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Physicochemical properties of starch and protein are reliable indexes of the desired characteristics of rice intended for specific food uses, particularly those involving boiled rice. Less is known of characteristics desired for rice food products for which processing factors other than amylose content may be important. Unless the rice processors, food scientists, and technologists inform breeders and cereal chemists of the particular characteristics they need for rice products, sources of those properties may ultimately be lost as new varieties replace the old ones in the breeding program. These two groups should work together to systematicallyy produce rice varieties for definite objectives, since different characteristics are desired for each type of processed rice product.

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CHEMICAL BASIS OF DIFFERENCES IN MILLING, COOKING, AND EATING QUALITY OF RICE VARIETIES

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INTRODUCTION

Consumers usually base their preference for milled or polished rice on the appearance of the raw grain, which is not always related to eating quality. Processors require rice that have special characteristics for particular food purposes, but little is known how they test the rice for such characteristics. Rice breeders and chemists in order to establish reliable and scientific criteria for rice quality must establish the physicochemical criteria for identifying the cooking behavior of rice for specific rice foods. Such information should be useful for the screening breeding lines for genetic differences in cooking quality. This paper describes the feasibility and advantages of establishing physicochemical properties as criteria for rice quality.

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PROCEEDINGS OF THE SYMPOSIUM TOWARD MORE PROGRESSIVE BARRIOS
April 17 and 18, 1972, University of the Philippines at Los Baños, Laguna

Physicochemical properties of starch and protein

Rice is a starchy food. It contains about 7% protein. Filipinos obtain 30 to 50% of their protein from rice, and also a major part of their minerals and vitamins. The important nutrients in rice namely the vitamins, thiamine and riboflavin, are distributed unevenly. The endosperm is starchy but the outer layers and germ are richer in the other nutrients. Thus, brown rice or pinawa is richer in nutrients than milled rice or bigas.

Basically, starch is a collection of glucose molecules. Depending on the way the molecules are arranged, there are two forms of starch; amylose (linear) and amylopectin (branched). The starch of glutinous or waxy rice is about 99 percent amylopectin. Incidentally, it contains neither wax nor gluten. Nonglutinous, common, or nonwaxy milled rice contains 10 to 34 percent amylose (12 to 37% starch basis), the rest of the starch is amylopectin. The mean amylose content of nonglutinous milled rice may be low ($<$ 20%), intermediate (20 to 25%), moderately high (25 to 27%), or high ($>$27%). Philippine rice varieties range from low to high amylose. A variety may vary in amylose content by as much as 6%, as does IR8 whose amylose content ranges from 27 to 33%. In fact, samples of the same variety may vary in amylose classification. Hence a single analysis of a variety for total amylose content is unreliable, particularly when amylose ranges from 24 to 28 percent.

Starch is present in the rice endosperm as compound granules 3 to 10 μ in size. It is insoluble in cold water but is dispersed upon heating. Gelatinization temperature, a physical property of starch, is the range of temperature within which the starch granules start to swell irreversibly in hot water, simultaneously losing birefringence and crystallinity. Final gelatinization temperature ranges from 55 to 79°C in rice starch and may vary by as much as 10°C within a variety. It may be low ($<$ 70°C), intermediate (70 to 74°C) or high ($>$ 74°C). All classes of gelatinization temperature are represented in Philippine varieties.

Amylose content and gelatinization temperature, neither of which is correlated with grain size and shape, are affected independently by ambient temperature during grain development. In most of the Philippines ambient temperature does not vary much throughout the year.

Proteins are made up of amino acids linked by peptide bonds. In the rice endosperm they exist mainly as discrete particles (protein bodies), 1 to 4 μ in size. Nutritionally, rice protein has better quality than most cereal proteins because of its high level (3.5 to 4.5%) of lysine, the first limiting essential amino acid of cereal proteins. The high lysine content of rice protein is due to the low content (only 5%) of the low lysine protein fraction (prolamin). Rice protein is made up

principally (90%) of water-insoluble protein. The protein content of samples of the same variety may vary by as much as 6%.

Properties of the raw grain

Milled rice is preferred to brown rice because brown rice does not store as well, particularly when the grain is dehulled by stone or concrete rollers which damage the outer layers and promote enzyme activity, leading to a breakdown of fats. The rubber rollers used in modern mills minimize grain damage and thus improve the storage quality. Filipinos generally prefer translucent, slender, medium-grain rice.

Milled rice in the market place is usually graded and priced on the basis of grain size and shape, degree of milling, and grain translucency (absence of opaque portions). Degree of milling affects the appearance of the milled rice. Undermilled rice has a darker color and is less attractive than fully milled rice.

