Chapter 3 - Grain structure, composition and consumers' criteria for quality

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The rice grain (rough rice or paddy) consists of an outer protective covering, the hull, and the rice caryopsis or fruit (brown, cargo, dehulled or dehusked rice), (Juliano and Bechtel, 1985), (Figure 2). Brown rice consists of the outer layers of pericarp, seed-coat and nucellus; the germ or embryo; and the endosperm. The endosperm consists of the aleurone layer and the endosperm proper, consisting of the subaleurone layer and the starchy or inner endosperm. The aleurone layer encloses the embryo. Pigment is confined to the pericarp (Juliano and Bechtel, 1985).

The hull (husk) constitutes about 20 percent of the rough rice weight, but values range from 16 to 28 percent. The distribution of brown rice weight is pericarp 1 to 2 percent, aleurone plus nucellus and seed-coat 4 to 6 percent, germ 1 percent, scutellum 2 percent and endosperm 90 to 91 percent (Juliano, 1972).

The aleurone layer varies from one to five cell layers; it is thicker at the dorsal than at the ventral side and thicker in short-grain than in long-grain rices (del Rosario et al., 1968). The aleurone and embryo cells are rich in protein bodies, containing globoids or phytate bodies, and in lipid bodies (Tanaka et al., 1973; Tanaka, Ogawa and Kasai, 1977).

The endosperm cells are thin-walled and packed with amyloplasts containing compound starch granules. The two outermost cell layers (the subaleurone layer) are rich in protein and lipid and have smaller amyloplasts and compound starch granules than the inner endosperm. The starch granules are polyhedral and mainly 3 to 9 ,m in size, with unimodal distribution. Protein occurs mainly in the form of spherical protein bodies 0.5 to 4 m in size throughout the endosperm (del Rosario et al., 1968; Bechtel and Pomeranz, 1978), (Figure 3), but crystalline protein bodies and small spherical protein bodies are localized in the subaleurone layer. The large spherical protein body corresponds to PB -I of Tanaka et al. (1980) and the crystalline protein body is identical to PB-II. Both PB-I and PB-II are distributed throughout the rice endosperm.

FIGURE 2 Longitudinal section of rice grain

Non-waxy rice (containing amylose in addition to amylopectin) has a translucent endosperm, whereas waxy (0 to 2 percent amylose) rice has an opaque endosperm because of the presence of pores between and within the starch granules. Thus, waxy grain has about 95 to 98 percent the grain weight of non-waxy grain.

Rice classification

There is no international standard for brown rice grain size and shape. IRRI uses the following scale for size: extra long, >7.50 mm; long, 6.61 to 7.50 mm; medium, 5.51 to 6.60 mm; and short, <5.50 mm. Grain shape is characterized based on length-to-width ratio: slender, >3.0; medium, 2.1 to 3.0; bold 1.1 to 2.0; and round, < 1.0.

FIGURE 3 Schematic diagram of various protein bodies and compound starch granule in the endosperm subaleurone layer

The Codex Alimentarius Commission committee considering the draft standard for rice proposed the following classification of milled rice based on length-towidth ratio; long grain, <3.1; medium grain, 2.1 to 3.0; and short grain, <2.0 (Codex

Alimentarius Commission, 1990).

Proposed tolerances for defects for milled rices are 0.5 percent each for organic and inorganic extraneous matter, 0.3 percent for rough rice, 1.0 percent each for brown rice and waxy rice, 2.0 percent for immature grains, 3.0 percent each for damaged and heat-damaged grains, 4.0 percent for red grains, 8.0 percent for redstreaked grains and 11.0 percent for chalky grains (Codex Alimentarius Commission, 1990). The proposed tolerances for milled parboiled rices are identical to those for milled rices except for no tolerance for chalky grains, 6.0 percent for heat-damaged grains and additional tolerances of 2.0 percent each for raw milled rice and pecks (grains with >25 percent of the surface coloured dark brown to black). A more detailed description of milling is given in Chapter 4.

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Gross nutrient composition

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Among the milling fractions of rice, the bran has the highest energy and protein content and the hull has the lowest (Table 14). Only the brown rice fraction is edible. Abrasive or friction milling to remove the pericarp, seed-coat, testa, aleurone layer and embryo to yield milled rice results in loss of fat, protein, crude and neutral detergent fibre, ash, thiamine, riboflavin, niacin and a-tocopherol. Available carbohydrates, mainly starch, are higher in milled rice than in brown rice. The gradients for the various nutrients are not identical as evidenced from analysis of successive milling fractions of brown rice and milled rice (Barber, 1972), (Figure 4). Dietary fibre is highest in the bran layer (and the hull) and lowest in milled rice. Density and bulk density are lowest in the hull, followed by the bran, and highest in milled rice because of the low oil content. The nutritional properties of the rice grain are discussed further in Chapter 4.

The B vitamins are concentrated in the bran layers, as is a-tocopherol (vitamin E), (Table 15). The rice grain has no vitamin A, vitamin D or vitamin C (FAO, 1954). The locational gradient in the whole rice grain is steeper for thiamine than for riboflavin and niacin, resulting in a lower percent retention of thiamine (vitamin B1) in milled rice (Table 15). About 50 percent of the total thiamine is in the scutellum and 80 to

85 percent of the niacin is in the pericarp plus aleurone layer (Hinton and Shaw, 1954). The embryo accounts for more than 95 percent of total tocopherols (of which a-tocopherols account for one-third) and nearly one-third of the oil content of the rice grain (Gopala Krishna, Prabhakar and Sen, 1984). By calculation, 65 percent of the thiamine of brown rice is in the bran, 13 percent in the polish and 22 percent in the milled rice fraction (Juliano and Bechtel, 1985). Corresponding values for riboflavin are 39 percent in the bran, 8 percent in the polish and 53 percent in the milled rice fraction. Niacin distribution is 54 percent in the bran, 13 percent in the polish and 33 percent in the milled rice fraction.

FIGURE 4 Distribution pattern of major constituents of brown rice determined using a tangential abrasive mill

The minerals (ash) are also concentrated in the outer layers of brown rice or in the bran fraction (Table 15). A major proportion (90 percent) of the phosphorus in bran is phytin phosphorus. Potassium and magnesium are the principal salts of phytin. The ash distribution in brown rice is 51 percent in the bran, 10 percent in the germ, 10 percent in the polish and 28 percent in the milled rice fraction; iron, phosphorus and potassium show a similar distribution (Resurreccin, Juliano and Tanaka, 1979). However, some minerals show a relatively more even distribution in the grain:

milled rice retained 63 percent of the sodium, 74 percent of the calcium and 83 percent of the Kjeldahl N content of brown rice (Juliano, 1985b).

TABLE 14 - Proximate composition of rough rice and its milling fractions at 14 percent moisture

Rice fraction	Crude protein (g N x 5. 95)	Crude fat (g)	Crude fibre (g)	Crude ash (g)	Available carbohydrates (g)	Neutral detergent fibre (g)	Energy content		Density (g/ml)
							(kJ)	(hcal)	
Rough rice	5.8-7.7	1.5-2.3	7.2-10.4	2.9-5.2	64-73	16.4-19.2	1580	378	1.17-1.23
Brown rice	7.1-8.3	1.6-2.8	0.6-1.0	1.0-1.5	73-87	2.9-3.9	1520-1 610	363-385	1.31
Milled rice	6.3-7.1	0.3-0.5	0.2-0.5	0.3-0.8	77-89	0.7-2.3	1460-1 560	349-373	1.44-1.46
Rice	11.3-	15.0-	7.0-	6.6-	34-62	24-29	670-1	399-	1.16-

bran	14.9	19.7	11.4	9.9			990	476	1.29
Rice hull	2.0-2.8	0.3-0.8	34.5-45.9	13.2-21.0	22-34	66-74	1110-1 390	265-332	0.67-0.74

Sources: Juliano, 1985b; Eggum. Juliano & Manigat, 1982; Pedersen & Eggum, 1983.

TABLE 15 - Vitamin and mineral content of rough rice and its milling fractions at 14 percent moisture

Rice fraction	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	α - Tocopherol (mg)	Calcium (mg)	Phosphorus (g)	Phytin P (g)	Iron (mg)	Z (
Rough rice	0.26-0.33	0.06-0.11	2.9-5.6	0.90-2.00	10-80	0.17-0.39	0.18-0.21	1.4-6.0	1 3
Brown rice	0.29-0.61	0.04-0.14	3.5-5.3	0.90-2.50	10-50	0.17-0.43	0.13-0.27	0.2-5.2	0 2
Milled rice	0.02-0.11	0.02-0.06	1.3-2.4	75-0.30	10-30	0.08-0.15	0.02-0.07	0.2-2.8	0 2

Rice bran	1.20-2.40	0.18-0.43	26.7-49.9	2.60-13.3	30-120	1.1-2.5	0.9-2.2	8.6-43.0	4 2
Rice hull	0.09-0.21	0.05-0.07	1.6-4.2	0	60-130	0.03-0.07	0	3.9-9.5	0 4

Sources: Juliano, 1985: Pedersen & Eggum, 1983.

TABLE 16 - Amino acid content of rough rice and its milling fractions at 14 percent moisture (9 per 16 9 N)

Rice fraction	Histidine	Isoleucine	Leucine	Lysine + cysteine	Methionine + tyrosine	Phenylalanine	Threonine
Rough rice	1.5-2.8	3.0-4.8	6.9-8.8	3.2-4.7	4.5-6.2	9.3-10.8	3.0-4.5
Brown rice	2.3-2.5	3.4-4.4	7.9-8.5	3.7-4.1	4.4-4.6	8.6-9.3	3.7-3.8

Milled rice	2.2-2.6	3.5-4.6	8.0-8.2	3.2-4.0	4.3-5.0	9.3-10.4	3.5-3.7
Rice bran	2.7-3.3	2.7-4.1	6.9-7.6	4.8-5.4	4.2-4.8	7.7-8.0	3.8-4.2
Rice hull	1.6-2.0	3.2-4.0	8.0-8.2	3.8-5.4	3.5-3.7	6.6-7.3	4.2-5.0

[a] Based on 5.8 g lysine per 16 g N as 100% (V/HO, 1985).

Sources: Juliano, 1985b; Eggum. Juliano & Manigat, 1982; Pedersen & Eggum, 1983.

The amino acid content of the milling fractions is given in Table 16.

Starch

Starch is the major constituent of milled rice at about 90 percent of the dry matter. Starch is a polymer of D-glucose linked α -(1-4) and usually consists of an essentially linear fraction, amylose, and a branched fraction, amylopectin. Branch points are α -(1-6) linkages. Innovative techniques have now shown rice amylose to have two to

four chains with a number-average degree of polymerization (DP_n) of 900 to glucose units and a -amylolysis limit of 73 to 87 percent (Hizukuri et al., 1989). It is a mixture of benched and linear molecules with DP_n of 1100 to 1700 and 700 to 900, respectively. The branched fraction constitutes 25 to 50 percent by number and 30 to 60 percent by weight of amylose. The iodine affinity of rice amyloses is 20 to 21 percent by weight.

Rice amylopectins have -amylolysis limits of 56 to 59 percent, chain lengths of 19 to 22 glucose units, DP_n of 5 000 to 15 000 glucose units and 220 to 700 chains per molecule (Hizukuri et al., 1989). The iodine affinity of rice amylopectin is 0.4 to 0.9 percent in low- and intermediate-amylose rices but 2 to 3 percent in high-amylose rices. Isoamylase-debranched amylopectins showed more longest chain fractions (DP_n >100) (9 to 14 percent) in high-amylose samples with higher iodine affinity than in low- and intermediate-amylose samples (2 to 5 percent) and waxy rice amylopectin (0 percent), (Hizukuri et al., 1989).

Based on colorimetric starch-iodine colour absorption standards at 590 to 620 nm, milled rice is classified as waxy (1 to 2 percent), very low amylose (2 to 12 percent), low amylose (12 to 20 percent), intermediate (20 to 25 percent) and high (25 to 33

percent), (Juliano, 1979, 1985b). Recent collaborative studies showed that the maximum true amylose content is 20 percent and that additional iodine binding is due to the long linear chains in amylopectin (Takeda, Hizukuri and Juliano, 1987). Hence colorimetric amylose values are now termed "apparent amylose content".

The waxy endosperm is opaque and shows air spaces between the starch granules, which have a lower density than non-waxy granules. The structure of the starch granule is still not well understood, but crystallinity and staling are attributed to the amylopectin fraction.

Protein

Protein is determined by first carrying out micro Kjeldahl digestion and ammonia distillation and then using titration or colorimetric ammonia assay of the digest to determine nitrogen content, which is converted to protein by the factor 5.95. [The factor, based on a nitrogen content of 16.8 percent for the major protein of milled rice (glutelin), may be an overestimation; reappraisals have suggested values of 5.1 to 5.5 (5.17 + 0.25) (Moss, Huet and Baudet, 1988; Moss, 1990), 5.24 to 5.66 (mean 5.37) (Hegsted and Juliano, 1974) and 5.61 (Sosulski and Imafidon, 1990).]

Endosperm (milled rice) protein consists of several fractions comprising 15 percent albumin (water soluble) plus globulin (salt soluble), 5 to 8 percent prolamin (alcohol soluble) and the rest glutelin (alkali soluble), (Juliano, 1985b). Using sequential protein extraction, the mean ratio for 33 samples was found to be 9 percent prolamin, 7 percent albumin plus globulin and 84 percent glutelin (Huebner et al., 1990). The mean prolamin content of seven IRRI milled rices was 6.5 percent of their total protein (IRRI, l991b). The lysine content of rice protein is 3.5 to 4.0 percent, one of the highest among cereal proteins.

Rice bran proteins are richer in albumin than endosperm proteins and are found as distinct protein bodies containing globoids in the aleurone layer and the germ. These structures are different from endosperm protein bodies. Tanaka et al. (1973) reported the presence of 66 percent albumin, 7 percent globulin and 27 percent prolamin plus glutelin in aleurone protein bodies. Ogawa, Tanaka and Kasai (1977) reported the presence of 98 percent albumin in embryo protein bodies.

The endosperm protein is localized mainly in protein bodies (Figure 4). The crystalline (PB-II) protein bodies are rich in glutelin, and the large spherical protein bodies (PB-I) are rich in prolamin. Ogawa et al. (1987) estimated that endosperm storage proteins were composed of 60 to 65 percent PB-II proteins, 20 to 25 percent

PB-I proteins and 10 to 15 percent albumin and globulin in the cytoplasm.

Rice starch granule amylose binds up to 0.7 percent protein that is mainly the waxy gene protein or granule-bound starchy synthase, with a molecular mass of about 60 kilodaltons (kd), (Villareal and Juliano, 1989b).

Rice glutelin consists of three acidic or a subunits of 30 to 39 kd and two basic or subunits of 19 to 25 kd (Kagawa, Hirano and Kikuchi, 1988). The two kinds of subunits are formed by cleavage of a 57-kd polypeptide precursor (Sugimoto, Tanaka and Kasai, 1986). Prolamin consists mainly (90 percent) of the 13- cd subunit plus two minor subunits of 10 and 16 kd (Hibino et al., 1989).

The essential amino acid contents of the glutelin and prolamin subunits (Table 17) showed lysine as limiting in these polypeptides except in the IEF3 fraction of the 13-kd prolamin subunit, which has 5.5 percent lysine and is limiting in methionine plus cysteine. Thus, glutelin has a better amino acid score than prolamin except for the 16-kd prolamin subunit. The 10-kd prolamin subunit has a high (6.8 percent) cysteine content.

Lipid

The lipid or fat content of rice is mainly in the bran fraction (20 percent, dry basis), specifically as lipid bodies or spherosomes in the aleurone layer and bran; however, about 1.5 to 1.7 percent is present in milled rice, mainly as non-starch lipids extracted by ether, chloroform-methanol and cold water-saturated butanol (Juliano and Goddard, 1986; Tanaka et al., 1978). Protein bodies, particularly the core, are rich in lipids (Choudhury and Juliano, 1980; Tanaka et al., 1978). The major fatty acids of these lipids are linoleic, oleic and palmitic acids (Hemavathy and Prabhaker, 1987; Taira, Nakagahra and Nagamine, 1988). Essential fatty acids in rice oil are about 29 to 42 percent linoleic acid and 0.8 to 1.0 percent linolenic acid (Jaiswal, 1983). The content of essential fatty acids may be increased with temperature during grain development, but at the expense of reduction in total oil content (Taira, Taira and Fujii, 1979).

