Varietal Differences in Quality Characteristics of Puffed Rices

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Cereal Chem. 64(4):337–342

ABSTRACT

Varieties differing in amylose content (AC) and final gelatinization temperature (GT) were used to study the most suitable rices for three methods of producing puffed rice. Puffed rice was prepared from both parboiled and boiled milled rice by heating the dried milled rice in oil at 210–220°C and by heating raw milled rice in a puffing gun. Among the nine rices parboiled for 10 min at 100°C, waxy and low-AC rices gave higher puffed volume than higher AC nonwaxy rices; after parboiling at 127°C, most intermediate- and high-AC rices gave as high a volume expansion on puffing as waxy and low-AC rices. Puffed rice Instron hardness was lower for the more expanded products parboiled at 127°C than at 100°C. By boiling milled rices in excess water, volume expansion on puffing similarly improved for most samples, particularly the intermediate-GT rices, from 3.3–5.1 after 10 min of boiling to 4.8–5.8 after complete cooking (13–22 min). Thus, after complete starch gelatinization (similar water uptake), nonwaxy rice gave volume expansion as high as waxy rice. Expansion ratio on heating in a puffing gun for 3–7 min to 11.3 kg/cm^2 pressure or 200–210°C was higher for waxy milled rice than for nonwaxy rice, corresponding to 81–97% drop in gel viscosity. Protein content was negatively correlated with expansion ratio of puffed rices. Minimal losses of lysine, cysteine, and tryptophan in the puffed products were observed.

The study of processed rice products provides a means of obtaining information on causes of varietal differences in grain quality that may not be apparent in cooked rice. This explains our continued interest in varietal differences in processing quality of rice.

Puffed rice is a popular product, especially in Asia, because of its crispness and lightness. In the Philippines, *ampaw* (puffed rice balls or bars) is a good example. In the United States, puffed rice was introduced as a breakfast cereal (Brockington 1967). The food industry incorporates it into fatty pastes, chocolate, or boiled sugar confections, such as ice cream and chocolate candies.

Certain high-amylose varieties are preferred for puffed rice in Tamil Nadu, India (Thayumanavan and Sadasivam 1984). Antonio and Juliano (1973) showed that among steeped rough rices dry parboiled at 0 kg/cm^2 pressure, waxy rice had the highest puffed volume. Degree of parboiling was related to the water content of steeped grain. Rices parboiled at 1.5 kg/cm^2 steam pressure for 10 min, milled, and puffed in 250°C sand, had maximum expansion at 27% total amylose or 13.5% hot-water-insoluble amylose (Chinnaswamy and Bhattacharya 1983a). The amylose content that gave the best expansion was higher as the steam pressure of parboiling increased (from 0 to 3 kg/cm^2) (Chinnaswamy and Bhattacharya 1984). In contrast, Goodman and Rao (1983, 1984) reported that cooked long-grain rices expanded more on puffing in vegetable oil than medium- or short-grain samples cooked for 12–15 min: expansion volume correlated better with alkali spreading value ($r = -0.65^{**}$ [0.05 level]) than with amylose content ($r = 0.36^{**}$) for 118 samples.

In addition to parboiled and precooked milled rices, raw milled rice may be puffed directly in a puffing machine or gun, which is common in China, the Philippines, and Korea (Juliano and Sakurai 1985, Patterson and Bray 1985). Automated rotary machines are employed for machine puffing in the United States (Brockington 1967).

These three puffed rice processes were compared on selected samples representing various amylose contents (AC) and gelatinization temperature (GT) types. Amino acid analysis was undertaken on the puffed rices because lysine decomposition has been reported in commercial puffed rice (Khan and Eggum 1979).

MATERIALS AND METHODS

Rice samples were obtained mainly from crops that had been aged for at least three months and grown on the International Rice Research Institute farm. The variety Inga was obtained from the Agricultural Research Institute, Yanco, New South Wales, Australia. Century Patna 231 was from USDA-ARS Rice Research, Beaumont, Texas.

Parboiling

Rough rice (125 g) was packed in Miracloth bags, steeped for 6 hr in 45–50°C water, and steamed for 10 min both at 0 kg/cm^2 (100°C) and 1.5 kg/cm^2 (127°C) wet steam pressure in an autoclave to prepare mild and severely parboiled rices, respectively (Chinnaswamy and Bhattacharya 1983b). They were air-dried in trays in the laboratory and stored in glass bottles.