There is little price premium for head rice (unbroken grains) in the Philippines. Protein content and probably gelatinization temperature directly affect head rice yields. Grain cracks that occur in the field when the surface of drying grain expands after direct contact with dew or rain may cause breakage, too. Interestingly, the opaque glutinous rice give the same values for breaking hardness as nonglutinous rice.

Opaqueness in glutinous rice is caused by the presence of micropores within the starch granules. The opaque portions in nonglutinous rice, such as IR8, however, are due to air spaces between the loosely packed cell contents and they contribute to grain breakage.

Boiled rice and rice dishes

Rice is mainly consumed boiled. The method of cooking seems less important than varietal differences in determining the texture of cooked rice. Volume expansion and water absorption during cooking are positively correlated with the amylose content of the rice. Cooking time or rate of cooking correlates positively with gelatinization temperature and protein content. Protein acts as a physical barrier to water absorption because less than 10 percent of it is water soluble.

The eating quality (cohesiveness, tenderness, and color) and gloss scores of cooked rice are negatively correlated with amylose content (Table 1). Salon and Antonio (1965), reported a preference by a Filipino taste panel for Bengawan and similar varieties with intermediate amylose content over Peta, Tjere Mas, and Saraup Kechil 36 Str. 482, which have high amylose content. Similar results were reported at UPCA by Oñate and del Mundo (Table 2). The preference of Filipinos for intermediate amylose rice may be related to their practice of keeping leftover boiled rice overnight and frying it for breakfast the next morning.

Intermdiate amylose rice, when cooked, remain soft even when cold, but are more sticky than high amylose rice. Gloss differences may be directly correlated with the amount of volume expansion during cooking.

TABLE 1. Relationship between amylose content and taste panel scores of cooked rice of Philippine milled rices.

Variety	Amylose (% dry basis)	Taste panel scores[a/]			
		Tender-ness	Cohesive-ness	Color	Gloss
Malagkit Sungsong	3.9	8.5	7.3	4.1	8.0
Bengawan	24.2	6.5	6.2	1.2	5.0
BPI-76	21.5	6.9	5.7	3.4	5.9
Milfor 6	28.3	5.2	3.6	1.3	3.7
Peta	32.6	5.2	3.9	1.0	4.2
Tjere Mas	28.2	4.8	3.6	1.1	3.9
LSD (5%)		0.5	0.7	0.4	0.5

[a/] Rice:water (w/w) ratio of 1:1.8. Mean of triplicate assessment by a taste panel of five judges. Numerical scores of 1 to 9 were assigned, "1" representing the least expression of the property in question and "9" the highest expression.

TABLE 2. Preference for cooked rice by personnel from the UPCA (16) and reported amylose content of milled rice of 10 Philippine varieties and lines.

Rank	Variety	Total Score a/	Reported amylose content (% dry basis) b/
1	Bengawan	375	22-23
2	FK-178A	417	22
3	BE-3	486	21
4	Raminad Str. 3	538	21-24
5	BPI-121	591	23
	BPI-76	594	22-28
6	Tjere Mas	625	26-30
	C-18	631	28
	Norelon	632	30
7	Peta	682	27-32

a/ Sum of the preference score (rank) given by 102 judges.

b/ IRRI data.

Intermediate amylose rice have more flavor than high amylose rice. Differences can be detected between BPI-76, a moderately high amylose variety, and Wagwag, a high amylose variety (Table 3). In the market, Wagwag refers to a specific grain size and shape, and may be mixed with other varieties such as IR20 or BPI-76 which have lower amylose contents than Wagwag (Table 4). Water soluble amylose at 100°C of over 12 percent may be used to identify moderately high amylose rices. The flavor and taste differences may be related to texture differences. A negative correlation between palatability scores and amylose contents among Japanese rice with amylose content ranging from 18 to 22 percent of their starch is related to texture differences.

Low amylose nonglutinous rice are suitable for making paella or arroz valenciana, although glutinous rice may also be added to higher amylose rice to obtain the desired cohesiveness.

Glutinous rice have the best flavor and are used in cooking suman sa lihiya, cake with lye wrapped in banana leaves or suman sa ibus, cake with coconut milk and wrapped in palm leaves. Glutinous rice is used in puto bumbong, cake colored with purple pericarped glutinous rice (Pirurutong) or with food color and cooked by steaming in bamboo cylinders.

TABLE 3. Physicochemical properties and taste panel scores for cooked BPI-76 and Wagwag milled rice (16).