TABLE 17 - Aminogram (9/16 g N) of the acidic and basic subunits of rice glutelin and the mayor and minor subunits of prolamin

Amino acid	**Glutelin subunits**[a]		**Prolamin subunits**		
	30-39 kd (acidic)	19-25 kd (basic)	13 kd	10 kd	16 kd

Histidine	2.2-2.5	2.6-2.7	2.0-2.4	1.7	4.2
Isoleucine	3.2-3.3	4.1-4.9	3.8-5.4	1.6	3.6
Leucine	6.4-7.5	7.0-8.5	17.9-26.4	4.7	8.1
Lysine	2.2-3.0	3.0-4.1	0.4-5.5	1.0	3.3
Methionine + cystine[b]	0.2-1.9	0.1-2.4	0.7-1.2	22.5	5.3
Phenylalanine + tyrosine	10.0-10.5	10.1-10.8	12.7-21.6	4.3	7.6
Threonine	2.8-3.7	2.5-3.7	1.8-2.8	6.8	2.7
Valine	5.1-5.7	5.7-7.0	2.7-3.9	4.4	3.9
Amino acid score[c](%)	38-52	52-71	7-8[d]	18	57

[a] **S-cyanoethyl glutelin subunits.**

[b] **Only the IEF3 fraction of the 13-kd, 10-kd and 16-kd prolamin subunits had**

cystine. All glutelins had substituted cysteine residues

[c] Based on 5.8% lysine as 100% (WHO, 1985).

[d] Alternative value is 34% based on 2.5% methionine + cysteine as 100% (WHO, 1985).

Sources: Juliano & Boulter, 1976; Villareal & Juliano, 1978 (glutelin subunits); Hibino et al., 1989 (prolamin subunits).

Starch lipids are mainly monoacyl lipids (fatty acids and lysophosphatides) complexed with amylose (Choudhury and Juliano, 1980). The starch lipid content is lowest for waxy starch granules (<0.2 percent). It is highest for intermediatearnylose rices (1.0 percent) and may be slightly lower in high-amylose rice (Choudhury and Juliano, 1980; Juliano and Goddard, 1986). Waxy milled rice has more non-starch lipids than non-waxy rice. Starch lipids are protected from oxidative rancidity, and the amylose-lipid complex is digested by growing rats (Holm et al., 1983). However, starch lipids contribute little to the energy content of the rice grain. The major fatty acids of starch lipids are palmitic and linoleic acids, with lesser amounts of oleic acid (Choudhury and Juliano, 1980).

TABLE 18 - Yield and composition of defatted and protease-amylase treated cell wall preparations obtained from different histological fractions of milling of brown rice

Rice fraction	Yield (%deffated tissue)	Composition (% of total)				Uronic acid in pectin (%)	Arabino
		Pectic substances	Hemicellulose	α -cellulose	Lignin		Pectic substance
Caryopsis coat	29	7	38	27	32	32	1.63
Aleurone tissue	20	11	42	16	25	25	1.78
Germ	12	23	47	9	16	16	2.29
Endosperm	0.3	27	49	1	34	34	1.09

Source: Shibuya, 1989.

Non-starch polysaccharides

Non-starch polysaccharides consist of water soluble polysaccharides and insoluble dietary fibre (Juliano, 1985b). They can complex with starch and may have a hypocholesterolaemic effect (Normand, Ory and Mod, 1981; Normand et al., 1984). The endosperm has a lower content of dietary fibre than the rest of brown rice (Shibuya, 1989), (Table 18). Reported values for neutral detergent fibre are 0.7 to 2.3 percent (Juliano, 1985b), (Table 14). In addition, the endosperm or milled rice cell wall has a low lignin content but a high content of pectic substances or pectin. Endosperm pectin has a higher uronic acid content but a lower arabinose-to-xylose ratio than the other grain tissues. The hemicellulose of endosperm also has a lower arabinose-toxylose ratio than the three other grain tissues.

Volatiles

The volatiles characteristic of cooked rice are ammonia, hydrogen sulphide and acetaldehyde (Obata and Tanaka, 1965). Upon cooking, all aromatic rices contain 2-acetyl-1-pyrroline as the major aromatic principle (Buttery et al., 1983). Volatiles characteristic of fat rancidity are aldehydes, particularly hexanal, and ketones.

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Environmental influence on rice composition

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Environmental factors are known to affect the composition of the rice grain (Juliano, 1985b). Protein content tends to increase with wider spacing or in borders and in response to high N fertilizer application, especially at flowering. Short growth duration and cloudy weather during grain development, as occurs in the wet season, may increase protein content. Stresses such as drought, salinity, alkalinity, high or low temperature, diseases or pests may increase the protein content of the rice grain. An increase in protein content is essentially at the expense of a reduction in starch content.

Environmental factors that increase protein content, such as soil type, ambient temperature during ripening and growth duration, also increase the ash content of

brown rice but have no effect on its fat content. Mineral nutrition affects the protein content of the rice grain: soil organic matter, total nitrogen, exchangeable calcium, available copper and molybdenum and total chlorine all tend to increase the grain protein content (Huang, 1990).

As growth duration increases, brown rice protein content decreases (IRRI, 1988b). By contrast, yield and brown rice protein were not always significantly negatively correlated.

Upland culture had a variable effect on the protein content of eight varieties of rice grown in Cte d'Ivoire; five showed a lower milled rice protein content and two showed a higher protein content under upland culture (Villareal, Juliano and Sauphanor, 1990).

In Punjab, Pakistan, high soil salinity increased the brown rice protein content in three of four varieties differing in salinity tolerance but had no effect on the protein content of the fourth (Siscar-Lee et al., 1990). Soil sulphur deficiency reduces grain yield without having any adverse effect on the cysteine and methionine contents of the rice protein (Juliano et al., 1 987).

The mineral content of the grain is affected by the mineral content of the soil and of the irrigation water. For instance, pollution of irrigation water with mine tailings has resulted in high cadmium content in some Japanese rices which has proved to be harmful (Kitagishi and Yamane, 1981).

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Grain quality

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Consumers' criteria

When more rice becomes available in the market, consumers' demand for superior quality rice is increased. Although sensory evaluations by laboratory panels and consumer panels give some indication on important criteria for rice quality, they do

not reflect the properties for which consumers will actually pay a price premium in the retail market. By clearly identifying the quality characteristics valued by consumers, plant breeders can target attributes that are economically significant in breeding improvement research. The results could provide social scientists with an agenda for public policy research in rice marketing, technology assessment and research prioritization.

Rice grain quality denotes different properties to various groups in the postharvest system (Juliano and Duff, 1989). Although variety is the principal factor contributing to grain quality, good post-harvest handling can maintain or even improve it (Table 19). Moisture content is the most important quality criterion for rough rice. To the farmer, grain quality refers to quality of seed for planting material and dry grain for consumption, with minimum moisture, microbial deterioration and spoilage. The miller or trader looks for low moisture, variety integrity and high total and head milled rice yield. Market quality is mainly determined by physical properties and variety name, whereas cooking and eating quality is determined by physico-chemical properties, particularly apparent amylose content. In countries with marked variability in temperatures during the ripening periods, significant differences in grain quality have been reported within a variety. In tropical Asia, grain physico-chemical properties are relatively constant. Nutritional value is mainly determined

by the milled rice protein content.

The major findings of research on the economics of grain quality from 1987 to 1989 by IRRI and national rice research programmes in Indonesia, Bangladesh, Malaysia, the Philippines and Thailand are that rice grain quality and quality preferences vary across countries and regions but some quality preferences are widely shared (IRRI and IDRC, 1992). Consumers in all the countries studied prefer higher head rice yield and more translucent grain. High-income consumers pay higher premiums for a larger number of quality characteristics than low-income consumers, reflecting their ability to pay. Preferences do not vary much across income levels, with one exception: lowerincome consumers prefer rice that is more filling. Laboratory analysis showed that Philippine rice labelled with a traditional variety name is usually a modern variety with shape or cooking characteristics similar to those of traditional varieties (Juliano et al., 1989b). Thus, the "traditional" label signals consumers that these rices have some desirable characteristics.

TABLE 19 - Effects of environment, processing and variety on rice grain properties influencing quality at different steps of the post-harvest system

Post-harvest process and	**Environment**	**Processing**	**Variety**

associated grain property		method	
Harvesting	+[a]	+	+ (Growth duration, photoperiod, degree of ripening, dormancy)
Threshing	+	+	+ (Threshability, shattering)
Drying	+	+	+ (Crack resistance)
Yellowing	+	+	0
Storage/ageing	+	+	+ (Waxy rice ages less than nor waxy)
Parboiling	+	+	+ (Gelatinization temperature)
Pecky grain	+	+	+ (Stink-bug resistance)
Dehulling	0	+	+ (Hull tightness and content)
Milling			
Head rice	+	+	+ (Crack resistance)
Marketing			
Size and shape	+	0	+ (Genetically determined)

Degree of milling (whiteness)	+	+	+ (Depth of grooves)
Head rice	+	+	+ (Crack resistance)
Translucency	+	+	+
Aroma	+	+	+
Foreign matter	+	+	0
Shelf life	+	+	0
Cooking and eating			
Amylose content	+	0	+ (Volume expansion and texture)
Gelatinization temperature	+	0	+ (Cooking time)
Gel consistency	+	0	+
Texture of cooked rice	+	+	+

Grain elongation	+	+	+

[a] +, quality affected; O. no effect.

Source: Juliano & Duff, 1989.

Quality incentives appear to be transmitted from wholesale rice prices through to rough rice prices in Indonesia and the Philippines (IRRI and IDRC, 1992). However, this transmission is not perfect. The Philippine studies show that barriers to entry in milling influence pricing efficiency. The studies reveal the complexity of the transmission of information about quality from consumers to producers.

Given the importance of quality characteristics for creating and stimulating demand, especially among the higher-income urban sector, transmission of price and market signals and a greater degree of integration of the farm wholesale and retail market will be necessary to improve the farmgate price and to provide incentive to farmers to produce better-quality rice. Moreover, improvements in grain quality that do not lower yields will generally benefit all rice consumers by lowering the cost of better-quality rice (Unnevehr et al., 1985). If higher-quality varieties are widely adopted, producers will benefit by retaining better-quality rice for home consumption and by

having a wider domestic market for their products. In addition, countries exporting rice would benefit from quality improvements that would expand their potential export market.

Grain quality indicators

Physical properties such as length, width, translucency, degree of milling, colour and age of milled rice are grain quality indicators. The amylose content of the rice starch is the major eating quality factor. It correlates directly with volume expansion and water absorption during cooking and with hardness, whiteness and dullness of cooked rice (Juliano, 1985b). Genetic studies showed that the nonwaxy trait is dominant over the waxy trait (Kumar, Khush and Juliano, 1987). Among non-waxy parents, high amylose is completely dominant over low or intermediate amylose, and intermediate is dominant over low (Kumar and Khush, 1987).

Final gelatinization temperature (GT) of starch granules refers to the water temperature at which at least 90 percent of the starch granules have gelatinized or lost birefringence (Maltese cross) or swollen irreversibly in hot water. GT is classified for rice starch granules as low (55 to 69.5C), intermediate (70 to 74C) and high (74.5 to 80C). GT is indexed in the breeding programme by the alkali spreading value

based on the degree of dispersion of six grains of milled rice in 10 ml of 1.7 percent potassium hydroxide after 23 hours soaking at 30C (Little, Hilder and Dawson, 1958).

A high GT value is uncommon, particularly in high amylose rices. A low ambient temperature during ripening may increase amylose content and independently reduce GT (Nikuni et al., 1969; Resurreccin et al., 1977; Dien et al., 1987). The GT affects the degree of cooking of rice because of the cooking gradient from the surface to the core of the grain. Because GT correlates directly with cooking time, a low GT favours fuel conservation, provided eating quality is not adversely affected. GT also affects the molecular properties of amylopectin.

The gel consistency test was developed to index cooked rice hardness among high-amylose rices (Cagampang, Perez and Juliano, 1973). Rices are classified based on gel length as soft (61 to 100 mm), medium (41 to 60 mm) and hard (27 to 40 mm), (Table 18). Soft to medium gel consistency is preferred to hard gel consistency in both non-waxy and waxy rices. High protein content contributes to harder gel consistency. Amylopectin contributes more than amylose to starch gel consistency and viscosity.

Among rices of the same apparent amylose type, alkali spreading value and gel consistency may be used as quality indices. Among high-amylose rices, intermediate GT and soft gel consistency are preferred by consumers over low GT and hard gel consistency (Juliano, 1985b). Among intermediate-amylose rices derived from C4-63G, those with an intermediate GT value are preferred to those with a low GT value, as the cooked rice is softer. Gel consistency values are similar among these intermediate-amylose rices. Among low-amylose and waxy rices, a low-GT type is preferred to a type with a high GT value. In terms of rice improvement breeding, hard gel consistency is dominant over medium and soft gel, and medium gel consistency is dominant over soft (Tang, Khush and Juliano, 1989).

TABLE 20 - Relative importance of rice quality indicators in rice breeding programmes

Breeding programme properties[a]	**Physical texture**[b]	**Starch texture**[b]	**Cooked rice**
Traditional varieties	Main	Optional	Optional
Modern varieties	Major	Major	Verification

Grain quality	Major	Verification	Major

[a] Amylose content, alkali spreading value (gelatinization temperature), gel consistency.

[B] Deterrnined by sensory evaluation or instrument-Instron, Texturometer, Tensipresser, Viscoelastograph, etc.

Source: Juliano & Duff, 1991.

As many countries achieve rice self-sufficiency, grain quality becomes an important breeding objective (Juliano and Duff, 1991). In traditional breeding programmes, both parents are of known quality so that the quality of the breeding lines is predictable by indicators based on physical properties, namely apparent amylose content, alkali spreading value and gel consistency (Table 20). With modern or semi-dwarf varieties, derived from parents of contrasting grain qualities, evaluation of starch properties complements physical methods in indexing quality of breeding lines. Breeding for grain quality involves discrimination among lines with similar starch properties, as in the United States, Japan and the Republic of Korea and at IRRI, where cooked rice texture is the key indicator.

Heritability of protein content is very low. A six-percentage-point range is observed for each variety (Coffman and Juliano, 1987). Environmental factors contribute significantly to protein content. High-protein rice translocates straw N to the developing grain more efficiently, which results in a higher N harvest index (panicle N/panicle N + straw N), (Perez et al., 1973).

Quality characteristics of world rices - country samples

In Asian countries high-amylose rices predominate (Table 21). This is the principal rice type in Bangladesh, Sri Lanka, Thailand and Viet Nam.

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TABLE 21 - Amylose scattergram and protein content of milled rices of varieties grown in various countries In Asia (IRRI 1963-90)

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Country	Number of samples	Amylose type[a]					Percent protein[b]	
		Waxy	Very low	Low	Intermediate	High	Range	Mean
Bangladesh	58	0	0	2	7	49	5-12	7.7
Bhutan	40	0	0	2	22	16	5-9	6.9
Brunei	11	0	1	0	4	6	6-13	7.9
Cambodia	34	0	0	4	5	25	4-12	6.4
China	74	4	0	18	12	40	6-13	8.3
Taiwan	58	10	0	34	6	8	4-11	7.6
India	52	0	0	2	8	42	6-11	8.5
Maharashtra	14	0	0	0	2	12	5-8	6.3
Indonesia	133	5	2	5	50	71	5-11	7.9

Iran	33	0	0	11	15	7	3-12	9.2
Japan	67	5	0	57	5	0	5-12	7.2
Korea, South	147	4	2	121	19	1	6-11	8.2
Laos	20	11	2	1	5	1	6-9	7.4
Malaysia								
Sarawak	27	0	3	4	6	14	5-14	7.1
Sabah	10	0	0	0	3	7	6-8	6.8
West Malaysia	46	3	0	0	5	38	6-11	7.4
Myanmar	61	1	11	12	19	18	5-11	6.9
Nepal	46	0	0	10	8	28	5-9	7.0
Pakistan	66	0	0	3	33	30	6-10	8.1
Phillppines[c]	328	39	3	23	98	165	5-14	8.2
Sri Lanka	67	0	0	0	6	61	6-13	8.8
Thailand	83	22	2	6	13	40	4-14	8.0

Turkey	14	0	0	13	1	0	6-10	7.4
Viet Nam	133	1	0	6	24	102	5-11	7.7
Total	1 622	105	26	334	376	781	4-14	7 8

[a] Percent amylose, milled rice dry weight basis: waxy 0-5%, very low 5.1-12.0%, low 12.1-20.0%, intermediate 20.125.0%, high >25.0%.

[b] At 12% H2O.

[c] Includes varieties grown at IRRI.

