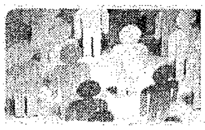

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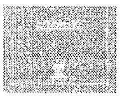

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GELATINIZATION BEHAVIOR OF GRAINS AND FLOUR IN RELATION TO PHYSICO-CHEMICAL PROPERTIES OF MILLED RICE (*ORYZA SATIVA* L.)

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ABSTRACT

Physico-chemical properties of milled rice grains of 13 japonica varieties were evaluated. The rice varieties differed in appearance. One sample had long grains (6.61 mm), two had short grains (5.27–5.32 mm) and the rest had grains of medium length (5.52–6.55 mm). The shape (length/width) of grains varied from bold (1.58–1.9) to medium (2.06–2.37). The protein content was high in all samples (7.82 to 9.72% on dry mass). Almost all, with exception of one cultivar (Osogovka), which had intermediate amylose content (23.3%), were low amylose varieties (12–19.4% amylose). Their minimum cooking time varied from 17.5 to 22.5 min. Significant correlations ($P < 0.05$) were established between some physico-chemical characteristics of evaluated rice cultivars. Elongation during minimum cooking time was correlated with protein content ($r = 0.6899$), shape (–0.7137), thickness (0.7234) and width (0.9134) of grains. The rice flour paste viscosity correlated significantly with shape (0.6148) and length (0.7353) of grains. On the basis of the established results, it was concluded that appearance of milled rice could be used as indicator for predicting gelatinization behavior: elongation ratio (length after minimum cooking time/length of the grains) of the rice grains and viscosity of rice flour during cooking.

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PRACTICAL APPLICATIONS

Results from this research constitute a useful tool to predict the gelatinization behavior of milled grains and flour of japonica rice varieties, on the basis of grain appearance. The appearance is critical in acceptability of rice varieties by the consumers. The possibility to predict rice grain behavior during cooking on the basis of its appearance could be an additional attribute or market value for consumer choice. The results could be used in selection of rice variety for rice grits or flour production and use in special applications.

INTRODUCTION

Rice grain quality is a multidimensional property and includes cooking, eating and nutritional characteristics. However, rice appearance is a very important criterion for the choice by consumers. It usually makes a simply visual preference character although does not affect nutritional quality. A high imbibitions ratio of the cooked rice is another preferable attribute. In essence, the gelatinization behavior of rice is very important for both consumers and the food industry. The overall cooking behavior and texture of cooked rice, as well as its product characteristics, are largely determined by rice grain quality described by physical and chemical characteristics. The factors that influence gelatinization properties of both rice grain and flour include: the size and shape of the starch granules, amylose content, chain length and degree of crystallinity in the amylopectin fraction, and possible placement and content of protein and lipid associated with the starch granule (Hamaker and Griffin 1993). Starch gelatinization is an irreversible process and includes granule swelling, native crystallite melting, loss of birefringence and starch solubilization (Yeh and Li 1996). It is found that swelling is characterized by an initial phase of slight swelling, a second phase of rapid swelling and a final stage in which maximum swelling of starch granule is reached (Tester and Morrison 1990). Based on viscosity structure relationship, it is pointed out that gelatinization of concentrated starch solutions is a two-step process consisting of initial swelling of the granule and its eventual disruption/dissolution (Kokini *et al.* 1992). The swelling is primarily a property of amylopectin, while amylose acts as a diluent. During swelling, at first internal structure of the starch granule is disrupted and amylose leaches from the starch granule. In the second step, dissolution of starch molecules in hot water occurs and a viscous solution is formed (Ziegler *et al.* 1993). With the temperature increasing from 35 to 55C, the size of starch granules increases slightly. However, at 65C, a dramatic increase in the size of starch granules occurs. The maximum increase of starch granules during swelling usually is reached at 75C. Above 75C, disruption/

dissolution of the starch granules proceed. The lower gelatinization temperatures are associated with a concomitant reduction of cooking time (Marshall 1992). According to Yeh and Li (1996), the disruption of starch granules occurs mainly at temperatures between 70 and 77.5C and almost no starch granules are disintegrated below 55C. The viscosity of rice flour hot-paste is implicitly related to gelatinization behavior of starch granules. The methods commonly used to measure the extent of gelatinization are: differential scanning calorimetry, light microscopy, enzymatic analyses and viscometry (Hamaker and Griffin 1993; Seow *et al.* 1996; Yeh and Li 1996). Paste viscosity differs among rice varieties and certain viscosity parameters well correlate to cooked rice texture (Hamaker and Griffin 1993). Studies on flour paste viscosity indicated that proteins specifically associated with the rice starch granules seem to control the extent to which the granules swell and gelatinize when heated in the presence of water (Hamaker and Moldenhauer 1991). Amylose content has been identified as the major determinant for cooking and eating quality of rice (Juliano 1984). Tetens *et al.* (1997) concluded that physico-chemical characteristics of milled rice are the simplest indicators for rate of starch availability from milled rice. They found that the widths and shapes of the raw grains and the elongation after cooking correlate significantly with starch digestion index.