The raw and parboiled rough rice was dehulled with a Satake THU-35A type testing dehusker, and brown rice was milled with either a Satake TM-05 testing mill or McGill miller no. 2 to 10% by weight bran-polish removal. Milled rice flours for analysis were prepared in a Udy cyclone mill with 40- or 60-mesh sieve. Head rice was obtained from total milled rice using a Satake testing rice grader TRG-05A to remove brokens.

Milled rices were analyzed for amylose content (Juliano et al 1981), alkali spreading value (Little et al 1958), gel consistency (Cagampang et al 1973; 100 mg of flour for nonwaxy and 170 mg of flour for waxy), and micro-Kjeldahl protein using the factor 5.95. Gel viscosity of gel consistency samples was measured at 25°C with a Wells-Brookfield cone-plate microviscometer RVT-C/P with a 1.565° cone at 2.5 rpm. Alkali spreading value was used as the index of starch GT, because these two properties have a significantly negative correlation (Juliano 1985).

Pregelatinized Milled Rice

Head-milled rice (25 g) was added to 200 ml of boiling water and cooked for 10 min (Goodman and Rao 1983). Another set was cooked until the center of the grain was completely gelatinized (checked by pressing 10 grains every minute between glass plates). The cooked rices were then collected in a strainer, air-dried to 10–13% moisture, and stored in sealed plastic bags.

Puffing in Oil

Milled parboiled rice and pregelatinized milled rice (10 g) were puffed in a coconut oil bath at 210–220°C for 4–8 sec, and excess oil was removed by straining (Roberts et al 1951) and patting between paper towels.

Gun-Puffed Milled Rice

A locally fabricated puffing gun (from the Institute of Food Science and Technology, University of the Philippines at Los Baños) consisted of a spherical metal chamber (175 mm i.d.), a spout for feeding milled rice with a metal lid, and a mechanism for quickly releasing pressure (Patterson and Bray 1985). Conditions for gun puffing were optimized by trial and error. Milled rice (500 g) was premoistened to 13–15% moisture by adding 10–15 ml of

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water or being exposed to high humidity overnight and fed into the chamber, which had been heated earlier. The chamber was tightly closed and rotated manually over a strong gas burner flame to heat the grains for 3–7 min until gauge pressure reached 11.3 kg/cm^2. The lid's safety catch was quickly tapped to release the pressure, and the puffed grains were collected in a receptacle. Chamber temperature was 200–210°C.

Puffed rice hardness was measured on individual grains using the Instron model 1140 food tester with a 35-mm diameter plunger at a crosshead speed of 10 cm/min, and the maximum force was recorded. The mean hardness of 10 grains was reported.

Expansion ratio was estimated by measuring the volume of 500 grains of rice before and after puffing, using graduated cylinders tapped 25–30 times to allow uniform compacting of the grains.

Scanning electron micrographs of unpuffed and puffed milled rices were obtained on a Philips scanning electron microscope 505 unit. The grains were cracked transversely, mounted in colloidal silver suspension on a scanning electron microscope stub, and given a coating of gold by a gold sputtering machine before observation.

Puffed rice of three varieties and their unpuffed counterparts were ground in a Udy cyclone mill, hydrolized for 23 hr at 110°C in 6*N* HCl in sealed tubes after flushing with N_2, and analyzed in a Beckman Spinco amino acid analyzer 120C with PA-35 and AA-15 resins in an LKB 4400 amino acid analyzer with an Ultropac 8 resin column. Cysteine was determined in the AA-15 column after performic acid oxidation of the rice sample and hydrolysis with 6*N* HCl. Tryptophan was also determined by pronase hydrolysis of the protein at pH 7.4 followed by reaction with a reagent described by Opienska-Blauth et al (1963).

Correlation coefficients and pooled standard deviations were calculated (Snedecor and Cochran 1980).

RESULTS AND DISCUSSION

Puffed Rice from Parboiled Rice

Water uptake during parboiling at 0 kg/cm^2 steam pressure (100°C) correlated negatively with AC and positively with alkali spreading value (Table I). The waxy and low-AC rices gave higher puffed volumes than the intermediate- and high-AC rices. However, hardness values for puffed rice parboiled at 100°C were highest for waxy rice and lowest for high-amylose rice (Table I). IR64, IR36, and the IR line, which are of intermediate GT, had the lowest water uptake and puffed the least. Under these parboiling conditions, the center of the endosperm was still chalky or not parboiled. The similar correlations of expansion ratio and water uptake during parboiling with AC and alkali spreading values suggest that expansion ratio must be related to severity of parboiling, because the latter is indexed by water uptake during parboiling.