Source: Juliano & VillareaL 1991.

Intermediate-amylose rices predominate in Bhutan, Myanmar and Pakistan, whereas low-amylose rices predominate in Taiwan Province (China), Japan and the Republic of Korea. Very low amylose rices are identified only in Brunei, Indonesia, the Republic of Korea, Laos, Sarawak (Malaysia), Myanmar, the Philippines and Thailand. Waxy rices are represented in China, Indonesia, Japan, the Republic of

Korea, Laos, West Malaysia, Myanmar, the Philippines and Thailand. Waxy rice is the staple in Laos and north and northeast Thailand.

Protein content in these milled rice samples ranged from 4 to 14 percent and mean protein ranged from 6.3 to 9.2 percent (Table 21). The overall mean protein content is 7.8 percent.

Of the varieties grown outside Asia, low-, intermediate- and high-amylose rices are equally represented (Table 22). High-amylose rices predominate in Colombia, Ghana, Guatemala, Nigeria, Paraguay, Peru, Sierra Leone and Venezuela. Intermediate-amylose rices predominate in Chile, Greece, Hungary, the Islamic Republic of Iran, Italy, Suriname and Venezuela. Low-amylose rices predominate in Argentina, Australia, Bulgaria, Egypt, France, Portugal, Turkey, the United States and the area of the former Soviet Union. The United States has the only very low amylose rice and has waxy rices as does Australia.

The protein content of milled rice samples grown outside Asia ranged from 5 to 13 percent and mean values ranged from 6.2 to 10.5 percent (Table 22). Mean protein is 7.2 percent, which is lower than that of Asian rice (Table 2 1).

The amylose types preferred in various rice-producing countries in Asia and elsewhere producing 0.1 percent or more of total world production are tabulated in Table 23 (Juliano and Duff, 1991). Intermediate-amylose rice seems the most popular, followed by low- and high-amylose rices and lastly waxy rice. Lowamylose rices were mainly japonica except in Thailand and Argentina. The Thai rices are the jasmine or Khao Dawk Mali 105 type that is becoming popular in the United States and Europe. Intermediate-amylose rices were preferred in the most countries; these include Basmati rices, Indonesian bulu (Javanica) varieties, Myanmar's Nga Kywe or D25-4 elongating rices and United States long-grain varieties. High-amylose rices with medium to soft gel are preferred in most of South Asia (Bangladesh, India, Pakistan and Sri Lanka) for their suitability for parboiling.

TABLE 22 - Amylose scattergram and protein content of milled rices of varieties grown in various countries outside Asia (IRRI, 1963-90)

Country	Number of samples	Amylose type[a]					Percent protein[b]	
		Waxy	Very	Low	Inter-	High	Range	Mean

		low		**mediate**				
Argentina	46	0	0	23	16	7	6-9	7.6
Australia	25	2	0	13	7	3	5-10	6.7
Bolivia	6	0	0	1	5	0	7-10	8.2
Brazil	91	0	0	23	26	42	5-13	8.5
Bulgaria	23	0	0	14	8	1	6-10	7.4
Cameroon	2	0	0	0	1	1	8-11	9.8
Chile	14	0	0	5	4	0	6-10	7.4
Colombia	20	0	0	0	5	15	6-11	7.9
Costa Rica	4	0	0	0	2	2	9-13	10.5
Cte d'lvoire	23	0	0	6	8	9	6-11	7.9
Cuba	24	0	0	7	7	10	6-9	7.6
Dominican Republic	9	0	0	1	2	6	4-9	7.6
Ecuador	17	0	0	0	3	14	6-8	6.8

Egypt	44	0	0	29	8	7	5-10	6.7
El Salvador	12	0	0	0	5	7	6-11	8.2
France	43	0	0	27	14	2	5-12	7.0
Ghana	22	0	0	0	7	15	6-9	7.8
Greece	10	0	0	3	5	2	5-8	6.4
Guatemala	8	0	0	0	2	6	6-8	6.8
Guyana	10	0	0	0	4	6	7-12	8.8
Hungary	42	0	0	15	26	1	6-11	7.2
Italy	37	0	0	14	23	0	5-8	6.9
Liberia	12	0	0	2	3	7	6-9	7.6
Madagascar	9	0	0	1	3	5	5-10	7.5
Mexico	35	0	0	1	12	22	5-11	7.2
Nigeria	66	0	0	7	16	43	6-11	7.4
Panama	2	0	0	0	0	2	6	6.2

Paraguay	15	0	0	1	2	12	7-10	8.4
Peru	35	0	0	11	8	16	5-11	7.5
Portugal	31	0	0	17	13	1	5-8	6.8
Senegal	11	0	0	0	1	10	5-10	7.2
Sierra Leone	108	0	0	9	14	85	5-10	7.0
Soviet Union	25	0	0	16	9	0	5-7	6.4
Spain	12	0	0	9	3	0	6-13	8.2
Suriname	34	0	0	8	15	11	6-9	7.5
Togo	2	0	0	0	1	1	8	7.6
United States	87	5	1	40	23	18	5-10	7.0
Venezuela	6	0	0	0	0	6	6-7	7.1
Total	1 017	7	1	303	316	390	5-13	7.2

[a] Percent amylose, milled rice dry weight basis: waxy 0-5%, very low 5.1-12.0%, low 12.1-20.0%, intermediate 20.1-25.0%, high >25.0%.

[b] At 12% H_2O

Source: Juliano & Villareal, 1991.

Quality of rice in international markets

The quality types of rices in the international markets are basically high-quality long-grain rice, medium-quality long-grain rice, short-grain rice, parboiled rice, aromatic or fragrant rice and waxy or glutinous rice (Efferson, 1985). Each is demanded by different markets. Long-grain, higher-quality rice is sold mostly in Europe and the Near East, medium-quality long-grain rice in the deficit countries of Asia, the short-grain product in various special-demand areas, high-quality parboiled rice in the Near East and Africa and the lower-quality parboiled rice in special markets in Asia and Africa. Aromatic rice is demanded mostly in the Near East. Waxy rice meets market needs in Laos, while smaller volumes go to other countries.

TABLE 23 - Rice-grain apparent amylose type preferred in various ricegrowing countries contributing 0.1 percent or more to total world rice production

waxy	Low	Intermediate	High
Asia			
Laos	China (japonica)	Cambodia	Bangladesh
Thailand (north)	China-Taiwan (japonica)	China[a] (japonica)	China (indica)
	Japan	India	India
	Korea, Republic of	Indonesia	Pakistan (IR6 type
	Nepal	Malaysia	Philippines
	Thailand (northeast)	Myanmar	Sri Lanka
	Pakistan (Basmati)	Thailand (north,	
	Philippines	central, south)	

	Thailand (central)		
	Viet Nam		
Outside Asia			
	Argentina	Brazil (upland)	Brazil (irrigated)
	Australia	Cuba	Colombia
	Spain	Italy	Guinea[b]
	USA (short & medium grain)	Ivory Coast	Mexico
	USSR	Liberia	Peru
		Madagascar	
		Nigera	
		USA (long grain)	

[a] **Data from China National Rice Research Institute, Hangzhou.**

[b] Data from International Institute for Tropical Agriculture, Lagos, Nigeria.

Source: Juliano & Duff, 1991.

In the traditionally rice-consuming economies of Hong Kong and sectors of Rome, Italy, quality characteristics in major retail outlets were found to be an important consideration for retail price (Kaosa-ard and Juliano, 1989). In Hong Kong, low-amylose long-grain translucent rices are preferred, with higher head rice and softer gel consistency. In Rome, price correlated positively with chalkiness and the number of packings and negatively with gel consistency. Imported rices were more expensive than local japonica varieties, many of which were also parboiled. In Bonn, Germany, which is a traditionally non-riceconsuming market, head rice content was the only statistically important rice grain property, and level of processing, lot size and packing types were important price considerations.

Thai export rices were shown to be more variable in starch properties than United States long-grain rices, mainly intermediate-amylose, reflecting the greater heterogeneity of amylose and gelatinization temperature values among Thai varieties (Juliano, Perez and Kaosa-ard, 1990). Brokens and head rice are blended as required by the importer.

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Chapter 4 Nutritional value of rice and rice diets

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The gross composition of rice and its various milling fractions was given in Table 14. It shows that rice is rich in energy and is a good source of protein. Table 15 showed that rice contains a reasonable amount of thiamine, riboflavin, niacin, vitamin E and other nutrients. It does not contain any vitamin C, D or A. Because of the quantity consumed it is the principal source of energy, protein, iron, calcium, thiamine, riboflavin and niacin in Asian diets.

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Nutrient composition and protein quality of rice relative to other cereals

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Comparison of the nutrient content of staple cereals at 14 percent moisture and higher-moisture tuber foods (Tables 24 to 27) shows a somewhat higher energy content in cereals (Table 24), but a higher ascorbic acid content in tubers (Table 25). Because tubers contain more moisture they have lower nutrient and energy density than cereals. Cassava has an extremely low protein content (Table 24) even after correction for moisture differences.

The protein level of rice is similar to those of potato and yam on a dry weight basis but is the lowest among the cereals. Rice also has the lowest dietary fibre content.

Amino acid analysis (Table 26) showed lysine to be the first limiting essential amino acid in cereal proteins, but lysine content was highest in oats and rice among cereal

proteins (Eggum, 1979), (Table 26). In contrast, tuber proteins are adequate in lysine but deficient in sulphur amino acids cysteine and methionine particularly at high protein levels (Eppendorfer, Eggum and Bille, 1979; Food and Nutrition Research Institute, 1980).

TABLE 24 - Proximate composition of cereal and tuber staple foods (per 100 g)

Food	**Moisture (%)**	**Protein (g Nx 6.25)**	**Crude fat (g)**	**Available carbohydrates (g)**	**Fibre (g)**			**Crude ash (g)**	**En (kJ**
					Dietary	**Water insoluble**	**Lignin**		
Brown rice	14.0	7.3	2.2	71.1	4.0	(2.7)	(0.1)	1.4	1 6
Wheat	14.0	10.6	1.9	61.6	10.5	(7.8)	(0.6)	1.4	1 5
Maize	14.0	9.8	4.9	60.9	9.0	(6.8)	(0)	1.4	1 6
Millet	14.0	11.5	4.7	64.6	37	(2.3)	(0)	1.5	1 6

Sorghum	14.0	8.3	3.9	57.4	13.8	(12.4)	(3.0)	2.6	1
Rye	14.0	8.7	1.5	60.9	13.1	(8.4)	(1 4)	1.8	1
Oats	14.0	9.3	5.9	63.0	5.5	(39)	(0)	2.3	1
Potato	77.8	2.0	0.1	15.4	2.5	(1.9)	(0)	1.0	29
Cassava	63.1	1.0	0.2	31.9	2.9	(2.2)	(0)	0.7	55
Yam	71.2	2.0	0.1	22.4	3.3	(2.6)	(0)	1.0	41

Nitrogen-free extract by difference.

Sources: Souci, Fuchmann & Kraut, 1986; Eggum, 1969,1977,1979.

Whole-grain maize meal had protein quality comparable to that of wheat because of its large germ which is high in lysine-rich protein. Calculated amino acid scores based on the WHO/FAO/UNU pattern (WHO, 1985) showed tuber proteins to be superior to cereal proteins but do not take into consideration actual digestibility.

Rice has the highest protein digestibility among the staples (Table 27). Potato protein had a higher biological value than cereal proteins, consistent with its high

amino acid score, but its net protein utilization (NPU) was lower than that of rice. Utilizable protein was comparable in brown rice, wheat, maize, rye, oats and potato but was lower in sorghum and higher in millet. Rice has the highest energy digestibility, probably in part because of its low dietary fibre and tannin content (Tables 24 and 26).

Cereal proteins are less digestible by children and adults than egg and milk protein, except for wheat endosperm (WHO, 1985), (Table 28). Digestibility values for cooked milled rice proteins were lower than those for raw milled rice (almost 100 percent) when tested on growing rats but were close to the values for other cereal proteins, except for the low value for sorghum. Based on the mean true digestibility of egg, milk, cheese, meat and fish protein of 95 percent, the relative digestibility of milled rice is 93 percent (WHO, 1985). The protein of cooked rice has a lower true digestibility in humans than the protein of raw rice in growing rats (Table 28). Cooked rice protein also has a true digestibility of 89 percent in growing rats (Eggum, Resurrecin and Juliano, 1977).

TABLE 25 - Vitamin and mineral content of cereal and tuber staple foods (per 100 g)

Food	**Carotene**	**Thiamine**	**Riboflavin**	**Niacin**	**Ascorbic**	**Vitamin**	**Iron**	

	(mg)	(mg)	(mg)	(mg)	acid (mg)	E (mg)	(mg%)	Zinc[a] (mg%)
Brown rice	0	0.29	0.04	4.0	0	0.8	3	2
Wheat	0.02	0.45	0.10	3.7	0	1.4	4	3
Maize	0.37	0.32	0.10	1.9	0	1.9	3	3
Millet	0	0.63	0.33	2.0	0	0.07	7	3
Sorghum	10.0	0.33	0.13	3.4	0	0.17	9	2
Rye	0	0.66	0.25	1.3	0	1.9	9	3
Oats	0	0.60	0.14	1.3	0	0.84	4	3
Potato	0.01	0.11	0.05	1.2	17	0.06	0.8	0.3
Cassava	0.03	0.06	0.03	0.6	30	0	1.2	0.5
Yam	0.01	0.09	0.03	0.6	10	0	0.9	0.7

[a] **Zinc level of cassava and yam from Bradbury & Holloway (1988).**

Sources: Souci, Fuchmann & Kraut, 1986: Eggum, 1969,1977, 1979.

Nitrogen balance studies in Peruvian preschool children fed cooked cereals (Graham et al., 1980; MacLean et al., 1978, 1979, 1981) and potato (Lopez de Romaa et al., 1980) showed the highest apparent N absorption for wheat noodles but the highest apparent N retention for peeled potato and the highest protein quality, based on apparent N retention of casein control diets, for potato and milled rice (Table 29). Utilizable protein is highest for wheat and rice. High-lysine or opaque-2 maize is inferior to milled rice in protein quality but better than normal maize. Energy digestibility, indexed by faecal dry weight, was lowest for sorghum, probably because of its high tannin content (see Table 26).

TABLE 26 - Amino acid and tannin content in whole-grain cereals and tubers

Food	**Lysine (g/16 g N)**	**Threonine (g/16 g N)**	**Methionine + cystine (g/16 g N)**	**Tryptophan (g/16 g N)**	**Amino acid score^a(%)**	**Tannin(%**
Brown rice	3.8	3.6	3.9	1.1	66	0.4

Wheat	2.3	2.8	3.6	1.0	40	0.4
Maize	2.5	3.2	3.9	0.6	43	0.4
Millet	2.7	3.2	3.6	1.3	47	0.6
Sorghum	2.7	3.3	2.8	1.0	47	1.6
Rye	3.7	3.3	3.7	1.0	64	0.6
Oats	4.0	3.6	4.8	0.9	69	1.1
Potato	6.3	4.1	3.6	1.7	100	
Cassava	6.3	3.4	2.6	1.0	91	
Yam	6.0	3.4	2.9	1.3	100	

[a] All based on 5.8% lysine as 100%, except based on 1.1% tryptophan as 100% for cassava (WHO, 1985).

Sources: Eggum, 1969, 1977, 1979; Food and Nutrition Research Institute, 1980.

TABLE 27 - Balance data of whole-grain cereals and potato in five rats

Food	True N digestibility (%)	Biological value (%)	Net protein utilization (%)	Utilizable protein (%)	Digestible energy	
					(kcal/g)	(% of total)
Brown rice	99.7	74.0	73.8	5.4	3.70	96.3
Wheat	96.0	55.0	53.0	5.6	3.24	86.4
Maize	95.0	610	58.0	5.7	3.21	81.0
Millet	92.0	60.0	56.0	6.4	3.44	87.2
Sorghum	84.8	59.2	50.0	4.2	3.07	79.9
Rye	77.0	77.7	59.0	5.1	3.18	85.0
Oats	84.1	70.4	59.1	5.5	2.77	70.6
Potato	82.7	80.9	66.9	5.2	-	-

Sources: Eggum, 1969, 1977, 1979.

TABLE 28 - Calculated true digestibility by adults and children of various cereal proteins as compared to egg, milk and meat protein

Protein source	Mean	Digestibility relative to reference proteins
Rice, milled	88 4	93
Wheat, whole	86 5	90
Wheat endosperm (farina)	96 4	101
Maize, whole	85 6	89
Millet	79	83
Sorghum	74	78
Oatmeal	86 7	90
Egg	97 3	100[a]
Milk	95 3	
Meat, fish	94 3	

[a] Mean true digestibility of 95%.

