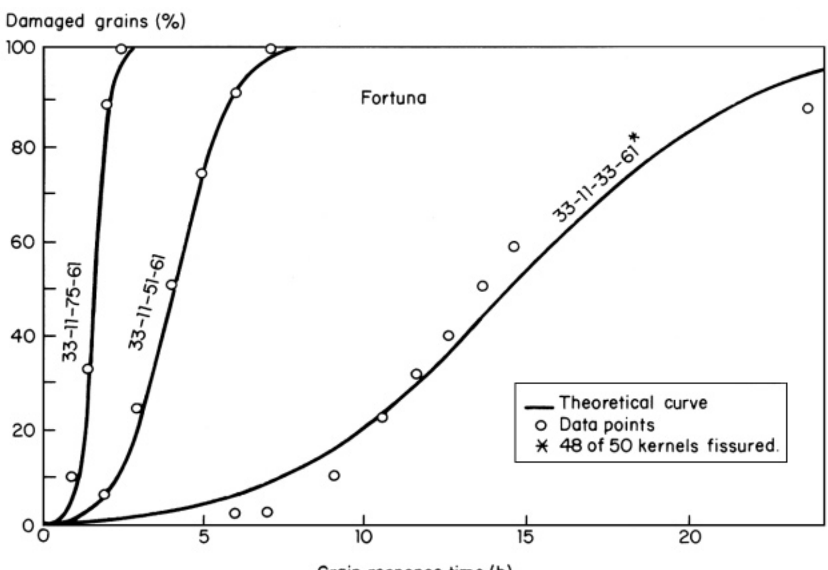
Table 1. Brown rice grain dimensions (7).

Variety	Classification	Length (mm)	Width (mm)	Thickness (mm)
Zenith	Medium grain	6.20	2.51	1.75
Fortuna	Long grain	7.44	2.34	1.80
Rexoro	Long slender	7.24	2.03	1.61
Bluebonnet 50	Long gram	7.57	2.18	1.70
Century Patna 231	Long gram	7.24	2.06	1.65

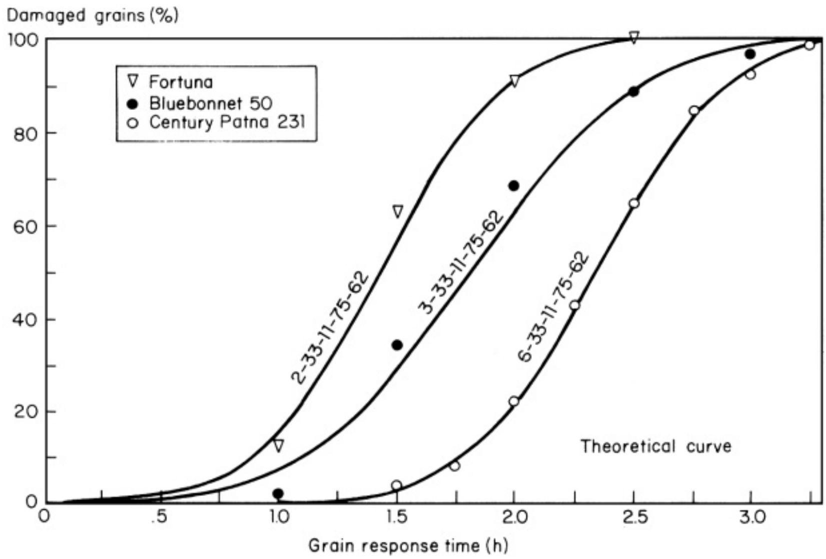
231. Physical measurements, made by Kramer (7), of brown rice grains of five of the six varieties used by Kunze and Hall, are shown in Table 1.

Zenith and Fortuna varieties fissured the most and also had the widest and thickest grains (bold grains). This could indicate that grain dimensions influence fissure susceptibility. As a grain becomes more bold, the distance increases for moisture diffusion from its surface to its center. Stresses from moisture adsorption may be proportional to grain width and thickness. The bold grain may be physically stronger because it is larger and, therefore, may resist milling stress better. Kunze and Hall (10) indicated that moisture stresses are more detrimental to bolder grains. Researchers seem to agree that long grain and long slender-grain varieties resist stress less for the same degree of milling and, therefore, may break more during milling than the bold-grain varieties.

The curves in Figure 2 illustrate the responses achieved with a single variety and age of rice when the grain samples were exposed to different humidity



2. Cumulative percentage of fissured gram of Fortuna brown rice when samples equilibrated at 33°C and 11% relarive humidity were subjected to relative humidities at 75, 51, and 33% (left to right) (10).



3. Cumulative percentage of fissured grains of three varieties of brown rice when samples equilibrated at 33° C and 11% relative humidity were subjected to 75% relative humidity at the same temperature (10).

increases at a temperature of 33° C. When plotted on probability paper, points of the cumulative percentage of fissured grains were essentially in a straight line, indicating that fissuring followed a normal distribution. The mean response time and the standard deviation for any sample provided the information to plot the normal curve.

Just as one variety responded differently to different relative humidity increases, likewise different varieties responded differently to the same relative humidity increase (Fig. 3). Grain dimensions were probably one reason for the different responses. However, the chemical compositions may have been different. Kunze and Hall (10) did not relate grain chemistry to fissure susceptibility, a relationship some researchers feel is even stronger than with grain dimensions. This belief is reinforced by data of the last three varieties listed in Table 1. Grain physical dimensions were similar but their susceptibility to fissuring differed greatly. Therefore, grain fissure susceptibility related to the chemical composition of the rice grain needs researching.

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EFFECT OF VARIETY AND ENVIRONMENT ON MILLING QUALITY OF RICE

T. SRINIVAS and M. K. BHASHYAM
Central Food Technological Research Institute
Mysore, India

SUMMARY

This research has clearly demonstrated the wide varietal variation in crack resistance of rice.

A standard technique has been evolved for intravarietal selection for crack resistance and shedding quality.

Using varieties improved for grain crack resistance, breakage losses could be reduced about 25 to 85% even under traditional practices.

Eliminating white belly and reducing groove depth on the kernel surface can substantially improve milling and nutritional properties.

The isogenic lines established for pairs of characters (such as crack resistance vs crack susceptibility, translucent vs complete chalkinedwhite belly) serve as versatile material for genetic research and breeding.