The starch properties AC and GT are known to affect water absorption properties of milled rice during cooking (Juliano and Perez 1986). High AC required more water uptake for cooking, whereas high GT required a longer cooking time. Antonio and Juliano (1973) also found waxy rices have the highest puffed volume among rices parboiled with dry heat at 100°C after steeping in water.

Complete parboiling without chalky centers was obtained at 1.5 kg/cm^2 steam pressure (127°C) for 10 min. With complete parboiling, water uptake during parboiling no longer correlated with AC and alkali spreading value (Table I). Expansion ratio and hardness of puffed rice were no longer correlated with AC and alkali spreading value. The waxy and nonwaxy rices, regardless of GT, gave puffed rices of comparable quality. IR64 puffed the least when parboiled at 100°C for 10 min but was among the most puffed when parboiled at 127°C. With greater puffed volumes at the more severe parboiling temperature, the puffed grains were also softer, as indexed by lower hardness values. Thus, starch properties were less important factors in more complete parboiling than in partial parboiling at 100°C for 10 min. However, expansion ratio was negatively correlated with protein content. Although our expansion ratios were similar to those of Chinnaswamy and Bhattacharya (1983a,b), we could not duplicate their results of maximum expansion for parboiled rices with 27% amylose.

The pressure (127°C) parboiled milled rices had darker color than those parboiled at 100°C. Kett whiteness values were 20–26% (mean 23.0%) at 100°C and 11–16% (mean 13.0%) at 127°C, and the color was evident even in the puffed rice. With severe parboiling, the gel consistency of parboiled waxy rices was harder than that of the raw waxy rices, which was not the case with the nonwaxy rices. Fat content of oil-puffed 127°C-parboiled milled rice was 19%. Because of fat interference with gel consistency, the high fat content made it impossible to obtain reliable gel

TABLE I
Properties of Raw, Parboiled, and Puffed Parboiled Milled Rice and Their Correlation with Water Uptake During Parboiling and Puffed Rice Properties

	Amylose		Alkali Spreading	Protein Content	Water Uptake During Parboiling (% dry wt)		Puffed Rice			
							Expansion Ratio		Hardness (kg)	
Sample	Type	(% db)	Value	(%)	0 kg/cm^2	1.5 kg/cm^2	0 kg/cm^2	1.5 kg/cm^2	0 kg/cm^2	1.5 kg/cm^2
IR29	Waxy	1.0	7.0	7.3	39.1	33.1	3.0	5.9	6.9	1.6
IR65	Waxy	1.2	7.0	7.8	38.3	39.6	2.8	5.6	8.9	1.6
Malagkit S.[a]	Waxy	1.4	7.0	7.3	38.0	40.2	3.0	5.1	6.4	1.4
IR24	Low	15.3	7.0	7.1	33.2	33.3	3.1	5.6	6.4	1.4
IR841-85-1	Low	15.9	7.0	8.0	35.9	36.4	3.2	5.9	6.3	1.1
IR line	Int.	20.6	3.2	8.0	33.0	34.2	1.8	5.5	7.2	1.3
IR48	Int.	21.4	7.0	8.3	32.7	35.6	2.4	5.0	4.2	1.7
IR64	Int.	22.4	3.7	7.6	26.6	33.9	1.8	5.9	7.0	1.9
IR36	High	25.6	4.8	8.9	31.2	36.4	1.8	4.0	2.5	1.8
IR42	High	26.4	7.0	7.6	32.4	37.3	2.0	5.0	3.1	1.3
Mean		···	···	···	34.0	36.0	2.5	5.4	5.9	1.5
Correlation coefficients[b] (n = 10)										
Amylose content					−0.85**	−0.33	−0.74*	−0.42	−0.68*	0.14
Alkali spreading value					0.65*	0.37	0.77**	0.07	−0.03	−0.31
Protein content					−0.31	0.11	−0.53	−0.65*	−0.52	0.26
Water uptake on parboiling					···	···	0.75*	−0.34	0.40	−0.27
Expansion ratio					···	···	···	···	0.45	−0.24

[a] Malagkit Sungsong.
[b] Significant r = 0.632 at the 5% (*) level and 0.765 at the 1% (**) level.