Sources: Hopkins, 1981; WHO, 1985.

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Milled rice protein

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The usual value assigned to the protein content of milled rice is 7 percent, based on a Kjeldahl conversion factor of 5.95. However, in nutritional studies the factor 6.25 is used to make the diets isonitrogenous with the standard proteins. The true digestibility of cooked rice protein in humans is 88 + 4 percent (WHO, 1985), (Table 28). Its amino acid score is about 65 percent based on 5.8 percent lysine as 100

percent (WHO, 1985). The NPU of milled rice in rats is about 70 percent (Eggum and Juliano, 1973, 1975). Biological value in growing rats is about 70 percent for raw rice and about 80 percent for cooked rice (Eggum, Resurreccin and Juliano, 1977).

Raw rice protein is 100 percent digestible in growing rats (Eggum and Juliano, 1973, 1975). Although cooking reduces true digestibility in growing rats to 89 percent, lysine digestibility remains close to 100 percent (Eggum, Resurreccin and Juliano, 1977; Eggum, Cabrera and Juliano, 1992). Thus the NPU of cooked rice is also about 70 percent. The effects of cooking are discussed in more detail in Chapter 5.

TABLE 29 Comparative protein utilization and faecal dry weight for Peruvian preschool children fed cooked cereals and potato

High-protein rice

Feeding trials in growing rats and a study of growth rate data (Blackwell, Yang and Juliano, 1966), determinations of protein efficiency ratio and nitrogen growth index (Bressani, Elias and Juliano, 1971), net protein utilization studies (Eggum and Juliano, 1973,1975; Murata, Kitagawa and Juliano, 1978) and values for relative

nutritive value (Hegsted and Juliano, 1974) showed that an increase in milled rice protein from 7 to 9 percent has nutritional advantages, based on utilizable protein (protein content x protein quality), (Tables 30 and 31). The lysine content of rice protein drops only slightly with an increase in the protein content of milled rice to 10 percent and then becomes constant above 10 percent protein (Cagampang et al., 1966; Juliano, Antonio and Esmama, 1973).

These rat trials were verified by isonitrogenous N balance studies in preschool children in Peru (MacLean et al., 1978) and the Philippines (Roxas, Intengan and Juliano, 1979), (Table 32). Although apparent N retention was somewhat lower for the high-protein rice, the decrease was just a fraction of the increase in protein content. Short-term N balance studies also showed that with the replacement of average-protein rice (7.5 to 7.8 percent) by an equal weight of high-protein rice (11.4 to 14.5 percent) apparent N retention increased from 3.6 to 11.7 percent in adults on rice diets (Clark, Howe and Lee, 1971), from 27.7 to 29.8 percent in adults on rice/ fish diets (Roxas, Intengan and Juliano, 1975) and from 21.6 to 31.6 percent in children on rice/mung bean diets (Roxas, Intengan and Juliano, 1976), (Table 33).

Long-term feeding trials in children's institutions in India and the Philippines demonstrated that replacement of average-protein (6 to 7 percent) milled rice with

an equal weight of high-protein (10 percent) milled rice in children's diets improved growth, provided that other nutritional factors, such as zinc, did not become limiting (Pereira, Begum and Juliano, 1981; Roxas, Intengan and Juliano, 1980). The absence of height or weight response by the Indian children who were without a vitamin and mineral supplement may have resulted from a deficiency in zinc and other minerals and in vitamins at the higher protein intake.

TABLE 30 - Relation of protein content and protein quality of milled rice based on NPU and various slope ratio assays (weight gain) and reference proteins In growing rats

Rice protein source	**Protein content (% Nx 6.25)**	**Lysine (g/16g N)**	**Amino acid score[a] (%)**	**Npub (%)**	**Relative nutritive value (%)**			
					I[c]	II[d]	III[e]	IV[f]

Intan	6.0	4.1	70	75	78	77	82	
Commercial	6.7	3.4	58	56	-	-	-	51
IR8-	7.7	3.6	62	70	69	72	63	-
IR22	7.9	3.8	65	-	78	-	-	-
IR22	10.0	3.9	67	69	77	-	-	-
IR8	10.2	3.5	60	65	68	67	-	-
IR480-5-9	10.3	3.5	61	-	-	-	57	-
IR480-5-9	11.0	3.2	55	63,56	-	-	-	48
IR1103-15-8	11.6	3.6	63	71	65	-	-	
IR58	11.8	3.5	60	68	-	-	-	
IR48-5-9	11.8	3.3	58	64	53	-	-	
IR480-5-9	12.3	3.3	58	-	54	-	-	
BPI-76-1	15.2	3.2	55	66	46	60	42	

[a] **Based on 5.8% lysine as 100% (WHO, 1985).**

[b] Eggum & Juliano, 1973, 1975; Murata, Kitagawa & Juliano, 1978.

[c] Based on 0, 28, 56 and 84% rice diets and lactalbumin slope as 100% (Hegsted & Juliano, 1974).

[d] Based on 0, 1, 2, 3, 4 and 5% protein diets and casein slope as 75% (Bressani, Elias & Juliano, 1971).

[e] Based on 2, 5 and 8% protein diets and casein slope as 75% (B.E. McDonald, personal communication, 1974).

[f] Based on 0, 4, 8,12 and 15% protein diets end egg slope as 100% (Murata, Kitagawa& Juliano, 1978).

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Glycaemic index, starch digestibility and resistant starch

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Glycaemic index, based on the relative increase in plasma glucose within 3 hours after ingestion of carbohydrate, with white bread or glucose as 100 percent, has been used as a guide for the diets of non-insulin-dependent diabetes mellitus (NIDDM). Waxy and low-amylose rices had higher glycaemic indices than intermediate- and high-amylose rices (Goddard, Young and Marcus, 1984; Juliano and Goddard, 1986; Jiraratsatit et al., 1987; Tanchoco et al., 1990; M.I. Prakoso, 1990, personal communication), (Table 34). Processing, such as parboiling and noodle-making, tends to reduce the glycaemic index of rice, particularly that of high- and intermediate-amylose rices (Panlasigui, 1989; Wolever et al.,1986). By contrast, Tsai et al. (1990) reported that waxy rice, rice gruel, steamed rice and rice noodles had similar glycaemic indices to that of white bread in NIDDM patients. Among high-amylose rices, the low-GT, hard-gel IR42 had a higher glycaemic index than the intermediate-GT, softer-gel IR36 and IR62 (Panlasigui, 1989). By contrast, Srinivasa Rao (1970) reported that the ingestion of hard-gel IR8 resulted in a lower peak plasma glucose level than ingestion of the softer-gel Hamsa; both have high amylose

and low GT.

TABLE 31 - Effect of protein content on protein quality of raw milled rice based on nitrogen balance in growing rats

Rice protein source	**Protein content (% N x 6.25)**	**Lysine (g/16g N)**	**Amino acid score[a] (%)**	**True digesti- bility (%)**	**Biological value (%)**	**NPU (%)**	**Utilizable protein (%)**
Intan	6.0	4.1	70	100.1	75.2	75 3	4.5
Commercial	6.7	3.4	58	-	-	56b	3.8
IR8	7.7	3.6	62	96.2	73.1	70.3	5.4
IR8	8.1	3.6	62	99.2	69.5	68.9	5.6
Perurutong	8.1	3.7	63	97.5	68.4	66.7	5.4
IR32	8.3	3.6	62	98.4	67.5	66.4	5.5

H4	9.7	3.4	58	99.2	65.7	65.2	6.3
IR8	9.9	3.4	59	98.0	69.2	67.8	6.7
IR480-5-9	9.9	3.5	60	99.8	71.0	71.0	7.0
IR22	10.0	3.9	67	98.5	69.7	68.7	6.9
IR8	10.2	3.5	60	95.4	68.4	65.2	6.7
IR2031-724-2	10.2	3.5	61	99.9	66.5	66.4	6.8
IR480-5-9	11.0	3.2	55	-	-	63,56[b]	6.9,6.2
IR480-5-9	11.2	3.4	59	100.4	66.8	67.1	7.5
IR480-5-9	11.4	3.4	58	100.6	68.4	68.8	7.8
IR1103-15-8	11.6	3.6	63	95.9	74.3	71.1	8.2
IR480-5-9	11.8	3.3	58	94.5	67.9	64.2	7.6
IR58	11.8	3.5	61	99.1	68.8	68.3	8.1
IR2153-338-3	12.2	3.6	61	98.5	69.9	68.8	8.4
IR480-5-9	13.0	3.3	57	100.1	67.7	67.8	8.8
BPI-76-1	15.2	3.2	55	94.4	70.1	66.2	10.1

IR32, destarched	18.7	4.0	70	96.8	69.0	66.8	12.5
IR480-5-9,destarched	49.4	3.3	56	94.7	65.4	61.9	30.6
IR480-5-9,gelatinizedand destarched	80.2	3.6	62	92.5	73.2	67.7	54.3

[a] Based on 5.8 g Lysine/16 g N as 100%% (WHO, 1985).

[b] Based on carcass N analysis (Murata, Kitagawa & Juliano, 1978).

Sources: Eggum & Juliano, 1973, 1975; Eggum, Alabata & Juliano, 1981 Eggum, Juliano & Manigat, 1982; Eggum et al., 1987 Murata, Kitagawa & Juliano, 1978; lRRI, 1976; Resurreccin, Juliano & Eggum, 1978.

TABLE 32 - Nitrogen balance data of and average-protein milled rice diets in male preschool children

Diet	Number of children	Protein content of rice (% N x 6.25)	Age (years)	Lysine (g/16 g N) body wt)	Daily N intake (mg/kg	Apparent N digestibility (% of intake)	Apparer N retentio (% of intake)
Flilpino childrena High-protein rice	8	11.0	1.2-2.0	3.4	250	60.0	23.4
Low-protein rice	8	7.2	1.2-2.0	3.9	250	66.2	26.9
Peruvian childlenb High-protein rice	8	11.0	1.0-1.5	3.4	240	64.9	23.0
Low-protein rice	8	7.2	1.0-1.5	3.8	240	66.6	28.6

[a] First casein diet: 76.8% apparent digestibility and 30.8% apparent retention (Roxas,

Intengan & Juliano, 1979).

[b] First casein diet: 86.1% apparent digestibility and 35.2% apparent retention (MacLean et al., 1978).

TABLE 33 - Replacement of average-protein rice by high-protein rice in various diets: effect on nitrogen balance

Subjects and diet	**Number of subjects**	**Protein content of rice (% N x 6.25)**	**Daily N intake (mg/kg body wt)**	**Daily N retention (mg/kg body wt)**	**Apparent N digestibility (%)**	**Apparent N retention (%)**	**Lysine content (g/16 g N**
Adults[a] Low-protein	7	7.8	98.1	3.5	76.9	3.6	3.8

High-protein rice	6	14.5	172.7	20.2	78.0	11.7	3.1
Preschool childrenb Low-protein rice/fish	12	7.7	187.1	51.8	72.9	27.7	5.4
High-protein rice/fish	11	11.9	254.2	75.7	76.5	29.8	4.7
Low-protein rice/mung bean	4	7.5	197	42	67.0	21.6	4.9
High-protein rice/mung bean	4	11.4	256	81	75.0	31.6	4.4

[a] **Clark, Howe & Lee, 1971.**

[b] Milled rice/surgeon fish fillet (Acantharus bleaker)). (100:17 by wt), (Roxas, Intengan & Juliano, 1975)- milled rice/dehulled mung bean (Vigna radiata [L.] Wilczek), (100:18.6 by wt), (Roxas, Intengan & Juliano 19;6).

TABLE 34 - Glycaemic index of cooked milled rice and rice products of varying amylose content in normal and non-insulin-dependent diabetes mellitus (NIDDM) subjects (%)

Subjects	**Waxy (0-2%)**	**Gruel, waxy**	**Low amylose (10-20%)**	**Intermediate amylose (20-25%)**	**High amylose (>25%)**	**Noodles, high amylose**	**Parboiled rice, high amylose**
Normal, USA[a]	96ae	-	93[a]	81[b]	60[c]	-	-
Normal,Indonesia[b]	87	96	-	52	53, 70[f]	78, 82	-

Normal & NIDDM, Canada & Philippines[b]	116c	-	-	-	61a,[g] 72ab,[g] 84-91bc[h]	58-66ab	66a[h]
NIDDM Thailand[b]	75a	-	71a	-	-	53-55b	-
Normal & NIDDM,Thailand[c]	(100a)	-	(87a)	-	-	-	-
NIDDM,Taiwan[d]	118a	124a	111a	-	-	110a	-

[a] Glycaemic index (GI) based on insulin response.

[b] GI based on glucose response, with glucose drink as 100%.

[c] The two GI values given are only relative values based on waxy rice as 100%.

[d] GI based on white bread as 100%.

[e] Letters denote Duncan's (1955) multiple range test. Values in the same column followed by the same letter are not significantly different at the 5% level.

[f] Red rice

[g] Intermediate gelatinization temperature.

[h] Low gelatinization temperature.

It has been hypothesized that prolonged consumption of fibre-depleted milled rice is diabetogenic because of its low soluble fibre content (0.1 to 0.8 percent), particularly at minimum temperatures above 15C (Trowel!, 1987). Enzyme-resistant starch is reported to be affected by processing, particularly autoclaving. It acts as soluble dietary fibre in the large intestine and may have a hypocholesterolaemic effect (Englyst, Anderson and Cummings, 1983). However, reported values for enzyme-resistant starch in rice are trace to 0.3 percent (Englyst, Anderson and Cummings, 1983; Holland, Unwin and Buss, 1988). In vitro resistant starch values are 0 percent for raw and cooked waxy rice and less than I percent in raw non-waxy rice

and rice noodles, but 1.5 to 1.6 percent for cooked nonwaxy rice including parboiled rice. The low values may be related to the fact that rice is cooked as whole grains, which could prevent extensive starch association. A raw milled rice of amylose-extender IR36-based mutant rice had 1.8 percent in vitro resistant starch. Because of the importance of parboiled rice in South Asia, researchers at the National Institute of Animal Science, Foulum, Denmark are determining the enzyme-resistant starch of IR rices differing in amylose content using antibiotics to suppress hind-gut fermentation of the resistant starch (Bjrck et al., 1987). Resistant starch was higher in cooked intermediateGT rices than in low-GT rices and was increased by parboiling (B.O. Eggum, unpublished data). In vitro resistant starch obtained from cooked rices using pullulanase and -amylase was characterized to be essentially amylose (90 to 96 percent 13-amylolysis limits) with 55 to 65 glucose units (IRRI, 1991b), as earlier also reported for wheat and maize starch (Russell, Berry and Greenwell, 1989).

Microbial anaerobic fermentation of resistant starch in the large intestine produces lactate, short-chain fatty acids (acetate, propionate and butyrate), carbon dioxide and hydrogen. The fatty acids are absorbed from the intestinal lumen into the colonic epithelial cells and provide about 60 to 70 percent of the energy which would have been available had the carbohydrate been absorbed as glucose in the small intestine (Livesey, 1990). Thus, the complete digestion of cooked waxy and

non-waxy rice starch in infants (De Vizia et al., 1975; MacLean et al., 1978) and of raw starch in growing rats (El-Harith, Dickerson and Walker, 1976; Eggum, Juliano and Manigat, 1982; Pedersen and Eggum, 1983) includes the resistant starch fermented in the large intestine or hind gut. Breath-hydrogen tests in Myanmar village children 1 to 59 months old showed a high prevalence of rice-carbohydrate malabsorption (66.5 percent), (Khin-Maung-U et al., 1990a). About half of the children were in a state of current underfeeding with past malnutrition, but there was no difference between children with or without rice-carbohydrate malabsorption (Khin-Maung-U et al., 1990b). Levitt et al. (1987) reported that rice was nearly completely absorbed by healthy adult patients and caused only a minimal increase in hydrogen excretion as compared to oats, whole wheat, maize, potatoes or baked beans.

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Other properties

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Parboiled rice or rice powder gruel (Molla, Ahmed and Greenough, 1985), rice water (Wong, 1981; Rivera et al., 1983) and extrusion-cooked rice (Tribelhorn et al., 1986) have all been effectively used for the treatment of non-infectious diarrhoea since starch has a lower osmolality than glucose. Even the high concentration of 80 g rice per litre in an oral rehydration solution is drinkable by patients and is highly effective, providing four times more energy than does standard glucose oral rehydration solution (20 percent), (Molla, Ahmed and Greenough, 1985).