Substantial grain is lost due to breakage in milling. Cracks formed in grain due to delayed harvesting and severe drying, and the linear shape and soft texture of the grain are basically responsible for breakage during milling (1, 8, 12, 22, 23). The unevenness in the surface morphology and the predominant distribution of nutrients in the peripheral layers account for the nutritional losses (6, 36). Measures suggested for controlling milling losses include scientific methods in harvesting, threshing, and drying of grains (3, 16, 26), and adoption of improved storage and milling technologies (34). However, these methods are not regularly used in most developing countries because of socioeconomic and crop management problems, and breakage losses have not been reduced substantially (30).

We have recently offered varietal improvement in cracking and other grain properties as a solution to minimize breakage (6, 7, 29, 32). Research clearly demonstrates the high promise of this approach. This paper explains the present status of varietal improvement for milling quality and the future for achieving a breakthrough in reducing milling losses.

MILLING QUALITY OF RICE — A PERSPECTIVE

Rice is consumed predominantly as whole grains. Therefore, milling quality refers to obtaining maximum whole rice with minimum breakage. Factors influencing milling quality are discussed.

Morphogenetic origin of rice breakage

Rice inflorescence is a determinate panicle which blooms from top to bottom. Generally, the difference in blooming of top and bottom flowers in a panicle is about 5-10 d (17, 20, 37). This nonsynchronous blooming leads to uneven grain maturity. Maturity variations are further aggravated by differences in tillering period and by improper field management. Grain yield and its quality depend on the right judgment at harvesting. Early harvesting leads to both yield and breakage losses due to higher proportion of immature grains; in late harvesting, overmature grains may be shed in the field and/or may develop cracks and break (16, 19, 21, 28). Therefore, reducing maturity differences within a panicle and among panicles of the same plant could greatly reduce harvesting and milling losses. Varietal studies are needed to examine to what extent synchronous blooming can be attained in rice without sacrificing grain yield. In any case, harvesting paddy at optimum maturity is extremely important for minimizing grain losses due to shedding and breakage (16, 26, 28).

GRAIN CRACKING: A CHALLENGE TO TRADITIONAL HARVEST AND DRYING PRACTICES

Customary harvesting at dead ripe stage (av grain moisture 16-17%) results in breakage losses, a great concern to both rice scientists and farmers. In the field, alternate drying and wetting cycles due to sun and dew induce cracks in the mature grains. This effect is more severe in the cut crop left for drying (16, 28). Drying threshed paddy (rough rice) continuously for more than 3 h at temperatures above 35°C and below 18% grain moisture causes cracking (3).

Efforts to minimize breakage have largely concentrated on optimum stage of harvest (at av grain moisture ranging from 20 to 24%), immediate threshing and controlled drying of threshed grains (1, 3, 8, 22), and modernizing milling equipment (11). Such practices show enormous potential for reducing breakage losses (3, 21, 28). However, their adoption is slow in most developing countries (23, 30).

Logic, not custom, resists change

Farmers' ignorance and habit are reasons frequently given for their failure to adopt new methods. Our close association with paddy farmers while working on a rural project during 1975-80 has, however, convinced us that farmers follow the best possible methods to get maximum returns, given situational constraints. The resistance to adopt the improved methods is not because farmers are reluctant or ignorant but because of factors largely beyond their control. The following factors are largely responsible for farmers not adopting scientific methods in harvesting, threshing, and drying (30, 33).

1) Uneven maturity of the crop due to varietal mixture, and improper field management due to scarcity and timing of water and fertilizer,
2) Labor shortage during peak harvesting period,
3) Inclement weather at harvest, and
4) Problems with space and drying of straw.

These observations underline the need for an overall improvement of the farmers' socioeconomic conditions as a prerequisite for adopting improved harvesting and drying techniques. Farmers need sympathy and support rather than to be blamed and ignored for their failures.

VARIETAL IMPROVEMENT FOR MILLING QUALITY

Kunze and Hall (14), Stermer (35), and Kunze and Prasad (15) noted varietal differences in cracking of rice, however, their findings were not exploited. Hence, we undertook studies on varietal improvement for low cracking and breakage properties. We developed a paddy crack detector (24) to systematically screen many varieties.

Varietal screening for crack resistance

In 20 varieties studied, enormous genetic variation was recorded for crack resistance (Table 1) (27). One variety, Halubbulu, showed phenomenal resistance to cracking and breakage in milling, a few varieties were extremely susceptible, and the rest were intermediate. These studies confirmed the possibility of varietal improvement for crack resistance and milling quality. The existence of intravarietal variation for crack resistance was first tested in some popular varieties (29). Aspects involved in developing crack-resistant lines are discussed.

Factors affecting crack formation

In rice, the characteristic structure and orientation of endosperm cells cause cleavage across the grain (25). Severely dried grains may develop longitudinal cracks when they are suddenly wetted, accounting for small brokens and losses (8). When varieties with high crack resistance were compared with those with high crack susceptibility, the critical moisture level at or below which cracking occurred on soaking was 14.2% for crack-resistant and 18.3% for crack-susceptible varieties. Above this moisture level, grains of all varieties did not develop cracks on soaking. The percentage of cracking on soaking increased with a decrease in the initial moisture content of paddy. An increase in the temperature of the soak water generally favored quicker and greater proportion of cracks, although high temperatures induced gelatinization and

Table 1. Percentage of cracked grains in rice varieties harvested at different levels of grain moisture (27).

Variety	Group	% cracked grains at grain moisture levels of					
		26%	24%	22%	20%	18%	16%
Halubbulu	(R, 2)	0	0	1.0	2.5	5.5	7.0
MR 297	(M, 1)	3.0	5.0	7.5	9.0	12.5	18.0
MR 44	(M, 2)	3.5	5.0	7.5	9.5	20.0	23.0
MR 298	(M, 1)		9.0	13.0	17.0	18.0	24.0
IET 2254	(M, 1)	2.0	3.0	3.5	7.5	16.5	30.0
MR 36	(S, 1)			15.5	21.5	28.0	36.5
IET 2501	(S, 2)	5.0	7.0	21.0	26.5	31.0	37.5
GMR 2	(S, 1)	5.5	7.0	13.0	23.5	30.0	38.0
Sona	(S, 1)	6.5	10.0	15.0	21.0	32.0	41.0
MK 62	(S, 2)	4.0	14.0	23.0	28.0	35.0	41.0
MK 301	(S, 2)		22.0	28.0	36.0	40.0	44.0
Madhu	(S, 2)			22.0	27.0	45.0	50 8
Jaya	(S, 2)	11.0	20.5	24.0	34.0	41.0	53.0
Satya	(S, 2)		11.5	30.0	38.0	52.0	59.0
IET 2246	(HS, 3)	12.5	27.0	36.0	42.5	52.0	64.0
IR 20	(HS, 3)	15.0	22.5	35.0	40.0	55.0	67.0
IET 2295	(HS, 2)	10.0	27.5	44.5	52.5	58.0	68.0
Suhasini	(HS, 2)				43.5	58.0	70.0
Surya	(HS, 2)				55.0	63.0	72.0
MR 272	(HS, 3)		14.0	29.0	48.0	73.0	89.0