TABLE II
Properties of Raw, Cooked and Puffed Gelatinized Milled Rice and Their Correlation with Water Uptake during Cooking and Puffed Rice Properties

Sample	Amylose		Alkali Spreading Value	Protein Content (%)	Optimum Cooking Time (min)	Water Uptake During Cooking (% dry wt)		Puffed Rice			
								Expansion Ratio		Hardness (kg)	
	Type	(% db)				10 Min	Optimum	10 Min	Optimum	10 Min	Optimum
IR29	Waxy	1.0	7.0	7.3	14	174	225	4.6	4.8	1.1	1.0
IR65	Waxy	1.2	7.0	7.8	13	181	189	4.4	4.8	1.1	1.1
Malagkit S.[a]	Waxy	1.4	7.0	7.3	19	...	171	...	5.2	...	1.0
RD4	Waxy	1.3	3.0	11.3	14	...	207	...	3.4	...	1.6
IR24	Low	15.3	7.0	7.1	16	166	220	4.7	5.2	2.2	1.7
IR841-85-1	Low	15.9	7.0	8.0	16	178	202	4.7	5.4	2.2	1.7
Inga	Low	16.4	3.6	5.8	16	...	254	...	5.4	...	1.7
CP 231[b]	Low	12.8	3.2	8.3	18	...	260	...	4.5	...	1.3
IR line	Int.	20.6	3.2	8.0	21	168	236	4.1	5.0	2.1	1.6
IR48	Int.	21.4	7.0	8.3	20	153	243	4.4	4.9	2.4	2.2
IR64	Int.	22.4	3.7	7.6	22	192	277	5.4	5.8	2.4	1.7
IR36	High	25.6	4.8	8.9	18	178	220	3.3	5.2	3.3	2.0
IR42	High	26.4	7.0	7.6	17	195	254	4.8	5.1	2.5	1.8
Mean		...	...	...	...	176	228	4.5	5.0	2.1	1.6
Correlation coefficients[c]											
Amylose content						−0.12	−0.65*	−0.12	−0.52	−0.93**	0.82**
Alkali spreading value						−0.13	−0.48	0.15	0.27	−0.36	−0.15
Protein content						−0.17	−0.20	−0.74*	−0.77**	0.58	0.18
Water uptake on parboiling						...	...	0.35	0.24	0.09	0.47
Expansion ratio						...	...	...	...	−0.31	0.18

[a] Malagkit Sungsong.
[b] Century Patna 231.
[c] Significant $r = 0.666$ at the 5% (*) level and 0.798 at the 1% (**) level for $n = 9$, and $r = 0.553$ at the 5% level and 0.684 at the 1% level for $n = 13$.

TABLE III
Properties of Raw and Gun-Puffed Milled Rices and Their Correlation with Puffed Rice Properties

Sample	Amylose		Alkali Spreading Value	Protein Content (% N × 5.95)	Gel Viscosity (cP)		Puffed Rice	
	Type	(% db)			Raw	Puffed	Expansion Ratio	Hardness (kg)
IR29	Waxy	3.2	7.0	7.5	1,680	250	16.3	0.90
IR65	Waxy	3.2	7.0	8.2	1,640	189	14.8	1.07
Malagkit S.[a]	Waxy	2.8	6.9	6.6	1,150	160	17.4	0.74
RD4	Waxy	4.8	3.0	6.8	2,110	317	15.0	0.63
IR24	Low	14.8	7.0	7.8	839	106	11.2	1.09
IR841-85-1	Low	15.8	3.2	8.9	930	83	11.7	1.00
IR43	Low	16.4	7.0	8.0	877	95	13.4	0.16
Inga	Low	19.0	3.6	8.0	628	70	14.0	1.19
Milyang 77	Low	15.0	6.0	10.0	779	142	8.8	0.77
Suweon 332	Low	12.9	6.9	9.5	653	32	9.3	0.84
Cheolweon 41	Low	13.8	7.0	8.5	621	19	11.6	0.81
IRI 378	Low	15.2	6.6	7.0	643	19	15.4	1.02
Nagdongbyeo	Low	16.2	6.0	7.7	653	32	9.3	0.62
Akibare	Low	16.8	6.4	8.3	803	26	13.2	0.73
Daechongbyeo	Low	16.6	6.0	8.2	653	19	14.1	0.68
Intan	Int.	23.0	4.0	7.0	677	91	14.8	1.00
IR48	Int.	22.7	7.0	8.6	827	99	11.2	1.96
IR64	Int.	25.0	4.6	6.4	599	58	14.5	1.24
IR28150-84-3	Int.	23.0	3.5	8.4	659	58	10.1	1.43
IR36	High	27.5	4.2	8.0	700	118	12.3	1.53
IR42	High	28.6	7.0	7.3	1,030	128	10.1	1.47
IR62	High	25.8	4.7	9.2	617	83	10.3	1.70
Mean		...	...	...	899	100	12.7	1.06
Correlation coefficients[b] ($n = 22$)								
Amylose content						−0.52*	−0.49*	0.66**
Alkali spreading value						−0.11	−0.01	−0.11
Protein content						−0.26	−0.70**	0.13
Gel viscosity of raw rice						0.91**	0.45*	−0.24
Expansion ratio						0.37	1.00	−0.27