Consumption of cereal foods including rice has been correlated with dental caries (Bibby, 1985). Dentists agree that dental decay is the result of tooth demineralization by acids produced on the tooth surface when bacteria from carbohydrates ferment. Boiling, pressure cooking and extrusion cooking increase acid formation by starch in dental plaque. Phytate is an enamel-protective factor, together with amino acids, phosphates and lipids, etc. Refining removes cariespreventing factors from the rice foods and increases these foods' cariogenicity. The inclusion of rice bran or of a hot water extract of rice bran in human diets has a preventive action against caries (Ventura, 1977).

There is a popular belief that some rice varieties have medicinal properties, such as the Myanmar variety Na ma the lay. In China black rice is believed to have a body-strengthening fraction and pharmaceutical value. Thus it is known as "blood strengthening rice", "drug rice" or "(con)tributed rice" (Li and Lai, 1989). Blackrice, which has a pigment level of 1 ma per 100 g rice, has 3 mg vitamin C and 0.2 mg riboflavin per 100 g and has more iron, calcium and phosphorus than non-pigmented rice. In Kerala, India, the variety Navara is believed to have medicinal properties and is used to rejuvenate the nerves in paralytic conditions: oridine, an alkaloid present in rice, has some antineurotic properties when impure (Chopra, 1933).

The anthocyanin pigments of red rice, "tapol", extracted with 95 percent ethanol containing 0.1 percent hydrochloric acid, are 70 percent cyanidin-3-glucoside (chrysanthemin),12 percent peonidin-3-glucoside (oxycoccicy-anin) and two other anthocyanin pigments (Takahashi et al., 1989). Pigmented brown rices were shown to have higher riboflavin but similar thiamine contents to non-pigmented IR rices (Villareal and Juliano, 1989a). The total carbohydrates and starch contents of milled red rices were reported to be lower than those of unpigmented milled rice in India (Srinivasa Rao, 1976), probably because of the higher protein content and residual phenolics with 7 percent milling in India. As brown rice, purple Perurutong had a

lower NPU in growing rats (59.1 percent) than red rice (66.6 percent) and non-pigmented brown rice (66.7 to 70.6 percent) because of the extremely reduced true digestibility of its protein (72.4 percent) due to its high levels of phenolics (anthocyanin), (0.62 percent versus 0.01 to 0.25 percent), (Eggum, Alabata and Juliano, 1981). These differences are removed upon milling, which removes most of the pigments.

Varietal differences were found in cadmium (Cd) levels of brown rice grown in Tsukuba, Japan (seedlings transplanted in June 1983 and June 1985); five semidwarf indica rices had 24 to 74 ppb Cd, as compared to 2 to 27 ppb Cd for japonica varieties and 4 to 56 ppb Cd for non-dwarf indica varieties (Morishita et al.,1987). The mean Cd content in rice from various countries ranged from 5 to 99 ppb on a wet basis, with the highest Cd content occurring in Hokuriku, Japan; daily Cd intake from rice ranged from I to 36 g and was also highest in Hokuriku, but the same value (36) was also observed in Celibes, Indonesia, where the Cd content in rice was lower but rice intake was higher (Rival, Koyama and Suzuki, l 990). A high cadmium content in rice was one of the major causes of an epidemic of "itai-itai" disease in Japan (Kitagishi and Yamane, 1981).

Analyses from 1979 to 1982 showed selenium (Se) deficiencies in feedstuffs in 70

percent of Chinese counties, where 80 percent of the feeds and forages analysed had less than 0.50 ppm Se (Liu, Lu and Su, 1985). The Se content of brown rice and of milled rice grown in Japan was reported to be 30 to 40 mg/g (Node, Hirai and Dambara, 1987). Distribution of Se is 13 percent in the hull, 15 percent in bran and 72 percent in milled rice (Ferretti and Levander, 1974).

The silicon (Si) content of six milled American rices was reported to be 0.046 0.030 percent (Kennedy and Schelstraete, 1975); the silicon was located mainly in the outer layer of milled rice. Energy-dispersive X-ray fluorescence spectrometry of seven IR rices indicated a mean Si content (wet basis) of 0.041 0.016 percent for brown rice and 0.015 0.009 percent for milled rice (Villareal, Maranville and Juliano, 1991). Colorimetric Si assay using phosphomolybdate showed that in a 7 percent protein IR32 milled rice, the Si content was 0.035 percent in the subaleurone layer (outer 9 percent), 0.014 percent in the middle endosperm (next 11 percent) and 0.009 percent in the inner endosperm (80 percent), (Juliano, 1985b), equivalent to 0.010 percent Si in the entire grain.

Hypocholesterolaemic effect of rice bran

In hamsters, addition to the diet of 10 percent dietary fibre from stabilized rice bran, defatted, stabilized rice bran end oat bran significantly reduced the animals' plasma cholesterol compared to the control (Kahlon et al., 1990). In repeat experiments, only undefatted bran and oat bran lowered the cholesterol level (Haumann, 1989). Heat-stabilized rice bran providing 7 percent dietary fibre lowered the level of liver free cholesterol and surpassed wheat bran, when combined with 5 percent fish oil, in lowering plasma and hepatic triglycerides and hepatic lipogenesis (Topping et al., 1990). Recent confirmatory human studies demonstrated the hypocholesterolaemic effect of fullfat rice bran (Gerhardt and Gallo, 1989; Nicolosi, 1990; Saunders, 1990), but limited feeding trials did not confirm the hypocholesterolaemic activity of rice bran in Japanese (brown versus milled rice), (Miyoshi et al., 1987a, 1987b) or Filipino adults (Dens et al., 1987).

The hypocholesterolaemic effect of oat bran is due to its high content of soluble hemicelluloses. By contrast, the hypocholesterolaemic activity of ricebran oil in humans and rats (Raghuram, Brahmaji Rao and Rukmini, 1989) is due to the unsaponifiable matter fraction (Suzuki et al., 1962; Sharma and Rukmini, 1986, 1987). Rice-bran oil lowered human blood cholesterol more effectively than did sunflower, corn and safflower oils (Suzuki et al., 1962). A polysaccharide fraction in bran has also been reported to have a hypocholesterolaemic effect in rats

(Vijayagopal and Kurup, 1972). The hypocholesterolaemic effect of rice-bran hemicellulose (defatted rice bran), (Ayano et al., 1980) was due to the reduction of dietary cholesterol absorption from the small intestine of rats (Age, Ohta and Ayano, 1989).

Antinutrition factors

Antinutrition factors in the rice grain are concentrated in the bran fraction (embryo and aleurone layer). They include phytin (phytate), trypsin inhibitor, oryzacystatin and haemagglutinin-lectin. All except oryzacystatin have been previously reviewed (Juliano, 1985b).

All the antinutrition factors are proteins and all except phytin (phytate) are subject to heat denaturation. Phytin is located in 1 - to 3-m globoids in the aleurone and embryo protein bodies as the potassium magnesium salt. Its phosphate groups can readily complex with cations such as calcium, zinc and iron and with protein. It is heat stable and is responsible for the observed poorer mineral balance of subjects fed brown rice diets in comparison to that of subjects fed milled rice diets (Miyoshi et al., 1987a, 1987b).

Trypsin inhibitor has also been isolated from rice bran and characterized (Juliano, 1985b). The partially purified inhibitor is stable at acidic and neutral pH and retained more than 50 percent of its activity after 30 minutes of incubation at 90C at pH 2 and 7. Steaming rice bran for 6 minutes at 100C inactivates the trypsin inhibitor, but dry heating at 100C for up to 30 minutes is not as effective. The inhibitor distribution is 85 to 95 percent in the embryo, 5 to 10 percent in germ-free bran and none in milled rice.

Haemagglutinins (lectins) are globulins that agglutinate mammalian red blood cells and precipitate glycoconjugates or polysaccharides. The toxicity of lectins stems from their ability to bind specific carbohydrate receptor sites on the intestinal mucosal cells and to interfere with the absorption of nutrients across the intestinal wall. Rice-bran lectin binds specifically to 2-acetamido-2-deoxy-Dglucose (Poole, 1989). It is stable for 2 hours at 75C but sharply loses activity after 30 minutes at 80C or 2 minutes at 100C (Ory, Bog-Hansen and Mod, 1981). Rice lectin agglutinates human A, B and O group erythrocytes. It is located in the embryo but has receptors in both rice embryo and endosperm (Miao and Tang, 1986).

Oryzacystatin is a proteinaceous (globulin) cysteine proteinase inhibitor (cystatin) from rice seed and is probably the first well-defined cystatin superfamily member of

plant origin (Kondo, Abe and Arai, 1989). Incubation at pH 7 for 30 minutes at 100C had no effect on its activity but inhibition decreased IS percent at 110C and 45 percent at 120C. Oryzacystatin effectively inhibited cysteine proteinases such as papain, ficin, chymopapain and cathepsin C and had no effect on serine proteinases (trypsin, chymotrypsin and subtilisin) or carboxyl proteinase (pepsin).

An allergenic protein in rice grain, causing rice-associated atopic dermatitis in Japan, is an a-globulin and shows stable immunoreactivity (60 percent) even on heating for 60 minutes at 100C (Matsuda et al., 1988). It is present mainly in milled rice rather than in the bran. Hypoallergenic rice grains may be prepared by incubating milled rice in actinase to hydrolyse globulins in the presence of a surfactant at an alkaline pH (Watanabe et al., 1990a) and washing. The color of the processed grain is improved by treatment with 0.5-N hydrochloric acid and washing with water (Watanabe et al., 1990b).

Protein requirements of preschool children and adults on rice diets

The daily safe-level-of-protein requirements of preschool Filipino children consuming rice-based diets (as measured by the multilevel N balance or slope ratio

method, two-thirds of nitrogen from rice) is lower for rice/milk (1.11 g/kg body wt) and rice/fish (1.18 g/kg) diets than for rice/mung bean (1.34 to 1.56 g/kg) and rice (1.44 g/kg) diets (Intengan et al., 1984; Cabrera-Santiago et al., 1986). True digestibilities were 70 to 78 percent. Amino acid scores of these Filipino weaning diets based on 5.8 percent lysine as 100 percent were 100 percent for rice/fish, 93 percent for rice/milk, 90 percent for rice/whole mung bean, 81 percent for rice/dehulled toasted mung bean and 60 percent for IR58 rice. The protein quality of the IR58 high-protein rice, as determined by the very short-term N balance index for three children, was 79 to 80 percent that of milk (CabreraSantiago et al., 1986). On the basis of the safe-level-of-protein requirements for milk of 0.89 g/kg body weight (Huang, Lin and Hsu, 1980), IR58 rice had 62 percent the protein quality of milk. Toasting and dehulling of mung bean prior to boiling did not significantly improve the rice/mung bean diet because of amino acid decomposition during toasting (Eggum et al., 1984). The true digestibility of rice/mung bean (2:1 by weight) diets in Thai children was 72.7 + 6.1 percent for whole mung bean and 74.6 + 5.9 percent for dehulled mung bean (Hussein, Tontisirin and Chaowanakarnkit, 1983).

Long-term studies in preschool children, testing protein intakes derived from short-term studies, were undertaken on two rice/fish weaning diets at 1.7 g/kg/day (Tontisirin, Ajmanwra and Valyasevi, 1984; Cabrera et al., 1987). The results tend to

indicate that at the protein level of 1.7 g/kg/day, the currently recommended energy intake of 100 kcal/kg/day is inadequate for growth, but further investigations using more subjects are necessary. The calculated safe level of protein intake for a 6- to 9-month-old child is 1.75 g/kg/day in developing countries, where children are exposed to infections and perhaps periodic shortages of food (WHO, 1985).

The daily safe-level-of-protein requirements for rice-based Chinese (Chen et al., 1984; Huang and Lin, 1982) and Filipino (Intengan et al., 1976) adult diets ranged from 1.14 to 1.18 g/kg body weight. By contrast, the safe-level-of-protein requirements for egg protein in adults were 0.89 g/kg/day (Huang and Lin, 1982) and 0.99 g/kg/day (Tontisirin, Sirichakawal and Valyasevi, 1981). The aggregated value for highly digestible, good-quality protein in healthy young men is 0.63 g/kg/day (WHO, 1985). On this basis, the rice diets provided 68 to 98 percent of the protein quality of the reference proteins. The relative NPU of rice protein in Japanese adults has been estimated by the slope ratio method as 65 percent that of egg protein (Inoue et al., 1981), while NPUs of 56 percent for an egg diet and 43 percent for a Chinese rice diet have been reported (Huang and Lin, 1982).

Long-term studies (50 to 90 days) in adults, testing protein intakes derived from

short-term studies, showed that protein intakes of 0.94 to 1.23 g/kg/ day, at energy intakes of 37 to 63 kcal/kg/day, were adequate for Chilean, Chinese, Filipino, Korean and Thai subjects (Intengan et al., 1982; Rand, Uauy and Scrimshaw, 1984). The amino acid score for the Filipino rice diet was 100 percent (Intengan et al., 1982) based on the WHO/FAO/UNU (WHO, 1985) amino acid scoring pattern for preschool children. Rice diets were calculated to be sufficient in lysine (Autret et al., 1968). The calculated true digestibility of protein ranged from 80 to 87 percent for the rice diets. Based on 0.75 g of good-quality protein as the safe-level-of-protein requirement (WHO, 1985), the rice diets tested had 61 to 80 percent of the quality of the reference animal proteins. Digestibility appears to be the most important factor determining the capacity of the protein sources in a usual mixed diet to meet the protein needs of adults (WHO, 1985). Thus, because of the relatively high level of sulphur amino acids and 3.5 to 4.0 percent lysine in rice protein, milled rice complements lysine-rich sulphur amino acid deficient legume proteins in human diets, the combination having a higher amino acid score than either rice or legume alone.

Protein, energy and mineral utilization of brown and milled rices and rice diets

FAD/WHO and the United Nations University have reviewed the research findings on energy and protein requirements using typical diets in developing countries (Town, Young and Rand, 1981; Rand, Uauy and Scrimshaw, 1984).

Compared with milled rice, brown rice has a higher content of protein, minerals and vitamins and a higher lysine content in its protein (Resurreccin, Juliano and Tanaka, 1979; Eggum, Juliano and Maningat, 1982), (Table 35); however, it also has a higher level of phytin, neutral detergent fibre and antinutrition factors (trypsin inhibitor, oryzacystatin, haemagglutinin) in the bran fraction. Nitrogen balance studies in rats showed a slightly lower true digestibility for the protein in brown rice, but similar biological value and NPU for both brown and milled rices (Eggum, Juliano and Manigat, 1982), (Table 36). IR480-5-9 brown rice (10.9 percent protein) had a true digestibility of 90.8 percent, biological value of 70.8 percent and NPU of 64.2 percent (Eggum and Juliano, 1973). Digestible energy is lower in brown rice than in milled rice. Fat digestibility was 95.8 0.5 percent for milled rice and 95.0 0.4 percent for brown rice (Miyoshi, Okuda and Koishi, 1988). Protein digestibility was 95.3 0.7 percent for milled rice and 94.1 0.5 percent for brown rice.

TABLE 35 - Composition and nutritional value of milling fractions of IR32 brown rice at 14% moisture

Rice fraction	**Crude protein (%Nx6.25)**	**Neutral detergent fibre (%)**	**Crude fat (%)**	**Crude ash (%)**	**Total P (%)**	**Energy value (kJ/g)**	**Lysine (g/16 g N)**	**Amino acid score (%)**
Brown rice	8.5	2.5	2.3	0.8	0.14	15.9	3.8	66
Undermilled rice	8.3	1.8	1.5	0.6	0.14	15.7	3.6	62
Milled rice	8.1	0.8	0.7	0.4	0 08	15.5	3.6	62
LSD	0.3	0.3	0.4	0.4	0.06	ns	0.1	

Source: Eggum, Juliano and Manigat, 1982.

Balance studies in rats showed digestible energy of 80.1 percent for Italian rough rice and 67.4 percent for its bran; for rough rice, N digestibility was 87.8 percent, biological value 72.6 percent and NPU 63.7 percent (Pedersen and Eggum, 1983). For

IR32 rice bran (5.8 percent lysine digestible energy was 67.4 percent, N digestibility 78.8 percent, biological value 86.6 percent and NPU 68.3 percent (Eggum, Juliano and Manigat, 1982). Corresponding values for rice polish (5.0 percent lysine) were 73.3 percent digestible energy, 82.5 percent apparent N digestibility, 86.3 percent biological value and 71.2 percent NPU. IR32 bran polish with 13.2 percent protein (4.4 g lysine per 16 g N) and 15.4 percent fat, fed to growing rats, had 79.1 percent digestible energy, 85.9 percent true N digestibility, 81.1 percent biological value and 69.7 percent NPU (Eggum, et al., 1984). Even with a mineral mixture in their diets, rats fed rough, brown and undermilled rices were unable to maintain their femur zinc concentration; deposition of calcium and phosphorus also appeared to be affected (Pedersen and Eggum, 1983).