[a]R = resistant, M = moderately resistant, S = susceptible, HS : highly susceptible. 1 = soft, 2 = medium, 3 = hard,

apparent healing of cracks. Crack susceptibility was in increasing order for paddy, brown rice, and milled rice. Yellow grains suffered more cracking than greenish grains when soaked in water (28).

Computing the selection index

Plants of each variety to be screened for crack resistance were grown under normal agronomic conditions. Healthy primary panicles were randomly collected at a stage when all the grains turned yellow except one or two green grains at the bottom. The presence of at least one green grain was essential in deciding panicle maturity. One hundred panicles of almost identical maturity were finally selected in the laboratory from the many collected in the field. The grains were threshed immediately and the number of green and yellow grains in each panicle were counted. The green grains were discarded after counting. Yellow grains were equilibrated to 13% moisture (w.b.) by exposing the grains to temperature of 33° C and 70% RH for 10 d. The grains were then screened in the paddy crack detector for presence of natural cracks. Cracked grains were preserved for next sowing. Crack-free paddy grains equilibrated to 13% moisture were soaked in water at 30° C for 3 h. Then they were surface-dried and percentage of cracked grains was determined. This was the artificial stress test (28, 29).

Grain crack resistance may be defined as resistance to cleavage due to any stress. In the field test, the highest crack-resistant variety is that which produces the fewest cracked grains even at an advanced stage of maturity. This property was measured in the successive generations by a selection index computed as follows (31).

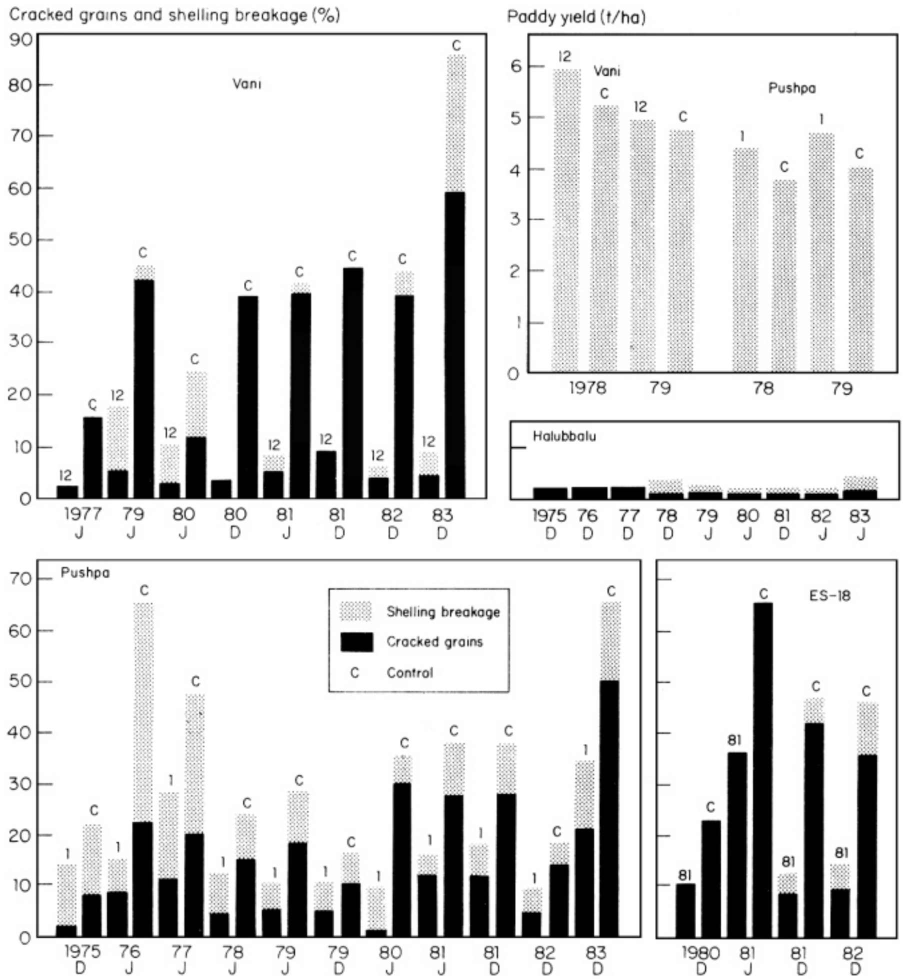
In the first generation, the index value of each panicle that formed a progeny line was the arithmetic mean of the percentages of green, naturally cracked, and stress-cracked grains. Moisture content could not be estimated in the first generation because of the few grains in a panicle, therefore, number of green grains was used to determine grain maturity. In the second and succeeding generations, the percentage of dehulling breakage was used instead of the percentage of green grains, and grain maturity was measured by moisture content.

Evaluating crack resistance using isogenic lines

In the first generation, lines having index numbers less than 10 were considered crack resistant (CR). In ensuing seasons, the CR lines and a few highly crack-susceptible (CS) lines, together with their parents, were grown in progeny lines for comparing cracking and breakage properties. Four CR lines, namely FT-12 and FT-19 in Vani, FT-1 in Pushpa, and FT-81 in ES-18 varieties; and four CS lines, FT-14 and FT-28 in Yani, FT-2 in Pushpa, and FT-97 in ES-18 were finally established (5, 29, 31). In other varieties tested (Jaya, Mangala, Pusa-150, and Intan), the genetic variation for crack resistance was either very small or nil and was further masked by environmental variation (5). With such varieties, intravarietal selection was not possible. The CR lines were identical with their parents in plant and grain characters. The yields of the CR lines of Yani and Pushpa were also comparable with those of their respective parents, and thus they confirmed the test of isogenic nature by being different only in one property, i.e., cracking (Fig. 1).