[a] Malagkit Sungsong.
[b] Significant $r = 0.423$ at the 5% (*) level and 0.537 at the 1% (**) level.

consistency values for the product (Juliano 1985). Gel viscosity of defatted milled rices decreased by from 0 to 34.8% (mean 11.9%) because of puffing of pressure-parboiled rice.

Puffed Cooked Milled Rice

Cooking in excess boiling water for 10 min gave only partially gelatinized grains with chalky centers. Water uptake during cooking was independent of amylose content, protein content, and alkali spreading value (Table II). Expansion ratio on oil puffing was not correlated with starch properties but was correlated negatively with protein content. Puffed rice hardness correlated positively with AC. The similar behavior of rice varieties in this process explains why intermediate- and high-amylose rices, and not low-amylose rice, are successfully used for puffed rice manufacture in the Philippines.

When the milled rices were cooked to full gelatinization, requiring 13–22 min, water uptake during cooking correlated with AC (Table II). Expansion ratio on puffing was only correlated negatively with protein content. A commercial sample of U.S. long-grain parboiled rice gave an expansion ratio of 5.1 and puffed rice hardness of 1.9 kg. Hardness of puffed rice was again positively correlated with AC. Complete gelatinization of the grain improved expansion ratio and reduced hardness of the puffed rice, probably due to cooking the ungelatinized center. IR64 gave the highest puffed volume expansion among the rices tested. The laboratory panel found gelatinized puffed samples more acceptable than those derived from rice cooked 10 min.

High protein content in the grain again effected an appreciable decrease in puffed volume expansion as exemplified by RD4 (Table II).

Controlled cooking of milled rice, regardless of variety, should result in a predictable expansion ratio of commercial puffed rice (Littlejohn 1967, Juliano and Sakurai 1985). The absence of a significant correlation between AC and expansion ratio for puffed, completely cooked milled rice was similar to the results for puffed 127°C-parboiled rice (Table I).

Solids loss during cooking in excess water was 9–14% for waxy rice, 10–31% for low-amylose rice, 5–14% for intermediate-amylose rice, and 6–10% for high-amylose rice (mean of 12.8%). Oil content of oil-puffed cooked rice was 29%. Oil puffing of fully gelatinized milled rice reduced defatted milled rice gel viscosity 0–57.5% (mean 24.2%). AC of the grain was not affected by puffing.

The variety IR42, which is very much susceptible to moisture-adsorption fissuring (IRRI, *unpublished data*), showed extensive breakage during cooking.

The results in the two processes of pregelatinization seem to support the hypothesis forwarded by Biliaderis et al (1986) that when starch is heated in limited water only some of the starch crystallites melt readily. The high-ordered crystallites melted at a higher temperature. This was evident from the differential scanning calorimeter thermogram where two endotherms were observed. However, heating starch in excess free water showed only one endotherm on the thermogram—all the starch crystallites gelatinized at a temperature lower than their actual GT.

Gun-Puffed Milled Rice

Volume expansion in the puffing gun was two to three times the expansion ratio during oil-puffing of parboiled and cooked milled rice (Tables I–III). Waxy rices gave the greatest expansion ratio as confirmed by its correlation coefficient with amylose (Table III and Fig. 1). Brockington (1967) reported a 10-fold increase in volume on grain puffing. Puffed rice hardness was positively correlated with AC. Laboratory panel tests, however, showed