TABLE 36 - Balance data for milling fractions of IR32 brown rice in five growing rats[a]

Rice fraction	Digestible energy (% of total)	True digestibility (% of N intake)	Biological value (% of digested N)	Net protein utilization (% of N intake)

Brown rice	94.3b	96.9b	68.9ab	66.7a
Undermilled rice	95.5ab	97.3ab	69.7a	67.8a
Milled rice	96.6a	98.4a	67.5b	66.4a

[a] Means in the same column followed by a common letter are not significantly different at the 5% level by Duncan's (1955) multiple range test.

Source: Eggum, Juliano and Manigat, 1982.

Similar N balance studies for brown and milled rices were made with preschool children fed rice/casein or rice/milk (2:1 N ratio) diets (Santiago et al., 1984), (Table 37). Energy absorption was better for milled rice than for brown and undermilled rice. Because of their similar N balance, the major nutritional advantage of brown rice over milled rice is its high level of B vitamins. Roxas, Loyola and Reyes (1978) reported that the true digestibility of a rice/milk diet (1:1 N source) in preschool children improved with milling: brown rice/milk, 78 5 percent; undermilled rice/ milk, 85 5 percent; regular milled rice/milk, 87 4 percent; overmilled rice/milk, 88 4

percent. The brown rice diet was significantly lower in protein digestibility than the other diets.

Digestibility and balance studies in Japanese adults on brown rice and milled rice diets at low (0.5 g/kg) and standard (1.2 g/kg) protein intakes showed a higher energy, protein and fat digestibility for milled rice (Miyoshi et al., 1986), (Table 38). Neutral detergent fibre intake was at least twice as high in the brown rice diet. These results are consistent with the data from studies on children and on rats. Studies on the same subjects showed lower apparent absorption rates for sodium, potassium and phosphorus and a lower phosphorus balance for the brown rice diet at the low protein intake (Miyoshi et al., 1987b) when mineral intake was adjusted to be similar for the two diets by adding a mineral mixture. At the standard protein intake, even with higher potassium, phosphorus, calcium and magnesium levels in the brown rice diet, absorption rates of potassium and phosphorus were still significantly lower for the brown rice diet (Miyoshi et al., 1987a). The contributing factor must be the high phytate level in the bran fraction (aleurone and germ) of brown rice. The results confirmed earlier balance studies comparing brown and milled rices (FAO, 1954).

TABLE 37 - Balance data for milling tractions of IR32 brown rice in five preschool

children (% of intake) [a,b]

Rice fraction	Apparent N absorbed	Apparent N retained	Apparent energy absorbed	Apparent fat absorbed
Brown rice	63a	28a	90b	93b
Underrnilled rice,	613a	26a	90b	96ab
Milled rice	62a	27a	93a	98a

[a] Means in the same column followed by a common letter are not significantly different at the 5% level by Duncan's (1955) multiple range test.

[b] Intake of 200 g N/kg body weight daily. First rice-casein diet (2:1 N ratio) had 77%b mean N absorbed, 33%a N absorbed, 91%ab energy absorbed and 94%b fat absorbed

Source: Santiago et al., 1984.

TABLE 38 - Digestibility and nitrogen balance data for five men on brown rice and milled rice diets at low and standard protein intake (mean SE)

Diet	Neutral detergent fibre intake (g/day)		Apparent energy digesti-bility (%)	Apparent protein digesti-bility (%)	True protein digesti-bility (%)	Apparent fat digesti-bility (%)	Nitrogen balance (g/day)	Tran time (hou
	Total	From rice						
Low protein/brown rice	13.9	13.9	89.80.9b	48.43.8c	63.83.6a	76.63.7b	-1.090.33c	24.0
Low protein/milled	5.7	5.7	96.00.3a	68.03.5b	83.23.5ab	94.90.4a	-0.710.29bc	36.2

rice								
Standard protein/brown rice	31.4	23.2	89.31.2b	72.72.1b	80.22.1b	74.11.7b	-0.02 0.27a	27.1
Standard protein/milled rice	15.4	7.2	94.40.5a	79.61.3a	86.61.4a	94.7 0.7a	- 0.380.19ab	28.1

[a] Low protein intake, 0.5 g/kg body wt; standard protein intake, 1.2 g/kg body wt.

[b] Means in the same column followed by the same letter are not significantly different at the 5% level by Duncan's (1955) multiple range test.

Sources: Miyoshi et al., 1986, 1987a, 1987b.

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Chapter 5 Rice post-harvest processing, parboiling and home preparation

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Considerable variation in moisture content exists among grains in the same panicle, since panicles flower and develop from top to bottom. Grain weights tend to be lower and protein content tends to be higher in the bottom branches of a panicle. Optimum moisture content for harvesting varies with the season but is usually reached about a month after flowering. Uniformity of flowering among panicles affects the percentage of immatures in the harvest crop; photosensitive rices have more synchronous flowering than non-sensitive varieties. Immature grains reduce the head rice yield and are completely chalky.

Rice is still most frequently harvested by cutting the panicle with enough stem to allow threshing by hand. The panicles are sun-dried on the bund prior to threshing by hand, treading by people or animals or processing by mechanical threshers. When threshing is delayed while the cut crop is stored in heaps, "stack burning" often results as a consequence of the anaerobic respiration of microorganisms on

the straw (70 to 80 percent moisture) and grain. Yellow or tan grains are formed when the panicle temperature reaches 60C for a few days (Yap, Perez and Juliano, 1990). The discoloured grains have a better head rice yield and are more translucent than control grains. The mechanism seems to be non-enzymic browning (Reilly, 1990), which results in decreases in the lysine content of the protein (about 0.5 percent) and in the true digestibility to 92 percent and NPU to 61 percent (Eggum et al., 1984).

Delayed harvest in rainy weather frequently leads to grain sprouting on the panicle, particularly for non-dormant japonica rices. Lodging may also cause sprouting in the panicle for non-dormant rices. The incidence of the heavy rains (cyclones) during the harvesting season in India correlates with aflatoxin contamination of the rice crop (Tulpule, Nagarajan and Bhat, 1982; Vasanthi and Bhat, 1990). Aflatoxin is also a problem in the preparation of pinipig, a rice product from the Philippines wherein freshly harvested waxy grains are directly steeped, without drying, prior to roasting and flaking (Food and Nutrition Research Institute, 1987).

Rough rice drying has been reviewed by Kunze and Calderwood (1985) and Mossman (1986). Solar radiation is usually used, particularly in the dry season. Drying capacity is limited in the wet season, when more rice is grown because of

water availability. Flash dryers are ideal for the first drying of harvested rough rice, to decrease the moisture content to 18 to 20 percent, but no mechanical dryer has been adopted widely by Asian farmers (Habito, 1987; de Padua, 1988). Grain cracking is minimal above 18 percent moisture (Srinivas and Bhashyam, 1985; IRRI, 1991b). The initial drying will allow safe storage of the grain for up to four to five weeks before final drying. Deformation of the spherosome particles of the aleurone layer is observed during 6 to 12 months storage in grains dried with hot air at 50C, accompanied by a decrease in triglycerides and phospholipids (Ohta et al., 1990).

Cracking occurs not during drying as sun-cracking denotes, but when the overdried grain absorbs moisture on cooling (Kunze, 1985).

Storage

Storage changes, or ageing, occur particularly during the first three to four months after harvest and are also known as "after-harvest ripening" (Juliano, 1985b). The grain constituents probably equilibrate to their more stable physical form, which results in a harder, creamier-coloured grain (Yap, Perez and Juliano, 1990). After-harvest ripening is accompanied by a higher yield of total and head milled rice.

Stored rice expands more in volume and yields a more flaky cooked rice with less dissolved solids in the cooking water than freshly harvested rice. In tropical Asia, aged rice is preferred and is more expensive than freshly harvested rice (Juliano, 1985b).

The exact mechanism of storage changes is not fully understood, but such changes occur in all starchy foods. In rice they occur mainly above 15C (Juliano, 1985b). In regions where the sticky japonica rices are preferred, such as Japan and Korea, ageing in the spring and summer reduces grain quality.

The rice grain is very hygroscopic because of its starch content and equilibrates with the ambient relative humidity. The safe storage moisture content is generally considered to be 14 percent in the tropics. Storage pests (insects and micro-organisms) and rodents cause losses in both quantity and quality of the grains (Cogburn, 1985). Gross composition is not affected by storage, but vitamin content decreases progressively (Juliano, 1985b).

Rice is stored as rough rice in most of the tropics but as brown rice in Japan. Dehulling with rubber rollers minimizes bruising of the brown rice surface and improves the shelf-life of the dehulled grain. Brown rice, however, is more sensitive

to environmental stress in the absence of the insulating enclosing hull and readily fissures in transit.

Parboiling

The traditional parboiling process involves soaking rough rice overnight or longer in water at ambient temperature, followed by boiling or steaming the steeped rice at 100C to gelatinize the starch, while the grain expands until the hull's lemma and palea start to separate (Gariboldi, 1984; Bhattacharya, 1985; Pillaiyar, 1988). The parboiled rice is then cooled and sun-dried before storage or milling.

Modern methods involve the use of a hot-water soak at 60C (below the starch gelatinization temperature) for a few hours to reduce the incidence of aflatoxin contamination during the soaking step. Leaching of nutrients during soaking aggravates the contamination, with the practice of recycling the soak water. Soaking sound, rough rice in water inoculated with Aspergillus parasiticus did not result in aflatoxin contamination of parboiled rice (Yap et al., 1987), suggesting that contamination probably has to be present in the grain prior to soaking (Bandara, 1985).

Vacuum infiltration to de-aerate the grain prior to pressure soaking is applied to obtain a good-quality product, as is pressure parboiling. The parboiled product has a cream to yellow colour depending on the intensity of heat treatment. Aged rice may give a grayish parboiled rice, probably because it has a lower pH owing to the presence of free fatty acids.

Parboiling gelatinizes the starch granules and hardens the endosperm, making it translucent. Chalky grains and those with chalky back, belly or core become completely translucent on parboiling; a white core or centre indicates incomplete parboiling of the grain.

Heated-sand drying results in parboiling of the higher-moisture wetseason crop but not of the dry-season crop. Parboiling results in inward diffusion of water-soluble vitamins, in addition to partial degradation of thiamine during heat treatment, except in heated-sand drying (Padua and Juliano, 1974), (Table 39). Riboflavin content is not decreased by parboiling (Grewal and Sangha, 1990). Despite the degradation of thiamine, parboiled milled rice had a higher vitamin content than raw milled rices in all parboiling procedures tested (Padua and Juliano, 1974).

TABLE 39 - Effect of parboiling method on thiamine content and protein

Treatment	**Number of Samples**	**Degree of milling (%)**		**Thiamine (g/g)**				**Protein (%)**	
		Raw	**Treated**	**Raw brown**	**Treated brown**	**Raw milled**	**Treated milled**	**Raw milled**	**Treate milled**
Modified traditional(hot soak)	2	11.0	10.6	3.2	2.5	0.4	1.9	8.3	7.3
Lab. Method(hot soak) 121C 10 min	2	11.6	12.0	3.8	3.2	0.6	2.9	9.0	8.6
US commercial parboiling	3	12.2	12.6	3.9	2.8	0.5	2.1	6.6	6.2
Heated-sand drying	2	10.5	10.2	3.7	3.6	0.6	1.8	8.2	7.8

LSD (%)		0.8			0.3		0.5		0.9

Source: Padua & Juliano, 1974.

Earlier results demonstrated that the water-soluble B vitamins, thiamine, riboflavin and niacin, are higher in milled parboiled rice than in milled raw rice (Kik and Williams, 1945). Oil and protein are reported to diffuse outward during parboiling, based on microscopic observations; they cannot diffuse as readily through cell walls as water-soluble vitamins, but the spherosome structure is destroyed. At similar degrees of milling, parboiled milled rice has lower protein content than raw milled rice (Table 39), but parboiled rice bran has more protein and oil than raw rice bran (Padua and Juliano, 1974). The composition of the milling fractions can be explained by a lower endosperm contamination of the bran in parboiled rice.

Parboiling results in some yellowing of the grain depending on the severity of the heat treatment. In addition, black spots diffuse to form dark brown to black regions or pecks, wherein at least 25 percent of the grain surface is coloured. Although parboiled grains are harder than raw rice, they are also susceptible to fissuring during drying, particularly below 18 percent moisture when free water becomes scarce in the grain.

TABLE 40 - Nutritional properties of two milled rices, raw and parboiled.

Rice type	Crude protein (%NX6.25)	Lysine (g/16 8 N)	Balance data in five growing rats			
			True digestibility (% of N intake)	Biological value (% of digested N)	Net protein utilization (% of N intake)	Digestible Energy (% intake)
IR480-5-9[b] Raw	11.2	3.4	100.4	66.8	67.1	97.0

Parboiled 10 min	10.4	3.6	94.7	70.4	66.7	
IR8 [c] Rawd	7.7	3.6	96.2	73.1	70.3	96.6
Parboiled 20 min	7.2	3.7	89.7	78.1	70.0	95.2
Parboiled 60 min	7.4	3.5	88.6	79.5	70.4	94.7
LSD (5%)[b]	0.2	0.2	0.9	1.1	1.4	0.5

[a] **Parboiling done at 121C, properties at 14% moisture content,**

[b] **Eggum, Resumcci6n & Juliano, 1977.**

[c] **Eggum et al., 1984.**

[d] **Eggum & Juliano, 1973; Eggum, Alabata & Juliano, 1981.**

Freshly parboiled rice may be milled directly with little breakage since the grains are pliable at high moisture content. Because of the damage to the spherosome structure, the bran of parboiled rice tends to agglomerate during milling and clog the sieves. In addition, greater milling pressure is required for parboiled rice because of the hardened endosperm.

Although parboiled rice is claimed to have a better shelf-life than raw rice because of the gelatinized starchy endosperm, its slightly open hull also makes it more exposed to insect attack. In addition, Asian parboiled rice is known to have aflatoxin contamination which is rarely found in raw rice (Tulpule, Nagarajan and Bhat, 1982; Vasanthi and Bhat, 1990). However, most of the aflatoxin is removed by processing.

The pressure parboiling process decreases the true digestibility of rice protein in growing rats (Eggum, Resurreccin and Juliano, 1977; Eggum et al., 1984), (Table 40). However, there is a compensatory increase in biological value such that net protein utilization is comparable in raw and parboiled milled rice. Prolonging the pressure parboiling from 20 to 60 minutes did not further reduce the protein digestibility of IR8 rice.

Parboiling also removes cooked rice volatiles including free fatty acids, inactivates enzymes such as lipase and lipoxygenase, kills the embryo and decomposes some antioxidants (Sowbhagya and Bhattacharya, 1976). Hence, cooked parboiled rice lacks the volatiles characteristic of freshly cooked raw rice hydrogen sulphide, acetaldehyde and ammonia (Obata and Tanaka, 1965). The volatiles identified were mainly aldehydes and ketones (Tsugita, 1986).

Parboiled rice takes longer to cook than raw rice and may be presoaked in water to reduce the cooking time to be comparable to that of raw rice. The cooked grains are less sticky, do not clump end are resistant to disintegration; the grains are also harder. They also tend to expand more in girth rather than in length as compared to raw rice.

Most of the varieties parboiled in Bangladesh, Sri Lanka, India and Pakistan are the high-amylose rices that are common in these regions. In Thailand, both intermediate- and high-amylose rices are parboiled for export. Mainly long-grain, intermediate-amylose rice is parboiled in the United States, and intermediate- to low-amylose coarse japonica rices are parboiled in Italy.

Roasting of steeped rice grain at 250C for 40 to 60 seconds also results in parboiling,

but the product has a softer texture because the starch is immediately dried without permitting recrystallization or retrogradation of the starch gel, mainly the amylose fraction. The roasted grain is flattened or flaked with a wooden mortar and pestle, a roller flaker or an edge runner (Shankara et al., 1984) and then winnowed to remove hull and germ.

Processing

Dehulling of rough rice to brown rice can be carried out either manually (hand pounding) or mechanically. Mechanical hullers are of three main types: Engelberg mills, stone dehullers and rubber dehullers. Stone dehullers are still common in tropical Asia, where the surface-bruised brown rice is immediately milled with either an abrasive or friction mill. Rubber rollers are common in Japan, where brown rice is stored instead of rough rice, with a resultant space saving.