Studies carried out with the isogenic pairs of CR and CS lines have indicated that crack resistance is associated with lower equilibrium moisture content after soaking in water (EMC-S) and with lower alkali score, but with higher gelatinization temperature, pentosan content, and peak viscosity of milled rice (5). Higher pentosan content in crack-resistant lines may alter the cell wall properties and cause higher resistance to cleavage. The factors contributing to crack resistance were broadly grouped into 4 classes: (1) hydration, (2) starch, (3) cell wall, and (4) cellular structure and orientation. These CR lines grown in farmer's field during several seasons and harvested traditionally exhibited high resistance to cracking and reduced milling loss 25-85%.

Subsequently it was felt that varieties developed for late harvesting should possess optimum shedding quality but easy threshing. Therefore, we have standardized a technique for estimating the shedding quality of rice varieties with a shedding tester. To predict the shedding quality at an early stage of maturity, we developed a histological scale. Using these techniques, we explored intravarietal selection for shedding quality and eventually established an optimum shedding line FT-125 in the high shedding variety Madhu (29).



1. Comparison of crack-resistant lines with parent varieties in checking, breaking and yield properties at different seasons. Crack-resistant varieties: 12 = FT-12, 81 = FT-81, I FT-1.

Thus, highly crack-resistant varieties with optimum shedding qualities could substantially reduce field and milling losses under traditional harvesting practice.

REDUCING BREAKAGE BY CONTROLLING EXPRESSION OF GRAIN CHALKINESS

Chalkiness affects milling quality and appearance. Chalkiness is described according to its location in the grain: 1) white belly or abdominal white (chalkiness in the ventral side) (10); 2) white core or white center (in the central region), and 3) completely chalky (in the entire endosperm). Studies on the technological implications of this property have been largely subjective and contradictory (13). Therefore, we systematically studied chalkiness by using genetically established varieties. Results of our investigations are summarized.

Influence of grain dimension on white belly

Investigation of 138 varieties showed that chalkiness and grain dimension are related. In one variety, all grains were translucent when the breadth was 2 mm and almost all grains had white belly when the breadth was 2.8 mm. Varieties having intermediate breadth may have translucent or white belly or a mixture. Grain length, or length to breadth (L/B) ratio, appeared unrelated to white belly expression (4).

Technological properties of chalky grains

The relationship between milling quality and grain chalkiness was studied using three varieties with different forms of chalkiness. FT-199c, an isogenic line selected from S-199 (a translucent variety), was identical with the parent except in having uniformly expressed chalkiness in the entire endosperm (32). Mangala and Pankaj contained a mixture of both translucent and white-belly grains in different proportions and served as near-isogenic lines (7).

FT-199c, the chalky variety, exhibited high resistance to cracking and to milling breakage and also possessed outstanding culinary properties. Its percentages of naturally cracked grains, stress-cracked grains, and milling breakage were 1, 2, and 15%, respectively. In the parent variety, S-199, the corresponding values were 22, 42, and 30% (32).

The white-belly grains had higher values for breadth, kernel weight, and EMC-S%, compared to translucent grains of the same variety. However, white-belly grains generally showed higher cracking and milling breakage. Thus, white belly by itself does not affect milling quality. It causes higher breakage of rice because it is more susceptible to cracking (7).

In Pankaj, the maximum breadth within which grains were free of white belly was 2.5 mm. Increase in protein content of grains raised this threshold level to 2.65 mm and significantly reduced the proportion of white-belly grains. Pruning panicle branches associated with higher protein had a synergistic effect in reducing the frequency of white-belly grains (7).

White-belly grains tend to crack more under stress conditions, probably due to their heterogenic texture (10). The extreme resistance to cracking of complete chalky grains shows that far less stress develops in a homogeneous soft chalky endosperm than in a homogeneous translucent grain, probably because cells are loosely packed and proportion of pentosan is higher (9).

Economically, white belly is undesirable and its frequency can be controlled by altering the grain breadth and/or by changing the plant's nutritional status. Developing varieties with complete chalkiness could greatly improve milling and culinary properties of rice. These aspects need intensive research (7, 32).

ASSOCIATION OF MORPHOLOGICAL FACTORS WITH GRAIN BREAKAGE

Morphological characters of grains, such as shape, size, and topography (surface evenness), markedly influence rice's milling and nutritional properties (2). The effects of grain shape and size on milling quality have been reviewed by Bhattacharya (8). Breakage as a proportion of cracked kernels was less in medium grains than in long grains. Matthews and Spadaro (18) noted that thinner grains in a sample broke more than thicker ones.

Topography of brown rice

Furrows or grooves, varying in depth, run parallel along the rice grain. Deep grooved grains require more polish to attain the smooth and white surface consumers prefer, which increases quantitative and qualitative losses (2, 6). Therefore, reducing or eliminating groove depth is desirable.

Studies of 21 rice varieties (6) have shown that two dorsilateral grooves in positions 1 and 6 (Fig. 2) are caused by interlocking of the lemma and palea, the thickness of which influences the groove depth. Each of the two nerves (containing vascular bundle) of the lemma causes the formation of one ridge which is responsible for forming two grooves on each of the two lateral sides in positions 2, 5 (centrilateral) and 3, 4 (ventrilateral), respectively. Nerve prominence influences groove depth. The tightness with which the kernel is pressed by the glumes may also influence groove depth (6).

Varietal variation in groove depth

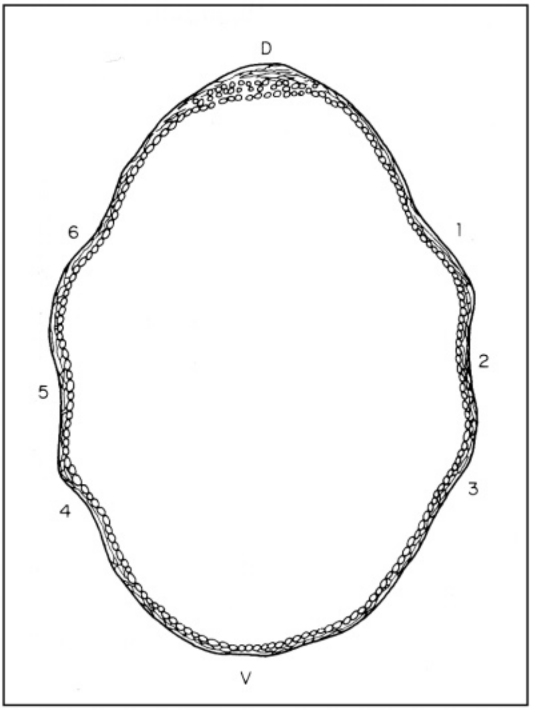
Varieties differ greatly in depth of the three pairs of grooves described above (6). The depth of the ventrilateral, centrilateral, and dorsilateral grooves varied between 1-18, 2-28, and 6-88 µm, respectively. In the grains of any one variety, the centrilateral groove depth was equal to or greater than the ventrilateral groove depth and always smaller than the dorsilateral groove depth. Between the dorsilateral grooves of any grain, one groove was generally deeper, with a range of variation of 2-50 µm in different varieties. In general, grains with higher breadth and low L/B ratio have deep grooves (6, 20).