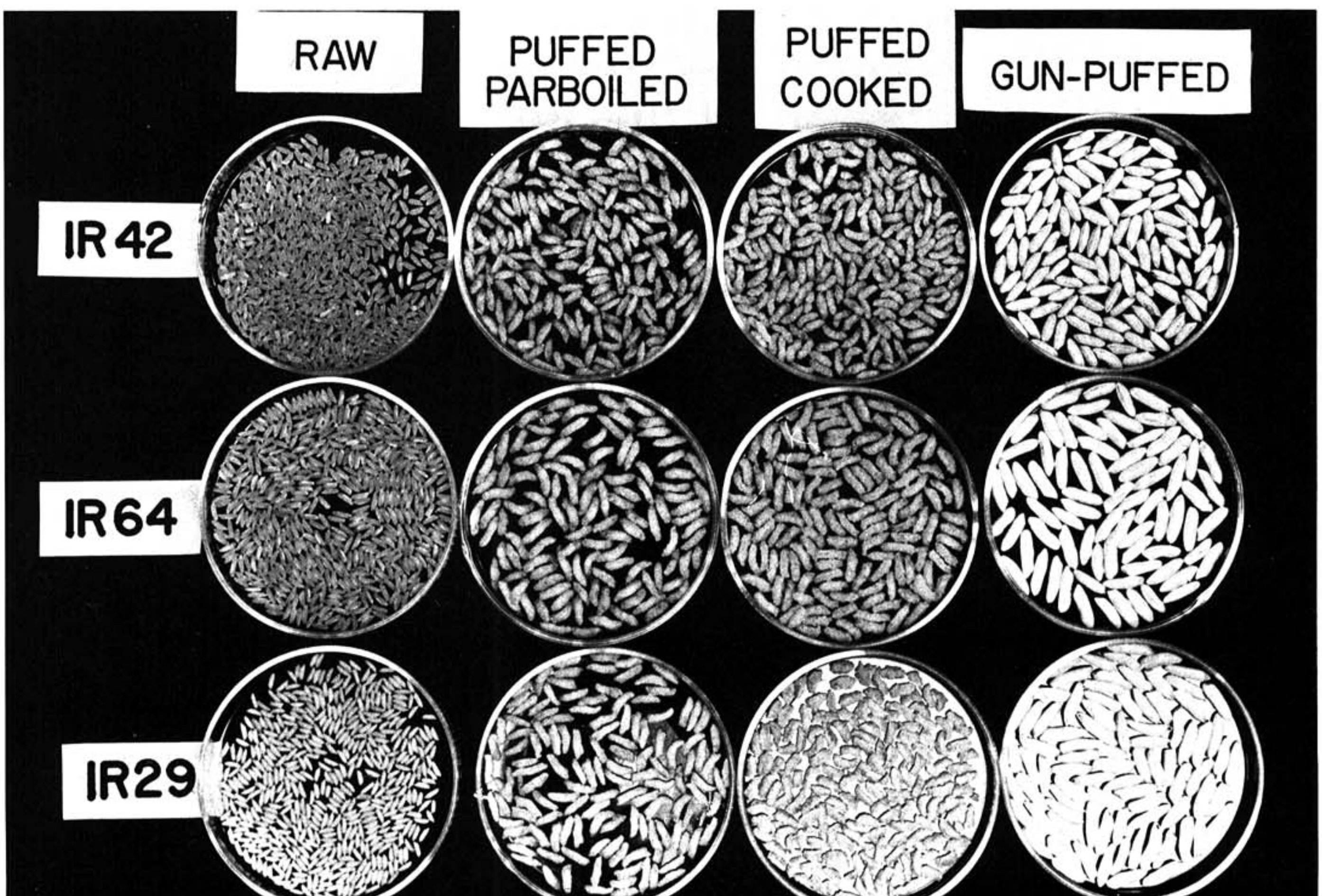

Fig. 1. Comparative appearance of raw milled rice, puffed milled 127°C-parboiled rice, puffed completely gelatinized cooked milled rice, and gun-puffed milled rice of IR42 (high amylose), IR64 (intermediate amylose), and IR29 (waxy) rices.

preference for intermediate- and low-amylose puffed rices of the indica varieties, e.g., IR24, IR43, IR64, Inga, and Intan, in terms of crispness and texture over waxy and high-amylose rices. Puffed waxy rice was soft textured and the lightest, almost melting in the mouth, but lacked crispness. The Korean rices (Milyang 77 through Daechongbyeo, Table III) although all of low-AC type, gave puffed rices whose texture was similar to that of indica waxy rices. Yanase et al (1983) reported more volume expansion and a more brittle product from extruder puffing of waxy rice than from nonwaxy rice. Alkali spreading value (index of GT) was not important for gun-puffed rice, but protein content negatively affected expansion ratio. Puffed grains had a smoother surface and were glossier after tempering the grains to 13–15% moisture in a high-humidity room than when water was added prior to puffing.