High humidity in the atmosphere during milling improves the yield of head rice. Increasing the moisture content of the grain to 14 to 16 percent by steam vapour prior to milling also improves the head rice yield and its taste (Furugori, 1985), since 14 to 16 percent is the critical moisture content range for crack susceptibility for

most rice varieties (Srinivas and Bhashyam, 1985). Susceptible varieties readily crack below 16 percent moisture when exposed to higher humidity, but resistant varieties become susceptible at 14 percent moisture. Thus breakage is minimized for all varieties by tempering the grain to 16 percent moisture before milling. However, the milled rice may have to be redried to 14 percent for safe storage.

Rice mills in Asia range from a single-pass Engelberg mill to multipass systems. Manual technology involving hand pounding results in undermilled rice, which is richer in B vitamins than machine-milled rice because of incomplete removal of the bran layers. In the Engelberg or huller-type mill, dehulling and milling are performed in one step with greater grain breakage. The by-product is a coarse flour mixture of hull and bran. Using a dehuller before milling improves both the head and total milled rice yields. Slender grains require less pressure to mill than bold (i.e. thick) grains because of their thinner aleurone layer, but they are more prone to breakage during milling. In modern mills the milling operation involves several steps and bran and polish fractions are collected separately. Milling of 10 percent bran polish from brown rice by abrasive and friction mills removes all of the pericarp, seed-coat and nucellus and virtually all of the aleurone layer and embryo (Figure 2), but removes very little of the non-aleurone endosperm, except from the lateral ridges (Ellis, Villareal and Juliano, 1986).

The abrasive mill can overmill readily, as in obtaining white core rices with low protein and fat content for sake (Japanese rice wine) brewing.

The presence of chalky regions in the endosperm (white belly or white core) contributes to grain breakage during milling. Presumably a heterogeneous endosperm is more susceptible to cracking since a chalky mutant (Srinivas and Bhashyam, 1985) and waxy rice with a uniformly chalky endosperm (Khush and Juliano, 1985) give good milled head rice yield.

The term "polished rice" refers to milled rice that has gone through polishers that remove loose bran adhering to the surface of milled rice and improve its translucency. The polisher has a horizontal or vertical cylinder or cone, covered with leather strips, that gently removes loose bran as it is rotated in a working chamber made of a wire-mesh screen or a steel screen with slotted perforations.

Some rice consumers prefer a very glossy or shiny rice called coated or glazed rice. This rice is prepared by adding dry talc and a glucose solution to well-milled rice in a tumbler. The rotation of the tumbler distributes the mixture over the grain. The talc used to coat rice in Hawaii does not cause a higher incidence of stomach cancer as it is claimed to do in Japan, where talc-coating is banned (Stemmermann and Kolonel,

1978).

Innovations introduced in the Japanese rice industry include microcomputer control of milling based on the desired degree of milling or whiteness of the milled rice (Furugori, 1985; van Ruiten, 1985). Electronic colour sorting is commonly used to remove discoloured pecky grains. High-degree refining of milled rice, introduced in 1977, includes spraying a mist of moisture through the hollow shaft with the high-pressure air during milling, in combination with a uniquely designed metallic roll-type refining machine. Water is evaporated during milling and keeps the grain temperature lower than in regular milling. A germ rice milling machine introduced in 1976 that uses gentle, abrasive roll milling under very low pressure leaves the germ intact for more than 80 percent of the grains. Germ rice is well received by Japanese consumers because it is rich in thiamine, riboflavin, tocopherol, calcium and linoleic acid. Small coin-operated mills are becoming quite popular in Japan to handle the daily requirements of a family and thus minimize fat rancidity during storage.

Aflatoxin is produced mainly in the bran polish fraction of brown rice (flag and Juliano, 1982). Dehulling removes 50 to 70 percent of the aflatoxin of raw rice, and milling further reduces the toxin content to 20 to 35 percent (Vasanthi and Bhat, 1990). Parboiling reduces the toxin content in already infested rice by 33 to 61

percent; dehulling reduces toxins in parboiled rice further to 19 to 31 percent and milling to 7 to 28 percent. However, parboiled rice is a better substrate for aflatoxin production than raw rice, probably because parboiling makes the fat in rice more available for metabolism by Aspergillus parasiticus (Breckenridge end Arseculeratne, 1986).

Shelf-life is usually shortest for milled rice, followed by brown rice and then rough rice, because of fat rancidity. Fat in the surface cells of milled rice undergoes fat hydrolysis by lipase followed by lipoxygenase oxidation of the liberated free unsaturated fatty acids. With brown rice, the dehuller used is the critical factor; a rubber dehuller is preferred over a stone dehuller, to reduce surface bruises on the grain that trigger lipase action on lipids.

Post-harvest losses

Rice losses occur at all stages of the post-harvest chain. Though quantitative losses are usually simple to assess, qualitative ones are more difficult to define and rely more on subjective judgements and cultural perceptions. Accepted figures for quantitative post-harvest losses in rice range from 10 to almost 40 percent, with the

following breakdown:

- **harvesting, I to 3 percent,**
- **handling, 2 to 7 percent,**
- **threshing, 2 to 6 percent,**
- **drying, I to 5 percent,**
- **storage, 2 to 6 percent,**
- **milling, 2 to 10 percent.**

These figures, initially collected in Southeast Asia (de Padua, 1979), were later confirmed for other parts of Asia and Africa by field activities of FAO's Prevention of Food Losses (PFL) programme, among others. They have become the standard values for rice losses.

The timing of the rice harvest influences the level of losses. Depending on the variety, delay in harvesting a mature rice crop leads to lower yields because of lodging and shattering and the exposure of the ripe grain in the field to insects, birds and rodents. It also leads to post-harvest losses by lowering milling yields and recovery of head grains.

Traditional threshing techniques are a frequent cause of loss. These include beating the straws against slats through which the grain falls into tubs or buckets, trampling with feet and occasionally using a tractor or tractordrawn roller. Quality is affected since grains might break or stones and soil become mixed with the threshed rice.

Often a considerable amount of grain is scattered around and gets eaten by poultry and household pets. However, while this quantity can be considered lost for human consumption, it becomes productive within the total household economy.

Threshed rough rice is commonly stored either in sacks or in bulk. The sacks or bags provide a means of separating varieties for specific requirements but do not provide protection against insects and rodents. Good store management, proper dunnage and adequate hygienic conditions significantly limit the losses.

On the large scale, bulk storage and controlled-atmosphere storage, if properly organized, are efficient and relatively inexpensive. However, efficient operation requires considerable capital investment and trained labour which often go beyond the single farmer's capability.

Storing rice as rough rice has advantages over storing milled rice, since the hull

protects the kernel against insects and fungal attacks. This possibility depends to some extent on the local economic situation and on supply and demand for rough rice and milled rice at different times in the season.

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Home preparation and cooking

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Washing of milled rice prior to cooking is a common practice in Asia to remove bran, dust and dirt from the food, since rice is often retained in open bins and thus exposed to contamination. During washing some water-soluble nutrients are leached out and removed. Table 41 presents the washing and cooking losses of nutrients from various types of rice. It indicates that a significant amount of protein, ash, water-soluble vitamins and minerals and up to two-thirds of crude fat may be

removed during washing. Marketing clean packaged rice will reduce or delete washing steps and prevent or reduce loss of nutrients during washing.

Boiling in excess water results in leaching out of water-soluble nutrients including starch and their loss when the cooking liquor is discarded. For example, 0.8 percent of the starch was removed on two washings of three milled rices, but 14.3 percent of the starch by weight was in the rice gruel after cooking for about 20 minutes in 10 weights of water (Perez et al., 1987). Protein removal was 0.4 percent during washing and 0.5 percent during cooking. Boil-in-the-bag parboiled rice in perforated plastic bags makes cooking in excess water simple and convenient. In the rice cooker or optimum-water-level method, the leachate sticks to the cooked rice surface as the water gets absorbed by the rice starch. The bottom layer is more mushy than the top layer.

TABLE 41 - Percent nutrient losses during washing and cooking in excess water

Nutrient	**Washing**[a]			**Washing and cooking**[b]	**Cooking without washing**[c]		

	Raw milled rice	**Brown rice**	**Parboiled milled rice**	**Milled rice**	**Milled rice**	**Brown rice**	**Parboile milled rice**
Weight	1-3	0.3-0.4		5-9	2-6	1-2	3
Protein	2-7	0-1		2	0-7	4-6	0
Crude tat	25-65			50	36-58	2-10	27-51
Crude fiber	30						
Crude ash	49				16-25	11-19	29-38
Free sugars	60			40			
Total polysaccharides	1-2			10			
Free amino acids	15			15			
Calcium	18-26	4-5		1-25	21		
Total	20-47	4		5			

phosphorus							
Phytin phosphorus	44						
Iron	18-47	1-10		23			
Zinc	11	1					
Magnesium	7-70	1	1				
Potassium	20-41	5	15				
Thiamine	22-59	1-21	7-15	11	47-52		
Riboflavin	11-26	2-8	12-15	10	3543		
Niacin	20-60	3-13	10-13	13	45-55		

[a] Kik & Williams, 1945; Cheigh et al., 1977a; Tsutsumi & Shimomura, 1978: Hayakawa & Igaue, 1979: Perez et al., 1987.

[b] Cheigh et al., 1977a. 1977b; Perez et al., 1987.

[c] El Bay, Nierle & Wolff, 1980.

Source: Juliano, 1985b.

Increasing the proportion of brokers in milled rice from 0 to 50 percent by weight increases loss of solids on cooking of raw rice from 13 to 27 percent (Clarke, 1982). A contributing factor is the shorter cooking time of brokers: the proportionate loss from the experiment was 22 percent for large brokers and 47 percent for small brokers.

Boiling in adequate cooking water also reduces the aflatoxin content of milled rice by 50 percent (Rehana, Basappa and Sreenivasa Murthy, 1979). Pressure-cooking destroys 73 percent of the aflatoxin, and cooking with excess water destroys 82 percent.

Boiling reduces the true digestibility of milled rice protein by 10 to 15 percent but has no effect on other cereal proteins (Eggum, 1973); however, it improves the biological value of the protein such that net protein utilization in rats is not reduced notably because lysine digestibility is not reduced (Eggum, Resurreccin and Juliano, 1977), (Table 42). The undigested protein, which passes out of the alimentary system as faecal protein particles, represents the lipid-rich core protein of spherical protein bodies (Tanaka et al., 1978), which is poor in lysine but rich in cysteine

(Tanaka et al., 1978; Resurreccin and Juliano, 1981), (Table 43). Mutants with reduced levels of minor sulphur-rich fractions of rice prolamin (10 and 16 kd) are being developed to improve the digestibility of the protein of cooked rice, since the minor prolamin fractions are probably in the core fraction. Parboiling further reduces protein digestibility and increases the biological value correspondingly, without any adverse effect on net protein utilization (Eggum, Resurreccin and Juliano, 1977; Eggum et al., 1984), (Table 40). The reported true digestibility of cooked milled rice is 88 4 percent in adults and children (Hopkins, 1981), (Table 28).

Tanaka and Ogawa (1988) found greater amounts of large spherical protein bodies (PB-I) in indica rice (30 percent) than in japonica rice (20 percent), (Ogawa et al., 1987) and suggested that the protein of cooked indica rice may be less digestible than that of cooked japonica rice.

TABLE 42 - Mean nutritional properties of various raw and cooked, freeze-dried milled rices at 14 percent moisture

Rice type	**Crude**	**Lysine**	**Balance dare in five growing rats**
	protein	**(g/16**	

	(%Nx6.25	**g N)**					
			True digestibility (% of N intake)	**Biological value (% of digested N)**	**Net protein utilization (% of intake)**	**Energy utilization [a] (% of intake)**	**Starch digestib (% of intake)**
IR29, IR32, IR480-5-9 [b] Raw	8.9	3.6	99.7	67.7	67.5	96.8	99.9
Cooked,freeze-dried	9.0	3 5	88.6	78.2	69.2	95.4	99.9
IR58 Raw [c]	11.8	3.5	99.1	68.8	68.3	97.0	-
Cooked,freeze-	12.7	3.5	85.8	73.7	63.2	92.5	-

dried[d]							

[a] IR29 and IR480-5-9 only

[b] Eggum, Resurreccin & Juliano. 1977.

[c] IRRI, 1984a.

[d] Eggum et al., 1987.

TABLE 43 - Properties of whole and pepsin-treated cooked IR480-5-9 and IR58 milled-rice protein bodies.

Protein bodies	**Weight recovery (% of milled rice)**	**Crude protein (%Nx5.95) (**	**Lysine (g/16.8 g N)**	**Cysteine g/16.8 g N)**	**Methionine (g/16.8 g N)**	**Crude lipids (%)**	**Neutral lipid: glycolipid: phospholipid ratio**	**Carbo gl**ucos

Whole protein bodies IR480-5-9	13.0	79.1	4.0	2.6	3.1	9.5	92:5:3	-
IR58	12.0	81.3	4.0	3.0	2.2	7.4	-	5.3
Pepsin-treated protein bodies IR480-5-9 (1X)b	4.6	62.4	1.3	4.6	4.8	22.0	92:5:3	-
IR58 (1X)	4 3	60.3	1.7	4.1	2.6	-		
IR58 (2X)	3.0	51.6	0.8	3.1	3.3	21.4	-	21.3

[a] **Protein content of 10.5% for IR480-5-9 and 11.8% for IR58 milled rice**

[a] Protein content of 10.5% for IR480-5-9 and 11.8% for IR58 milled rice

[b] Number of pepsin treatments.

Sources: Resurreccin & Juliano, 1981; Resurreccin et al., 1992.

However, Tanaka, Hayashida and Hongo (1975) and Tanaka et al. (1978) reported similar in vitro digestibilities for protein bodies from japonica and indica rices.

The low lysine content in the protein of pepsin-treated protein bodies and faecal protein particles (Tanaka et al., 1978) explains the retention of the high lysine digestibility of rice protein on cooking. Its high cysteine content also explains why cysteine has the lowest digestibility among the amino acids of rice proteins (Tanaka et al., 1978).

The FAD/WHO method of protein quality evaluation is based on the amino acid score times true digestibility (TD) in rats (FAO, 1990c). Application of this method to the cooked composite rice diets of preschool and adult Filipinos and to their cooked rice component (Eggum, Cabrera and Juliano, 1992) gave protein quality values 6 to 8 percent lower (56 percent for rice and 89 end 80 percent for the two rice diets) than those based on lysine digestibility (62 percent and 95 and 88 percent,

respectively). TD was 88 to 90 percent for the three samples, and lysine digestibility was 95 to 96 percent for the rice diets and 100 percent for cooked rice. Milled rice had higher digestible energy and protein but lower biological value and net protein utilization (NPU) than the rice diets. Amino acid scores and protein quality of the rice diets were as high or higher than their NPU, but the NPU of milled rice was higher than its amino acid score and protein quality. Thus, the new method will underestimate the protein quality of cooked rice, but not that of raw rice with 100 percent protein and lysine digestibilities in growing rats (Eggum, Resurreccin and Juliano, 1977).

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Chapter 6 Major processed rice products

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Consumption of processed rice products is probably highest in Japan, where it accounted for about 9.5 percent of total rice consumption in 1987 (4.8 percent sake, 1.0 percent miso, 2.0 percent crackers, 1.0 percent flour and 0.4 percent each packaged rice cake and boiled rice products), (Hirao, 1990). In comparison, processed rice products have accounted for about 2 percent of rice consumption in the Philippines (Food and Nutrition Research Institute, 1984), about 1 percent (as noodles) in Malaysia (FAO, 1985) and over I percent in Thailand (Maneepun, 1987).

In countries such as Japan and the Republic of Korea where per caput consumption of boiled rice is decreasing, maintenance of rice consumption is being pursued through the development of new products and the improvement of traditional products in order to maintain total rice production. Japan has the widest range of convenience rice products, including automated cooking equipment for catering (Juliano and Sakurai, 1985). Many national programmes are also looking into the improvement of the quality and shelf-life of traditional rice products (FAO, 1985). Japan's super-rice programme will incorporate selected preferred characteristics of foreign rice into the new Japanese rices (Yokoo, 1990).

Processed rice products may be derived from rough rice, brown rice, milled rice, cooked rice, brokers, dry-milled flour, wet-milled flour or rice starch (Juliano and

Hicks, 1993), (Figure 5). The nutrient composition of some rice products is summarized in Table 44.