The objective of this study was to establish some physico-chemical properties of milled rice and to identify some properties, which can be used as indicators for predicting gelatinization behavior of milled rice and rice flour.

MATERIALS AND METHODS

Samples

The 13 rice varieties (two short, 10 medium and one long grain) used in the study were grown at the Research Field for Rice of Kochani, of the Institute of Agronomy of the "Ss. Cyril and Methodius University," Skopje, R. Macedonia (harvested in 2005). Some of these samples (Monticelli, Montesa, San Andrea, R 76/6 and Prima riska) were Italian cultivars cultivated in R. Macedonia, while the rest (No. 51, Ranka, No. 69, Osogovka, Biser-2, R 76/6, Nada, Drago and Kochanski) were domestic cultivars obtained with cross breeding. The rough rice samples were stored 4 months before milling at ambient temperature.

Preparation

Paddy (50 g) was dehulled and milled in one step process, in laboratory mini mill (P Minghetti–Construzioni Meccaniche Vercelli, Italy), to 12%

degree of milling (weight of bran/[weight of milled grains + weight of bran]). The milled grains (whole and broken) were removed by hand from the blend, while the hulls and bran were separated by sieve with opening of 1 mm. Milled rice samples were kept in closed jars, at ambient temperature for 3 months until analyses were conducted. Grains were ground to flour in a coffee mill with a rotary knife. The particle size distribution was determined using a set of sieves with 0.2, 0.125, 0.100 and 0.025 mm openings. About 30–32% of the particles were smaller than 0.025 mm, 28–33% were in the range of 0.025–0.1 mm and about 35–42% were of size between 0.1 and 0.2 mm; only 0.1–0.2% were larger than 0.2 mm.

Physical Characteristics

The length, width and thickness of milled rice were measured on 30 unbroken grains using slide calipers. The grains could be classified into five categories based on their length: extra short, short (<5.5 mm), medium (5.51–6.6 mm), long (>6.61 mm) and extra long (>7.5 mm) (Jennings *et al.* 1979). The ratio of length to width (length/width = L/W) gives the shape of the grain. According to the shape, the grains could be classified as slender (>3.0), medium (2.1–3), bold (1.1–2.0) and round (<1.1). The elongation and changes of the shape during cooking were determined on 10 grains in duplicate, cooked in boiling tap water for 15 min, and time denoted as minimum cooking time (MCT). The length and width of grains evaluated for elongation ratio were measured before and after cooking as projections of the grains on overhead.

MCT

The MCT was established by subjective evaluation. Ten grains were cooked (15 min) in 100 mL tap water and their translucence was determined (Marshall *et al.* 1993). The time of each successive batch of cooking was prolonged for 20 s until all of the kernels were completely translucent. The procedure was repeated three times.

Alkali Spreading Value

Alkali spreading value was determined by the method of Little *et al.* (1958). Six milled kernels (without cracks) were arranged with enough space between them in a glass beaker (100 mL volume, diameter 48 mm, covered with a Petri dish lid) were soaked with 10 mL of 1.7% (w/v) KOH for 23 h at 30C. The kernel's appearance and disintegration were visually apprised and numerically scored using a scale of 1–7 for the following classification: 1–3 points for essentially unaffected grains by the alkali treatment (chalky kernel and powdery, cottony or cloudy collar) and they were accepted as grains with high gelatinization temperature; 4–5 points for grains with partially spread endosperm (center cottony, collar cloudy or clearing) and marked as grains with intermediate gelatinization temperature, and 6–7 points for completely dissolved grains in alkali solution (center cloudy or clear and collar clear) and they were termed as grains with low gelatinization temperature. The gelatinization temperature of milled rice ranges from about 55–79C and is divided into three main groups: low (<70C), intermediate (70–74C) and high (>74C) (Jennings *et al.* 1979).

Pasting Characteristics

The Brabender peak viscosity, onset temperature (To) and maximal temperature (Tmax) of gelatinization, and paste stability were determined at 10% concentration of rice flour (50 g flour in 450 mL salt water) in Brabender Amylograph (Brabender GmbH, Duisburg, Germany) (Hamaker and Griffin 1993). The temperature was increased in 1.5C/min increments until maximum viscosity was attained, and then viscosity was allowed to decrease for at least 100 AU. The procedure was triplicated.

Chemical Characteristics

Amylose content was determined by a modified colorimetric method of Chrastil (1994). Rice flour (16 mg), previously defatted with chloroform : methanol (2:1, v/v) by the method of Folch *et al.* (1957) and particle sizes lower than 0.1 mm was placed in a 5 mL flask, and then 0.1 M NaOH (3.5 mL) was added. The suspension was heated for 30 min in a vigorously boiling water bath, cooled and made up to exactly 5 mL with 0.1 M NaOH. Two hundred microliters of the prepared solution were pipetted into 5 mL of 0.5% trichloroacetic acid (TCA) placed in a 10 mL test tube. The solution was mixed, and 0.05 mL of a 0.01 N I_2/KI solution (1.27 g/L I_2 plus 3 g/L KI) was added and mixed immediately. The absorbance was read after 30 min at 620 nm versus H_2O in Hewlett-Packard (Germany) UV-spectrophotometer. Amylose content was estimated of standard curve prepared with pure potato amylose. Protein content was determined by *micro-Kjeldahl method* and calculated as N × 5.95. The experiments were three times repeated. All chemicals were analytical grade regents provided from Merck (Germany).