Effect of brown rice topography on milling quality

The milling breakage values of the varieties Sukanandi (deep grooved) and FT-12 (shallow grooved) were compared. In Sukanandi, 2% higher polish (from 4 to 6%) was required for attaining the same level of consumer acceptance (in whiteness), compared to 4% for FT-12. This higher polish increased breakage by 4%, attributable to the greater groove depth in grains of Sukanandi (6). The loss may be still higher in varieties prone to higher breakage due to inherent susceptibility or to adverse environment and processing.

Thus, deep-grooved grains require more polish to attain desired whiteness and cause more milling and nutritional losses. Evenness of kernel surface can be achieved by reducing the vascular bundle thickness and by glume interlocking.

2. Outline of a median transverse section of brown rice gram showing the positions of grooves: 1, 6 = dorsilateral, 2, 5= centrilateral, 3, 4 = ventilateral, D = dorsal, V = ventral



CONCLUSION

Varietal improvement in the milling quality of rice is a new frontier of research possessing great potential. Because varietal improvement for milling quality involves a complex genetic system, research must examine the interactions of related characters. Such research should be part of an overall rice improvement program. While developing high yielding varieties, breeders should try to combine the characters responsible for superior milling and shedding qualities. With established varieties, improvement can come only by intravarietal selection for crack resistance and other improved grain qualities associated with breakage. Technologists and chemists must work with breeders to achieve these objectives.

Only intensive research will elucidate the genetic, histological, and physicochemical bases for crack resistance and grain chalkiness. More precise techniques have to be standardized to evaluate these grain properties. In breeding for improved grain characteristics, other desirable agronomical, technological, and culinary properties must not be adversely affected.

As scientists improve varieties for milling quality, farmers should be encouraged to follow improved harvest and postharvest practices. We hope that this combined approach may lead to a breakthrough in improving the milling, culinary, and nutritional properties of rice.

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BREEDING FOR HIGH-YIELDING RICES OF EXCELLENT COOKING AND EATING QUALITIES

G. S. KHUSH and B. O. JULIANO
International Rice Research Institute
Los Baños, Laguna, Philippines

SUMMARY

Many types of traditional tropical rice varieties have excellent cooking and eating qualities but low grain yields. Most of these varieties have intermediate amylose content, intermediate starch gelatinization temperature, and soft gel consistency. A few have low gelatinization temperature or high amylose. In earlier years, breeding for excellent grain qualities received low priority because the major attention was devoted to incorporation of genes for disease and insect resistance and other adaptation traits such as shorter growth duration.

Milling quality has been improved at IRRI by eliminating bold chalky grains from nonwaxy rices characteristic of IR8 and IR5, in favor of long slender or medium-long slender translucent grains. Cooking and eating qualities have been improved by incorporating intermediate amylose content, intermediate starch gelatinization temperature, and soft gel consistency exemplified by IR64. Aroma and grain elongation characteristics of Basmati-type rices are also being incorporated into improved plant type materials.

Many types of traditional varieties have excellent cooking and eating qualities. They have characteristic grain sizes and shapes such as the pearl-shaped samba rices in Sri Lanka (3) and Southern India, and the bearded coarse bulu or javanica rices in Indonesia. But most others are slender-grained rices. Transferring a preferred grain type from the donor parents was the objective, 65% of the time, of using traditional varieties as parents in rice crosses in 27 research centers in 10 countries in 1974-75 (9).

In the IRRI program, amylose content determined by iodine colorimetry in pH 4.5-4.8 acetate buffer is classified as waxy (1-2%), low (12-20%), intermediate (20-25%), and high (25-32%) (16). Final gelatinization temperature (GT) measured photometrically is low (<70°C), intermediate (70-74°C), and high (>74°C). GTs indexed by alkali spreading values (18) are classed as low (6-7), intermediate (4-5), intermediate-high (3), and high (2). Gel consistency is classified as soft (61-100 mm), medium (41-60 mm), and hard (27-40 mm) (15).

AROMATIC RICES

Basmati-type rices are prized because of aroma, extreme grain elongation on cooking of soaked milled rice, and soft texture of cooked rice (1, 10, 13). Good-quality Basmati rices are produced in Punjab states of Pakistan and India. Location effect is evident when comparing the elongation quality of Basmati rices grown in the Punjab and Dokri area of Pakistan. Good-quality Basmati rices have intermediate amylose content, low GT, and medium gel consistency (13) (Table 1). IRRI-grown Basmati rice has intermediate GT and does not elongate as well as the Punjab crop. Final evaluation of Basmati-type rices, thus, should be done in the Punjab area to determine degree of aroma and grain elongation.

Differences in cell wall arrangement contribute to differences in the direction of expansion during cooking (11, 22). Elongating rices with poor or no aroma include Nga Kywe (D25-4) from Burma and Sadri varieties from Iran (13). Both have intermediate amylose content, medium gel consistency, but low to intermediate GT.

Eight aromatic or scented rices from several countries analyzed for aroma are richer in the principal aroma compound, 2-acetyl-l-pyrroline, than nonaromatic rices which contain only 0.004-0.006 ppm (4) (Table 2). None had high amylose content (12); further, Sood and Siddiq (21) found only 3 of 94 aromatic rices had high amylose content. 2-acetyl-1-pyrroline is probably

Table 1. Physicochemical properties of two samples of Basmati rice from Pakistan differing in location and elongation ratio (13).