AC correlated negatively with gel viscosity of puffed grains ($r = -0.52$*). Gel viscosity in 0.2*N* KOH decreased by 81–97% on gun puffing (Table III) but not as severely as extrusion cooking, with final gel viscosities of only 13–33 cP (Mosqueda et al 1986) except for the six Korean rices. Interestingly, the lowest gel viscosity of puffed rice was shown by low-AC rices rather than by waxy rices. AC of the samples was also retained, but the puffed rice from gun puffing of raw grain was more hygroscopic than that from parboiled or cooked rice because of extensive degradation of the starch as indexed by alkali viscosity. Starch lipids complexed to amylose probably reduced the degradation of amylose relative to amylopectin during gun puffing. The reduction in gel viscosity during gun puffing (88.9%) was greater than that during oil puffing of parboiled milled rice (11.9%) or precooked milled rice (24.2%).

The length-width ratios of puffed and raw grains were similar. In contrast, IR42 parboiled rice did not puff well and gave only 9.2 kg/cm^2 pressure, expansion ratio of 2.5, and a much lower length-width ratio than parboiled grain. Brockington (1967) reported 20% less volume expansion for parboiled rice than for raw rice on puffing. A puffing gun is used to prepare puffed rice from flattened parboiled waxy rice *pinipig* (Juliano and Sakurai 1985). Protein content was negatively correlated with puffed volume (Table III), exemplified by low-amylose Milyang 77 with 10.0% protein and a low expansion ratio of 8.8. The significant correlation between gel viscosity of raw rice and expansion ratio of puffed rice must be caused by the high viscosity of waxy rices.

Amino Acid Degradation

Oil puffing of 127°C parboiled milled rice and precooked milled rice did not adversely affect the nutritional value of rice proteins based on levels of lysine, cysteine, methionine, and tryptophan in protein before and after puffing (Table IV). Some lysine degradation was shown by puffed parboiled rice, specifically IR29, which dropped in lysine content from 4.6 to 3.8 g/16.8 g N. Only the gun-puffed product decreased significantly in cysteine content without any lysine degradation. Similarly, only the puffed-cooked rice showed some loss in tryptophan. In contrast, extrusion-cooking rice at 150°C reduced lysine by 11–13% and cysteine by 14–29% in two samples (Eggum et al 1986). Lysine degradation may have been minimal in the puffed products because of the absence of reducing sugars and the minimal toasting of the puffed rice resulting from the short exposure to high temperature. Toasting may be the cause of the low lysine content of commercial oven-puffed rice (Khan and Eggum 1979).

TABLE IV
Effect of Puffing on the Mean Lysine, Cysteine, Methionine, and Tryptophan Contents of Milled Rice Protein of Three Varieties[a]

Milled Rice Sample	Amino Acid Content (g/16.8 g N) Lys	Cys	Met	Trp
Parboiled at 1.5 kg/cm^2	4.7	2.8	2.4	1.2
Puffed parboiled (ER 5.6)[b]	4.2	3.0	2.4	1.2
Cooked to optimum cooking	4.4	2.9	2.2	1.3
Puffed cooked (ER 5.1)[b]	4.1	2.6	2.2	1.0
Raw	4.3	3.1	1.9	1.3
Gun puffed (ER 13.6)[b]	4.3	1.6	2.1	1.5
Pooled standard deviation	±0.3	±0.3	±0.4	±0.3

[a] IR29 (waxy), IR64 (intermediate amylose), and IR42 (high amylose). Mean protein content of raw milled rice was 7.1% at 12% moisture.
[b] ER is mean expansion ratio.

Scanning Electron Micrographs

Scanning electron micrographs showed the compound starch granules in the fractured surface of raw milled rice. The outline of the starch granule was less distinct after parboiling or cooking. The