Precooked and quick-cooking rices

Precooked rice is used for rice-based convenience food products in which nonrice ingredients are packed separately and mixed only during heating. Retort rice in Japan is made by hermetically sealing cooked non-waxy and waxy rice in laminated plastic or aluminium-laminated plastic pouches and pasteurizing at 120C under pressure (Juliano and Sakurai, 1985; Tani, 1985). Steamed waxy rice with red beans accounts for 80 percent of retort rice in Japan, with an annual production of 8 030 t in 1983 (Tani, 1985) and 4 264 t in 1986 (Iwasaki, 1987). An aluminium-laminated plastic pouch is warmed directly in hot water for 10 to 15 minutes, while plastic pouches may be punctured and heated in a microwave oven for 1 to 2 minutes.

FIGURE 5 Chart of processed rice products based on starting rice raw material

Frozen cooked rice packed in airtight plastic pouches had a production figure of 10 841 t in 1983 in Japan (Tani, 1985); 22 575 t were produced in 1986 (Iwasaki, 1987).

Deep freezing without dehydration is the best condition for keeping cooked rice from retrograding (hardening). Frozen rice produced in cooking centres is delivered to chain restaurants where it is heated in microwave ovens and served to customers.

TABLE 44 - Nutrient composition per 100 g of selected rice products

Product (g)	**Moisture energy (kcal)**	**Food (g)**	**Protein (mg)**	**Thiamine flavin (mg)**	**Ribo- (mg)**	**Niacin**
Instant rice, US	9.6	362	7.5	0.44	-	3.5
Rice, granulated, US[a]	7.4	383	6.0	0.42	0.11	5.8
Kaset rice-soybean infant food, Thailanda	5.2	401	11.0	0.2	0.4	1.0
Baby cereals, rice-based, UK[a]	4.9	386	10.9	1.60	1.20	23.0

Am, thin rice gruel, Philippines	95.9	17	0.1	0.02	0.02	0.4
Rice gruel, Philippines	91.5	30	0.6	0.01	0.01	0.1
Arroz caldo, rice gruel, Philippines	83.8	63	2.0	0.02	0.03	0.4
Bihon, rice noodles, Philippines	12.4	364	5.0	trace	0.01	0.2
Fermented rice/black gram idli, India	45.0	220	7.6	0.32	0.30	0.9
Puto, fermented rice cake, Philippines	46.6	214	2.8	0.01	0.01	0.4
Chinese waxy rice cake, UK	29.8	290	3.5	trace	0.02	0.9
Bibingka, rice cake, Philippines	41.5	234	3.6	0.12	0.05	0.6
Waxy rice bibingka, Philippines	36.8	256	2.8	0.03	0.01	1.1
Kutsinta, rice cake with lye, Philippines	58.9	167	1.4	trace	0.01	0.2

Suman, waxy rice cake with lye,Philippines	52.3	191	3.2	trace	0.02	0.5
Suman sa ibos, waxy rice cake with coconut milk, Philippines	57.5	171	3.1	0.01	0.01	0.3
Tikoy, waxy rice cake, Philippines	37.7	250	2.5	0.02	0.02	0.4
Puto bumbong, purple waxy rice cake,Philippines	38.5	251	3.5	0.03	0.01	0.4
Palitaw, waxy rice preparation,Philippines	51.8	206	2.6	0.04	0.02	0.7
Kalamay, waxy rice preparation with coconut syrup, Philippines	48.2	208	2.7	0.01	0.01	0.3
Espasol, waxy rice product, Philippines	25.8	312	4.0	0.06	0.04	1.1

Tamales, rice flour preparation,Philippines	75.2	100	1.3	0.01	0.02	0.4
Puffed rice, US.	3.7	399	6.0	0.44	0.04	4.4
Puffed rice, non-waxy, sweetened	5.6	385	4.5	0.01	0.14	1.6
Puffed rice, presweetened, with cocoa, US[a]	3.4	401	4.5	0.42	0.06	6.3
Pinipig, flattened parboiled waxy rice,puffed, Philippines	3.3	392	3.1	trace	0.04	2.0
Puto seko, toasted rice bread,Philippines	4.8	388	6.0	0.06	0.02	0.5
Rice pudding, canned, UK	77.6	89	3.4	0.03	0.14	0.2
Chicken with rice soup,condensed, US	89.6	39	2.6	trace	0.02	0.6
Japanese sake rice wine, 32 proof	78.4	134	0.5	0	0	0

Chinese rice wine, 34 proof	79.1	132	0	trace	0.01	0.12
Rice flour, UK	11.8	366	6.4	0.10	0.05	2.1
Rice starch	13.8	343	0.8	-	-	-

[a] With added vitamins and minerals.

Sources: Food and Nutrition Research Institute, 1980; Watt and Merrill, 1963; Luh and Bhumiratana, 1980; Holland, Unwin and Buss, 1988.

Quick-cooking rices are those that require significantly less cooking time than raw milled rices (15 to 25 minutes). Various methods are employed to fissure raw rice or to dry cooked rice to produce a porous structure. Dry-heat methods include heating milled and brown rice with 57 to 82C air for 10 to 30 minutes or with 272C air for 17.5 seconds to fissure the grain. Japanese companies heat brown rice in a countercurrent hot air stream at 105 to 130C for 30 minutes and quickly cool it to below 30C (Juliano and Sakurai, 1985). Parboiled brown rice may be made quick-cooking by scouring about I percent by weight of the pericarp to remove the outer water-impervious layer (Desikachar, Raghavandra Rao and Ananthachar, 1965). Precooked quick-cooking rice processes include soak-boilsteam-dry, gelatinize-dry-puff, gelatinize-roll or bump-dry, freeze-thaw, gun puff, freeze-dry and chemical

treatments (Roberts, 1972).

Pregelatinized or "alpha" rice production in Japan was 13 900 t in 1983 (Tan), 1985) and 14 500 t in 1986 (Iwasaki, 1987). Cooked rice is quickly dried by heated air to fix the starch in an amorphous state at about 8 percent moisture. Gelatinized rice is used as an emergency food and as rations in ships and mountain climbing because of its long shelf-life (three years), (Imai, 1990) and light weight (Juliano and Sakurai, 1985). It is consumed after hydration, cooking or warming for about 10 minutes and standing for about 15 minutes. Freeze-dried rice reconstituted by adding hot water to it best approximates cooked rice. Japanese instant rice gruel is prepared from pregelatinized brown-rice flour or flattened grains by adding hot water or cooking over low heat for several minutes and may be used as a weaning food.

In Taiwan Province (China), two kinds of dried cooked rice are produced commercially. One is a Cantonese-style rice congee made from non-waxy (lowamylose) milled-rice brokers, washed, ground in a hammer mill with a 5-mm screen, precooked with six times the volume of water, drum-dried for 3 minutes with a steam pressure of 5 kg/cm2 and a clearance of 1.5 mm, flaked, mixed with dried cooked meat, vegetables, salt, monosodium glutamate and other flavourings and packed in pouches. The other product is guo-ba, a thin block of dried cooked

waxy rice. Waxy rice is washed, soaked, cooked in a rice cooker, hand-spread in a thin uniform 0.6 cm layer on teflon-coated perforated trays, baked over a flame at 135C for 40 minutes or at 165C for 15 minutes, cut into 6 x 6 cm blocks and sundried to about 12 percent moisture. The guo-ba may be packaged for future use, may be further flavoured and fried, may be used as a ready-to-eat snack or breakfast food or may be added as an ingredient in cooked dishes. Both products involve spreading the cooked rice into layers by hand, which is both time consuming and a potential source of contamination.

Dry precooked rice cereal is produced by preparing and cooking a cereal slurry, which is then dried in a double-drum atmospheric dryer, flaked and packed (Brockington and Kelly, 1972). The slurry solids, drum speed and temperature and spacing between drums are carefully controlled. Hydrated precooked and readyto-eat infant foods must have the right consistency, soft enough to be swallowed easily but thick enough to feed without spilling. Malt and fungal a-amylase may be added to control the quantity of liquid required to reconstitute the dried cereal and to sweeten it by partial hydrolysis of the starch. Rice-based weaning foods are popular in Southeast Asia, such as the Kaset extrusion-cooked rice and full-fat soybean formulation (Luh and Bhumiratana, 1980). Heat-sensitive ingredients such as milk are preferably added after extrusion, to avoid lysine and cysteine degradation of the

protein.

Noodles

Flat and extruded round noodles and rice paper are traditionally prepared from wet-milled flour that has been ground using either a stone or a metal mill. The starting material is brokers with a low fat content, preferably freshly milled from aged rice with a high apparent amylose content and a hard gel consistency.

To make flat rice noodles, a wet-milled rice batter with a consistency of 42 percent rice by weight is placed on a noodle-making machine until the drum is half immersed. The smooth drum is then slowly rotated. The adhering batter is scraped off by a stainless steel sheet set at about a 45 angle and flows onto a moving taut cotton or stainless-steel conveyor belt that carries it into a steam tunnel for 3 minutes for gelatinization (to 62 percent moisture), (Juliano and Sakurai, 1985; Maneepun, 1987). The sheet dips momentarily into peanut oil before it is folded and cut into appropriate sheets (50 x 50 cm) for direct sale as fresh noodle. Very little starch degradation occurs in the process.

Rice paper and egg roll wrapper are also prepared from wet-milled high-amylose rice batter in Viet Nam, Thailand and Taiwan. A measured volume of rice batter, with the proper consistency, is poured with a flat shallow ladle over taut cheesecloth on top of a steamer. The batter is spread over the whole surface by a circular motion of the ladle and steamed until gelatinized. The sheet is then removed with a rolling motion onto a rolling pin and unrolled onto a slottedbamboo drying tray. Rice paper is thinner than egg roll wrapper and is used as translucent edible candy wrapper. The egg roll wrapper may have some added salt.

A cooked rice slurry with added food colours is poured onto various leaf surfaces, dried and peeled off and used as colourful decorations for homes during the annual May 15 festival at Lucban, Quezon in the Philippines. These edible decorations, kiping, retain the vein patterns of the various leaves on to which they are poured.

Traditionally, extruded noodles (bihon, bijon, bifun, mehon or vermicelli) are prepared from aged high-amylose brokers by wet-milling the steeped rice, kneading it into fist-sized balls, surface-gelatinizing the flour balls (about 500 g) in a boiling water bath until they float, remixing, extruding through a hydraulic press with a die, subjecting the extruded noodles to heat treatment for surface gelatinization,

soaking in cold water and sun-drying in racks (Juliano and Sakurai, 1985). Machines in Thailand knead the flour into cylinders that are steamed in portable racks and mixed mechanically into the extruder. Extruders may also be used to cook end kneed premoistened dry-milled flour and then extrude it as noodle at the end of the barrel. Considerable starch degradation occurs during extrusion, such that the gel consistency changes from hard to soft. Protein quality deteriorates very little.

Fermented extruded fresh rice noodle is quite popular in Thailand. Brokens are soaked for three days for fermentation, which reduces the pH from 7 to 3.5, with Lactobacillus spp. and Streptococcus spp. (Maneepun, 1987) and are then processed in the same manner as the unfermented noodle.

Protein decreases from 1.54 percent after one day of fermentation to 1.14 percent after three days at 70 percent moisture.

During wet milling, water-soluble nutrients and damaged starch are lost in the filtration step. Nutrient losses include vitamins, minerals, free sugars and amino acids, water-soluble polysaccharides and protein (albumin) and fat. The wastewater poses a pollution problem. Many Philippine extruded noodle plants use maize starch to minimize the pollution, but maize starch noodle has lower nutritional

value (<1 percent protein) than rice noodle.

Rice cakes, fermented rice cakes and puddings

Wet-milled non-waxy or waxy rice flour may be kneaded with water and converted to sweetened rice cake by adding sugar and other ingredients before steaming. A yeast-fermented steamed rice cake (puto) is produced in the Philippines, for which aged, intermediate-amylose rice yields the greatest volume expansion and optimum softness (Perez and Juliano, 1988). Nenkau is a traditional Chinese rice cake and is basically of three types: a sweetened cake made of waxy rice and sugar; a savoury cake with radish, made from high-amylose rice mixed with crushed radish; and a fermented rice cake, made of fermented rice dough of highamylose rice and sugar.

Idli (rice dumpling) and dosai (rice pancake) are prepared in India from a mixture of parboiled milled rice and black gram (Phaseolus mungo), about 3:1 by weight, typically as breakfast foods (Hesseltine, 1979; Steinkraus, 1983). Rice and decorticated black gram are separately washed, soaked 5 to 10 hours in 1.5 to 2.2 times by weight of water and wet-milled separately to give a coarse (0.6 mm) rice flour and a smooth, gelatinous gram paste. The flour and paste are mixed together

with 0.8 percent salt and the thick batter is fermented overnight, steamed (idli) or fried (dosai) and served hot. Ingredients added to idli for flavour include cashew nut, ghee, pepper, ginger, sour buttermilk and yeast. Dosai usually contains less black gram. The batter quality of idli is attributed to the globulin protein and the arabinogalactan of the black gram (Susheelamma and Rao, 1979). Parboiled highamylose rices are suitable for idli. During fermentation, B vitamins and vitamin C increase (Soni and Sandhu, 1989) and phytate is about 50 percent hydrolysed.

A Philippine rice cake, bibingka, is made from non-waxy and waxy rice flour (wet-milled) with sugar and coconut milk, baked in a banana-leaf lined pan in a charcoal stove with live charcoal on top until brown. Another rice cake, puto kutsinta, is an unleavened cake textured like a stiff pudding and is prepared from wet-milled rice flour with sugar and lye.

Japanese rice cake or paste (mochi) is traditionally prepared from waxy milled rice by washing the milled rice, steaming at 100C for about 15 minutes to a 40 percent moisture content, grinding (kneading or using a mortar and pestle), packing in plastic film, pasteurizing for 20 minutes at 80C and cooling (Juliano and Sakurai, 1985). Recently, gelatinized waxy-rice flour has been directly manufactured by extrusion cooking; it has diverse applications, including mochi. Mochi is usually

sliced into pieces (such as cubes), toasted and seasoned with soy sauce or wrapped and eaten as a snack. Preferred waxy rices have a final starch GT of 66 to 69C (Palmiano and Juliano, 1972). Ready-to-eat mochi is pasteurized under 95C in packaged containers (Tan), 1985). Annual consumption in Japan was 42 000 t in 1983 and 52 305 t in 1986 (Iwasaki, 1987).

Traditional Philippine waxy-rice snack foods or desserts include rice cakes (suman) made from milled rice. Suman sa antala and suman sa ibos are cooked with coconut milk and salt. Suman sa antala is wrapped in heat-wilted banana leaves and steamed for 30 to 35 minutes, but for suman sa ibos the waxy rice/coconut milk mixture is packed loosely into nipa or palm leaves (ibos) and boiled for 2 hours or until done. In suman sa lihiya, the steeped waxy rice is treated with lye,, wrapped in banana leaves and boiled for 2 hours or until done. Suman sa ibos is usually served with sugar, while suman sa lihiya is served with grated-coconut and sugar. Low-GT waxy rices are preferred for these cakes. Wetmilled purple waxy rice is added to waxy rice in preparing puto bumbong, wherein the rice flour is cooked by steaming in bamboo cylinders. Food colouring is now used to obtain the purple colour of the product, which is also eaten with grated coconut and sugar. Palitaw is made from a flattened wet-milled batter of waxy rice dropped into boiling water; after the cakes float they are dropped into cold water to prevent them from sticking to each other.

They are drained and served with grated coconut and pounded sesame seeds. Espasol is made from coconut milk and sugar syrup to which cooked waxy rice is added, followed by toasted and powdered waxy rice. The paste is rolled with a rolling pin and cut into various shapes. Rice powder is sprinkled over the paste to prevent sticking. Tamales contains toasted, ground rice and a mixture of peanuts, sugar, spices and meat which is cooked until thick enough to hold its shape. It is then wrapped in banana leaves and steamed for 2 hours.

The Japanese rice pudding uiro consists of waxy rice flour, cornstarch, sugar, water and flavourings that are mixed and steamed for 60 minutes at 100C and served with sweet bean curd, green tea, coffee, cherries and other fruits (Juliano and Sakurai, 1985). Low-amylose, short- to medium-grain rices are used in preparing Chinese rice pudding (Li and Luh, 1980). The rice is cooked in boiling water, strained and mixed with milk before the completion of cooking. Egg yolk, sugar, vanilla and light cream are added together with a variety of fruit combinations. Canned rice pudding in a milk base with added fruit has been available in Australia and the United Kingdom for more than two decades.

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