Property	Basmati 6129		Basmati 370		Palman
	Punjab	Dokri	Punjab	Dokri	246
Quality rating	Good	Poor	Good	Poor	Poor
Length (mm)	7.7	7.2	6.8	6.8	6.8
Width (mm)	1.7	1.7	1.8	1.8	1.6
Elongation ratio	2.09	1.68	1.79	1.61	1.14
Protein content (% at 14% H_2O)	9.0	7.8	7.5	7.6	9.4
Amylose content (% dry basis)	23.0	19.7	22.7	20.9	28.6
Alkali spreading value	7.0	2.9	4.0	3.2	4.0
Final gelatinization temp (°C)	66	76	72	75	73
Gel consistency (mm)	42	40	50	74	78
Amylograph viscosity (BE)					
Peak	975	1,000	750	1,000	–
Setback	–75	–170	+125	–365	–
Consistency	340	290	345	85	–

Table 2. Physicochemical properties and 2-acetyl-1-pyrroline of aromatic rices from five countries (4, 12).

Variety or line	Source	Milled rice property				
		Protein (% dry basis)	Amylose (% dry basis)	Alkali spreading value	Gel consistency (mm)	2-acetyl-I-pyrrollne content (ppm)
Basmati 370	Pakistan	6.8	23.2	6.6	47	0.06
Khao Dawk Mali 105	Thailand	7.7	14.5	7.0	60	0.07
IR841-76-1 [a]	IRRI	8.6	19.2	7.0	83	0.07
Azucena	Philippines	7.6	23.2	5.1	50	0.04
Milagrosa	Philippines	6.9	23.2	4.7	49	0.07
Seratus Malam	Indonesia	8.7	23.0	6.0	38	0.06
Hieri	Japan	7.6	20.3	4.7	88	0.04
Malagkit Sungsong	Philippines	9.8	1.2	7.0	74	0.09

[a] With Khao Dawk Mali 105 as low amylose content source.

present even in the raw grain and in the rice plant. Khao Dawk Mali 105 is the popular aromatic soft-textured Thai rice discussed by Unnevehr et al (23). IR841-76-1, a breeding line from the cross involving Khao Dawk Mali, has many of the grain properties of its parent. Popular upland Philippine rices, such as Azucena and Milagrosa, have 18-22% amylose (8). Seratus Malam is a bulu rice from Indonesia with typical intermediate amylose content and low GT. A Japanese aromatic variety has intermediate GT, unlike the characteristic low GT of nonscented japonica rices. The aroma of the waxy (glutinous) rice Malagkit Sungsong is “starchy.” Other unidentified aroma compounds probably distinguish among aromatic varieties.

NONAROMATIC RICES

Most prized traditional rices have intermediate GT (alkali spreading value of 4-5). The samba varieties had similar high amylose content and intermediate GT, as coarse long-grain Sri Lankan rices, but gave softer cooked raw and parboiled rices and had soft gel consistency (11). The Philippine variety Wagwag represents a high-quality rice with slender but small grains. It has high amylose content and intermediate GT (14). Mahsuri, a derivative from an indica X japonica cross (20), also has this combination of starch properties.

Differences in cooking and eating properties among high-amylose low-GT rices have been documented. Mehran 69 (IR6-159-2) is preferred over IR8 in Pakistan; it resists grain disintegration during cooking and has softer gel consistency than IR8 (11).

Intermediate-amylose rices with intermediate GT (alkali spreading value of 3–4) are popular in tropical Asia. An example is C4-63, developed at UPLB (19). It has softer texture than BPI-121-407 which also has intermediate amylose content but low GT. RD7 in Thailand also has similar properties (17). The popular Indonesian variety Cisadane has properties similar to those of C4-63G (2, 7).

BREEDING

Inheritance of endosperm properties (triploid) is much more complicated than that of agronomic characters, including disease and insect resistance. High amylose content is incompletely dominant to low amylose and is controlled by one major gene and several modifiers (5). High GT is dominant to low GT (5). Hard gel consistency is conditioned by a single dominant gene (6).

Progress in improving the grain quality of high yielding varieties has been made in several steps. Earlier improved varieties such as IR5 and IR8 had bold, chalky grains of low milling recovery with high amylose and predominantly low GT. Thus, their grain quality was considered poor for most consumers. We, therefore, set the goal of developing high yielding varieties with these grain quality characteristics: long slender or medium-long slender translucent grains, high milling recovery, intermediate amylose content, intermediate GT, soft gel consistency, aroma, and grain elongation.

We have made remarkable progress in achieving these objectives. Grain appearance received our immediate attention. All IR varieties released after IR5 and IR8 (except waxy rices IR29 and IR65) have long slender or medium-

Table 3. Typical milling recovery of IR varieties.

Variety	Milling recovery (% of rough rice)	
	Total milled rice	Head rice
IR8	66	49
IR5	62	40
IR20	67	57
IR22	65	56
IR24	70	54
IR26	66	59
IR28	70	46
IR29	68	67
IR30	63	50
IR32	68	49
IR34	68	53
IR36	69	50
IR38	70	50
IR40	70	46
IR42	67	58
IR43	67	41
IR44	69	38
IR45	67	52
IR46	69	49
IR48	69	54
IR50	65	43
IR52	62	48
IR54	70	59
IR56	68	61
IR58	68	56
IR60	68	61
IR62	68	43
IR64	68	57
IR65	66	51

long slender translucent grains. Consequently, their milling recovery is also high (Table 3).

In recent years, we have developed improved germplasm with intermediate amylose content, intermediate GT, and soft gel consistency (16). The latest IR variety, IR64, has these characteristics (Table 4). Most traditional varieties, grown in Southeast Asia in the pre-IR8 era had intermediate or high amylose content, intermediate GT, and soft gel consistency (Table 5). Even in South Asian countries where traditional varieties have high amylose content, a few preferred varieties have intermediate amylose content and intermediate GT. Thus, we expect that improved varieties like IR64 will have greater acceptance in all the indica rice growing areas. Therefore, we are developing new promising lines with these characteristics and with resistance to insects and diseases (Table 6).

Besides having intermediate amylose content and intermediate GT, high-quality rices in all the indica rice growing areas have varying degrees of aroma. Therefore, we are now in the process of incorporating aroma into the superior

Table 4. Grain quality characteristics of IR varieties.