Property	BPI-76	Wagwag
Protein (% at 14% moisture)	8.6	8.0
Amylose (% dry basis)	26.0	28.4
Final gelatinization temp. (°C)	72	72
Taste panel scores[a]		
Tenderness	6.6	5.7
Cohesiveness	4.6	2.7
Color	3.5	1.8
Gloss	4.8	3.0

[a] Rice:water (w/w) ratio of 1:2.2 for BPI-76 and 1:2.6 for Wagwag. Mean scores by a taste panel of six judges. Numerical scores of 1 to 9 were assigned, a score of "1" representing the least expression of the property in question and "9" the highest expression.

TABLE 4. Physicochemical properties of authentic samples of Wagwag milled rice and market samples from Calamba and Los Baños.

Source	Length/width (mm)	Alkali spreading, clearing values[a]	Amylose content (% dry basis)	
			Total	Water-sol. at 100°C
Authentic samples ex				
Cabuyao	5.3/2.0	6.0, 5.0 (L)	34.1	12.8
Acc. No. 5824	5.7/1.9	6.0, 5.0 (L)	30.1	11.2
IRRI breeding program	5.3/2.3	5.4, 4.5 (L/I)	29.9	14.9
Market samples				
Wagwag Calauan	5.6/2.2	4.4, 3.5 (I/L)	28.0	11.8
Wagwag Norte	5.2/2.1	6.9, 6.2 (L)	29.6	10.3
Wagwag San Jose, N.E.	5.4/2.2	6.8, 5.8 (L)	30.4	12.4
Wagwag Nueva Ecija	5.2/2.1	6.2, 5.1 (L/I)	30.4	13.2
Tipo Wagwag	6.0/2.1	4.0, 3.1 (I/H/L)	30.2	12.0
Tipo Wagwag	6.8/2.1	4.9, 4.3 (L/H/I)	29.9	13.2
Tipo Wagwag	6.0/1.9	6.7, 6.6 (L/H)	32.2	12.0

[a] Gelatinization temperature: L = low; I = intermediate; H = high.

Glutinous and nonglutinous rice are used in rice gruel and soups. Glutinous and low amylose rice are sensitive to overcooking and even disintegrate during soaking of the cooked grain. Hence glutinous rice gruel or lugaw tends to be thick. Nonglutinous rice are used in chicken-rice soups (arroz caldo).

Nutritional value

Supported by a contract with the National Institute of Health (USA), IRRI breeders and chemists are attempting to improve the protein content of milled rice by 2 percentage from its present level of about 7 percent, without sacrificing yield. Such an increase in protein content presumably has little effect on the eating quality of the rice, but it will increase protein intake by at least 10 percent without changing consumers' food habits and food intake. Trials with rats and humans have demonstrated the nutritional advantage of high protein rice over rice with normal protein content, due to the former's higher levels of essential amino acids. An increase in protein content is, however, usually accompanied by a slight decrease in the lysine content of the protein.

Aging and parboiling

During the first 3 to 4 months after harvest, the physicochemical properties of nonglutinous raw rice change. Aging improves head rice yield in milling tests, increases volume expansion and water absorption during cooking, and decreases cohesiveness and tenderness scores of

the cooked rice regardless of amylose content. There is little change in amylose and protein contents and gelatinization temperature. Starch and protein become less soluble in hot water during aging. Primo, Barber, and Barber (1971) attribute this decrease in solubility to crosslinking of protein, and perhaps starch, with oxidation products of rice fats. Fatty acids from fat hydrolysis may also decrease amylose solubility. Since these changes occur in stored rice, whether rough, brown, or milled, a general mechanism of aging still has to be demonstrated since fat changes are probably much slower in unmilled rice. Starch undergoes similar changes in properties during storage but the fraction involved in the oxidation change is small and cannot be detected readily by present methods. Filipinos find freshly harvested IR24 very sticky but find its texture acceptable when cooked after being stored for a few months. Interestingly, glutinous rice on aging, undergoes little change in taste panel scores of boiled rice.

Aging may be accelerated by dry or wet heating. Parboiling or steaming of steeped rough rice was probably originally developed for instantly aging freshly harvested rice. Dry heating in sealed containers has the same effect. Hot sand and infrared high-temperature drying of rough rice with over 25 percent moisture results in a parboiling effect that improves translucency and head rice yield. The main nutritional advantage ascribed to parboiling is the greater resistance of parboiled grain to milling so that more of the bran is left on the grain.

In the Philippines, aromatic varieties, such as Milagrosa, are often consumed at harvest or while still sticky, when the aroma is strongest. In other countries, such varieties are aged in sealed containers to minimize the loss of the volatile aroma.