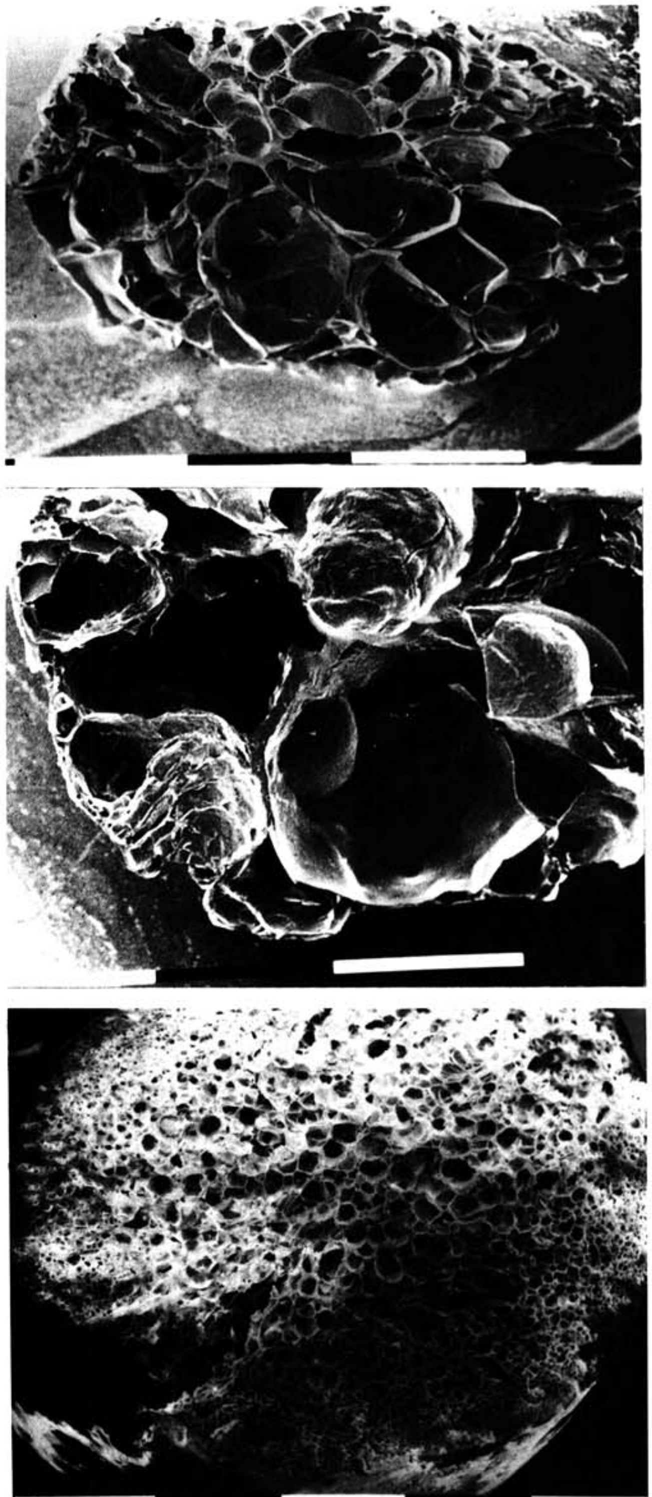

Fig. 2. Scanning electron micrographs of the fractured surface of, from top to bottom, IR64 puffed parboiled milled rice, puffed cooked milled rice, and gun-puffed milled rice. Bars correspond to 1 mm.

air spaces in oil-puffed parboiled and cooked milled rices were irregularly shaped, had variable sizes, and were randomly located (Fig. 2). In contrast, air spaces in gun-puffed raw milled rice had a regular matrix of uniform size. The high temperature of water vapor still inside the grain may have dextrinized the starch upon expansion and fixed the puffed structure.

CONCLUSIONS

Completely gelatinized rice grains, parboiled at high steam pressure or cooked in excess water, puffed well regardless of AC. Puffed volume expansion of rices cooked under mild parboiling conditions, where water becomes limited, showed dependence on rice starch GT and AC. The quality of gun-puffed rices was primarily controlled by AC. Waxy rices puffed the best, with the softest textured gun-puffed rice. However, the low- and intermediate-AC gun-puffed rices were preferred in terms of texture. It was evident in the three processes that a high protein content in the grain tends to inhibit the puffed volume expansion.

Gun puffing caused some loss in cysteine in the puffed rice products. Loss of lysine and tryptophan was negligible in the three puffed rice processes.

ACKNOWLEDGMENTS

The sample of Inga was kindly supplied by Anthony B. Blakeney and of Century Patna 231 by Bill D. Webb. The puffing gun was borrowed from Ricardo R. del Rosario, Institute of Food Science and Technology, University of the Philippines at Los Baños. The scanning electron microscope was provided by the Plant Pathology Department, IRRI.

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[Received April 8, 1987. Accepted May 7, 1987.]