Variery	Growth duration (d)	Height (cm)	Amylose content[a]	Gelatinization temperature[b]	Gel consistency[c]	Grain size and shape
IR5	140	130	H	I	S	Medium-long bold
IR8	130	100	H	L	H	Long bold
IR20	125	110	H	I	M-H	Medium-long bold
IR22	125	90	H	L	H	Long slender
IR24	120	90	L	L	S	Long slender
IR26	130	100	H	L	H	Medium-long bold
IR28	105	100	H	L	H	Long slender
IR29	115	100	W	L	S	Long slender
IR30	110	100	H	I	M-H	Medium-long slender
IR32	140	105	H	I	S	Long slender
IR34	130	125	H	L	H	Long slender
IR36	110	85	H	I	M-H	Long slender
IR38	125	100	H	I	M-H	Long slender
IR40	120	100	H	I	M-H	Medium-long slender
IR42	135	110	H	L	H	Medium-long slender
IR43	125	110	L	L	S	Long slender
IR44	130	110	H	L	H	Long slender
IR45	125	100	H	I	M-H	Long slender
IR46	130	110	H	I	S	Long slender
IR48	140	120	I	L	M-H	Long slender
IR50	105	90	H	I	M-H	Long slender
IR52	115	95	H	L	H	Long slender
IR54	120	95	H	L	H	Long slender
IR56	110	90	H	L	H	Long slender
IR58	100	80	H	L	H	Medium-long slender
IR60	108	95	H	L	H	Long slender
IR62	105	85	H	I	S	Long slender
IR64	112	110	I	I	S-M	Long slender
IR65	115	100	W	L	S	Long slender

[a]H = high, L = low, W = waxy, I = intermediate. [b]I = intermediate, L = low. [c]S = soft, H = hard, M = medium.

Table 5. Physicochemical properties of selected nonaromatic rice varieties and IRRI selections.

Variety or type	Contry	Milled rice properties				
		Length (mm)	Width (mm)	Amylose content[a]	Alkali spreadlng value[b]	Gel consistency[c]
Samba	Sri Lanka	3.8	2.4	H	I	S
Mahsuri [d]	Malaysia, India	4.9	2.0	H	I	S/M
Wagwag	Philippines	5.2	2.1	H	I	S/M
C4-63	Philippines	7.1	2.4	I	HI	S
Cisadane	Indonesia	6.3	2.7	I	HI	S
IR64		6.5	2.2	H	I	M
IR32429-47-3		6.9	2.1	I	I	S
IR28150-84-3		6.4	2.0	I	I	S/M
IR31868-64-2		6.5	2.0	I	I	S/M

[a]H = high, I = intermediate. [b]I = intermediate. [c]S = soft, M = medium. [d]Indica × japonica.

grain quality varieties. Basmati 370, Khao Dawk Mali 105, and Rojolele are being used as donors for aroma.

Grain elongation is a special characteristic of several high grain quality varieties such as Basmati 370, Nga Kywe (D25-4), and Barah and Sadri varieties of Iran. This trait, polygenically controlled, is difficult to transfer. However, some progress has been made.

Waxy (glutinous) rices, used for special preparations, are consumed as everyday diet in Laos and northeast Thailand. Two IR varieties, IR29 and IR65, are waxy.

PROSPECTS AND CHALLENGES

Many rices with intermediate amylose, intermediate GT, and soft gel consistency are being evaluated in our advanced yield trials. Additional reliable, fast screening methods are required in place of sensory evaluation to evaluate rices with similar starch properties. Similar situations exist among waxy lines in the Thai breeding program where selection is made for low GT followed by sensory evaluation of the low-GT, waxy lines (N. Kongseree, pers. comm.). In Korea, rices derived from indica-japonica crosses have been developed which have similar size and shape, low amylose content, low GT, and soft gel consistency as japonica rices, but consumers discriminate against the indica-japonica rices (G. S. Chung, pers. comm.). Further research is needed to develop methods to distinguish cooked rice properties among rices of similar starch composition, IRRI is beginning such research,

The exact nature of the quality characteristics of Basmati-type rices is not well understood. Translucent grains have elongation ratios similar to chalky grains (A. B. Blakeney, pers. comm.). Basmati aroma property is probably independent of elongation and soft texture. Some promising Basmati lines from Pakistan have intermediate GT instead of low GT, characteristic of Basmati 370 and 6129. The availability and use of isogenic lines differing in

Table 6. Elite breeding lines with superior grain quality and multiple disease and insect resistance.

Breeding line	Growth duration (d)	Amylose content (%)	Gelatinization temp[a]	Reaction to[b]							
				BL	BB	RTV	GSV	GLH	BPH biotypes		
									1	2	3
IR21820-154-3-2-2	130	23	I	MS	R	R	R	R	R	R	S
IR31802-48-2-2-2	107	22	I	MR	R	R	R	R	R	R	R
IR31851-63-1-2-3-2	108	22	I	R	R	R	R	R	R	R	R
IR31868-64-2-3-3-3	110	22	I	R	R	R	R	R	R	R	S
IR32429-47-3-2-2	105	21	I	RR	R	R		R	R	R	R
IR28228-12-3-1-1-2	135	24	I	MR	R	R	R	R	R	R	R
IR28150-84-3-3-2	135	23	I	MS	R	R	R	R	R	R	R
IR36	108	27	I	MR	R	MR	R	R	R	R	S
IR42	135	27	I	MR	R	MR	R	R	R	R	S

[a]I = intermediate, L = low. [b]BL = blast, BB = bacterial blight, RTV = tungro virus, GSV grassy stunt virus, GLH = green leafhopper, BPH = brown planthopper. MS = moderately susceptible, MR = moderately resistant, R resistant, S = susceptible.

grain elongation during cooking should facilitate basic studies on this aspect of Basmati quality. Dr. Ron Buttery of the U.S. Department of Agriculture Western Regional Research Center, Albany, California, is developing a gas chromatographic method for screening 2-acetyl-1-pyrroline in foods.

Most methods for assessing cooking and eating quality have been developed for raw rice, not for parboiled rice. Because parboiled rice dominates in areas of Bangladesh, Sri Lanka, India, Pakistan, etc., research is needed to verify the applicability of such methods to parboiled rice. Traditional and modern parboiling processes also produce drastically different parboil properties. Most modern parboiling plants have processed intermediate-amylose, intermediate-GT, long-grain rices. Extension of this assessment of suitability to traditional and modern parboiling on high- and intermediate-amylose rices differing in GT is being arranged by IRRI cereal chemists.