Processed rice products

Few studies have been published on varietal differences on the processing quality of Philippine rice. The standard glutinous variety, Malagkit Sungsong, is used for making pinipig or rice flakes in Laguna. Dry or freshly harvested grain is presoaked, heated to gelatinize the starch, and then pounded by hand while hot. A non-aromatic glutinous IR253 line (Gam Pai/2 x Taichung Native 1) is now grown extensively and is used in pinipig making but lacks the aroma and does not have the chewiness of Malagkit Sungsong. Another early-maturing glutinous line, IR833-6-2 (IR262-43-8-11 x Gam Pai 15), is also being evaluated. The UPCA variety Panpet 63 also lacks this aroma and has a high gelatinization temperature. Although gelatinization temperature has little effect on the texture of freshly boiled glutinous rice, it may have an effect on processed foods, as it has on Japanese rice cakes.

Glutinous rice flour and starch, which have no amylose, are ideal raw materials for desserts and frozen sauce because of their stable gel.

In making carameled popped rice or ampaw, pinipig from brown waxy rice is mainly used. It is either deep-fried in fat or puffed in a "gun." Manufacturer claim glutinous rice expands most during popping.

Popped or puffed rice are made from aged, low amylose, non-glutinous, medium-grain rice in the USA. Translucent, fully milled grains are needed for uniform processing. Long-grain varieties tend to expand unevenly. The higher water content of steeped raw glutinous and low amylose nonglutinous rice may be the cause of the superior puffing properties of these varieties compared with rice that have a higher amylose content. Puffed rice began to be produced in the Philippines as a breakfast cereal in 1971 but I do not know what kind of rice is used. To maintain crispiness the moisture content should be below 6 percent.

Precooked dried rice flakes imported into the Philippines from the USA are made from low amylose, nonglutinous, medium-grain rice used for making baby gruel. The integrity of the grain may be lost in low amylose rice but a thick texture is readily obtained because of high amylopectin content. Low amylose rice are used for precooked, packed, ready-to-eat baby foods because they have the desired texture and the starch tends to retrograde less than rice with higher amylose. IR24 may be suited for this purpose.

Highly milled, white nonglutinous rice is used as raw material for rice cakes or puto. The rice flour is usually fermented but baking powder may be added instead. Cakes from intermediate amylose rice, particularly C4-63, have the advantage of remaining soft even when exposed after storage for over 6 hours in contrast to cakes from high amylose rice which harden fast. Aged rice produces better quality puto than freshly harvested rice.

The intermediate amylose variety Intan is commonly used in dehydrated precooked rice in army rations and in dehydrated soups because of its tenderness and its resistance to disintegration if overcooked. Highly milled rice which are low in fat content are preferred because they minimize lipoxidation of the processed product.

Rice noodles or bihon are made from white milled rice or from white corn grits which are soaked, wet milled, and mixed with corn or cassava starch. The only requirement for the milled rice is a white color since most Philippine rice have at least intermediate amylose content so the noodles do not disintegrate when cooked. But since both resistance to disintegration and hardness of cooked noodles increase with amylose content, high amylose rice produce noodles that are resistant to disintegration. A sample of bihon that we tested contained 32% amylose (34% starch basis). Degermed grains of 18 Philippine corn varieties had 27 to 36% amylose, d[illegible]sis. Although corn starch provides better cooking stability because of its high amylose content (about 35%), cassava starch [illegible] about 25% amylose provides a more translucent noodle.

Wine and beer makers prefer highly milled rice as a substrate and an adjunct. Deep milling reduces protein content and fat content and thus produces a bland taste and stability in the product, particularly if rice is the major substrate. Only brewers' rice is used in beer making in the U.S. Rice used as adjunct in beer making should contain less than 0.75 percent fat. A low gelatinization temperature is advantageous since starch can be dispersed at a low temperature to prevent the destruction of the α-amylase enzyme in barley malt and to shorten the cooking time before the starch slurry is fermented.

SUMMARY

Physicochemical properties of starch and protein are reliable indexes of the desired characteristics of rice intended for specific food uses, particularly those involving boiled rice. Less is known of characteristics desired for rice food products for which processing factors other than amylose content may be important. Unless the rice processors, food scientists, and technologists inform breeders and cereal chemists of the particular characteristics they need for rice products, sources of those properties may ultimately be lost as new varieties replace the old ones in the breeding program. These two groups should work together to systematically produce rice varieties for definite objectives, since different characteristics are desired for each type of processed rice product.

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