Although milling quality has improved through breeding for translucent grains, the head rice yield range of 41-61% for IR20 to IR64 nonwaxy IR varieties (Table 3) is still lower than the 56-61% head rice yield of U.S. long-grain rice varieties (24). Further improvement of milling quality is desirable for tropical long-grain rices to be at par with export quality U.S. and Australian rices. A simple screening method of moisture adsorption stress, based on the work presented by Kunze and by Srinivas, will aid in incorporating into new varieties grain resistance to fissuring under moisture adsorption stress. IRRI cereal chemists and breeders are undertaking exploratory studies on varietal differences in fissuring resistance of rice grains. Field screening methods such as delayed harvest may not be feasible as a stress method in monsoonal Asia because of frequent showers and the wide range of maturity dates among rices.

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RECOMMENDATIONS[1]

Milling quality

The panel reviewed milling quality attributes. Broken grain detracts from appearance and reduces the value of milled rice. In the market place, milled rice is also judged on its grain size and shape, and on its appearance, such as whiteness and translucency. The panel identified these research priorities for improving milling quality.

1) Methodology for use in breeding programs to improve head and total milled rice yields in new varieties. Results would increase the value of the crop and minimize losses of edible milled rice that unavoidably pass into the bran fraction on milling.

This involves several research and testing areas:

- Determine the optimum size, shape, and grain appearance that give the least resistance to milling for each major grain type, i.e. long, medium, and short.
- Develop and test screening methods for measuring resistance to fissuring in the major grain types and determine the relation of fissuring to alkali spreading and other grain quality tests.
- Develop screening methods for evaluating chalkiness levels and types of chalkiness.
- Develop a consensus definition of hardness or strength in rice and establish its relation, if any, to milling yields.

2) Encourage development of simple, portable, moisture-measuring devices for use by breeders, farmers, and others to determine optimum harvest moisture levels and storage moisture levels.

[1] These recommendations were prepared by participants in the 3 June discussion: B. D. Webb, chairman; A. B. Blakeney, vice chairman; L. J. Unnevehr, rapporteur; and B. O. Juliano.

Market price and quality

Consumer preferences for grain quality are not well understood. These are priorities:

1) Mapping grain quality preferences in Asia, including regional variations within countries.

2) Determining quality preferences of parboiled- and waxy (glutinous)-rice eaters.

Simple econometric methodologies exist for quantifying consumer preferences for quality characteristics. Economists and chemists in national programs are urged to conduct such studies.

Rice exporting countries and self-sufficient countries anticipating export may wish to evaluate the trade-offs between breeding for better quality and breeding for higher yield. Appearance and milling qualities will be more, important to exporters, while domestic preferences for milling and cooking quality will be more important to self-sufficient countries. Plant breeding is only one way to improve grain quality. Measures to improve market information and postharvest processing can be equally or more important. Quality improvement in breeding and marketing should be coordinated. Laboratory measures of quality should correlate with the actual performance of varieties under field conditions.

Cooking, eating, and processing qualities

Rice consumers in all markets need product qualities that they consider optimum. Although grain cooking and eating quality can be differentiated by tests for amylose, gelatinization temperature (alkali spreading value), gel consistency, and texture, similar quality may not mean identical eating quality. This is illustrated by recent experience in South Korea where consumers considered indica × japonica rices inferior to true japonica rices. Preferences differ between California- and Southern-grown U.S. rices.

These are priorities:

1) Define the varietal characters associated with good quality in parboiled rice.
2) Develop a simple method to quantify rice grain aroma.
3) Investigate the varietal characters associated with good eating quality, as defined by waxy rice consumers.
4) Survey the special varietal quality characters and varieties unique in the production of traditional Asian rice-based foods and record the processing methods and uses of these foods.

Yield and quality

There should be no conflict between breeding for better appearance, milling and cooking qualities and breeding for yield. In the short term, the additional selection characters may slow breeding. However, most grain quality characters are apparently highly heritable and can be selected for at early generations. Selection for quality characters leads to varieties more readily acceptable to farmer and consumer. In addition, improvements in milling quality lead to more edible product per ton of rough rice produced.

PARTICIPANTS, DISCUSSION ON GRAIN QUALITY AND MARKETING

IRRI, 3 JUNE 1985

K. Attaviriyasook
Seed Standard and Grain Quality Branch
Rice Research Institute
P. O. Box 5-159
Bangkhen, Bangkok 10900
Thailand

A. B. Blakeney
Agricultural Research Institute
Yanco, N . S. W., Australia

A. G. Calub
Ring Around Research Station
P. 0. Box 810
East Bernard, TX 774355
USA

G. S. Chung
Yeongnam Crop Experiment Station
Rural Development Administration
P. O. Box 6
Milyang, Korea

D. S. Damardjati
Sukamandi Research Institute for Food Crops
Sukamandi, West Java, Indonesia

J. N. Efferson
5804 Boone Drive
Baton Rouge, LA 70808
USA

Z. Harahap
Plant Breeding Department
Central Research Institute for Food Crops
Jalan Merdeka 99
Bogor, Indonesia

M. H. Heu
Agronomy Department
College of Agriculture
Seoul National University
Suweon 170, Korea

D. HilleRisLambers
Plant Breeding
IRRI

B. O. Juliano
Cereal Chemistry
IRRI

G. S. Khush
Plant Breeding
IRRI

N. Kongseree
Seed Standard and Quality Branch
Rice Division, Department of Agriculture
Bangkhen, Bangkok 9, Thailand

O. R. Kunze
Department of Agricultural Engineering
Texas A&M University
College Station, TX 77843-2117
USA

A. Majeed
Rice Research Institute
Kala Shah Kaku, Lahore, Pakistan

B. B. Mathema
Department of Agriculture
Ministry of Food, Agriculture and Irrigation
Kathmandu, Nepal

A. M. del Mundo
College of Human Ecology
University of the Philippines at Los Baños
College, Laguna, Philippines

C. M. Perez
Cereal Chemistry
IRRI

S. Pushpavesa
Rice Division, Department of Agriculture
Bangkhen, Bangkok 9, Thailand

J. N. Rutger
Department of Agronomy and Range Science
University of California, Davis
Davis, CA 95616
USA

F. W. Sheppard Jr.
BRRI-IRRI Cooperative Project
G. P. O. Box 64, Ramna
Dhaka-2, Bangladesh

T. Srinivas
Discipline of Rice and Pulse Technology
Central Food Technological Research Institute
Mysore 570013, India

L. J. Unnevehr
Agricultural Economics
IRRI

S. S. Virmani
Plant Breeding
IRRI

B. D. Webb
Rice Research, USDA
Route 7, Box 999
Beaumont, TX 77706
USA