Statistical Analyses

Depending upon the analyses, three or more replications were conducted in a completely randomized design. One-way analysis of variance (ANOVA) and Duncan multiple range test were used to see differences among various groups. Significance was assumed at 5%. Pearson correlation coefficients were calculated for all investigated properties (Pezullo 2007).

RESULTS AND DISCUSSION

All investigated rice samples were japonica varieties. Physical, chemical and pasting characteristics of the rice varieties, given as mean values with standard deviation are presented in Tables 1–3.

Appearance of the Milled Grains

The milled grains of the evaluated rice varieties differed in appearance, Table 1. The milled grains varied both in length (Lo), width (Wo) and thickness (Thc). The appearance of milled rice is very important to consumers. It usually makes a simply visual preference characteristic, although it does not affect nutritional quality. The length between the grains of different rice varieties varied in the range of 5.27–6.61 mm, their width in the range of 3.11–3.46 mm. while the thickness in the range of 1.95–2.33 mm. However, according to the standard deviations differences were also identified among the grains of the same cultivar. According to the mean values of the length, rice cultivars No. 51 (5.27 mm) and Ranka (5.32 mm) could be classified as short grain, while only one cultivar, Kochanski (6.61 mm) as long grain. Most of the cultivars (Monticelli, No. 69, Osogovka, Montesa, Biser-2, San Andrea, Prima riska, R-76/6, Nada-115, and Drago) with length from 5.52 to 6.55 mm were classified as medium grain. However, with one-way ANOVA and Duncan multiple range tests, it was found that some grains of cultivar Drago were long. According to the values of the shape, ratio of length to width (Lo/Wo), most of the rice varieties were with bold grains. Only three cultivars (Nada 115, Kochanski and Drago) had a medium shape, which ratio of Lo/Wo was 2.06, 2.09 and 2.37, respectively. The results also have shown that some varieties are with very similar shape or shapes, which did not differ significantly. San Andea, Prima riska and R 76/6 were very similar among themselves, as well as Montesa and Biser-2, or No. 69 and Osogovka. It means it is not easy to recognize which rice varieties they really belong to according to their appearance. Jennings *et al.* (1979) reported that those people who prefer japonica rice almost always like short grains; however, Europeans prefer japonicas with medium to medium long grains and demand a slender to medium width rice grains.

Swelling Power and Cooking Time

The most important characteristic of rice is its behavior during cooking. According to Tetens *et al.* (1997), the minimum cooking time of modern Bangladesh rice varieties is in the range of 14.1–26.0 min. This wide range of variation in minimum cooking time among the rice varieties was the main reason why, at first, the changes of length and width of the grains were

TABLE 1.
APPEARANCE OF MILLED RICE VARIETIES WITH SHORT, MEDIUM AND LONG GRAINS*

Characteristics	Short grain†		Medium grain†										Long grain
	No. 51	R-ka	M-lli	No. 69	O-ka	M-sa	Biser-2	SA	P-ska	R 76/6	N-115	Drago	K-ski
Length (Lo), mm	5.27g	5.32g	5.52f	5.66f	5.74e	5.79e	6.21d	6.25d	6.30d	6.41c	6.49b,c	6.55a,b	6.61a
SD ($n = 30$)	0.062	0.069	0.089	0.099	0.147	0.102	0.080	0.082	0.129	0.064	0.134	0.162	0.107
Width (Wo), mm	3.33c,d	3.36b,c	3.22e	3.40a,b	3.46a	3.11f	3.44a	3.21e	3.29d	3.29d	3.16e,f	2.76g	3.17e,f
SD ($n = 30$)	0.075	0.041	0.054	0.068	0.055	0.096	0.075	0.047	0.093	0.057	0.056	0.058	0.049
Thickness, (Thc), mm	2.15c	2.33a	2.11d	2.17c,d	2.24b	2.15c,d	2.15cd	2.18b,c	2.15c	2.20b,c	2.04e	2.02e	1.95f
SD ($n = 30$)	0.066	0.086	0.075	0.032	0.069	0.097	0.076	0.041	0.048	0.061	0.049	0.056	0.047
Shape (Lo/Wo)	1.58h	1.58h	1.72f	1.63g	1.66g	1.86d	1.80e	1.95c	1.92c	1.95c	2.06b	2.37a	2.09b
SD ($n = 30$)	0.057	0.035	0.030	0.056	0.054	0.056	0.033	0.019	0.056	0.040	0.039	0.058	0.052

* Means and standard deviations (SD) with different superscripts across the rows are significantly different ($P < 0.05$).
† Abbreviations for the name of rice cultivars: R-ka, Ranka; M-lli, Monticelli; O-ka, Osogovka; M-sa, Montesa; SA, San Andrea; P-ska, Prima riska; N-115, Nada-115; K-ski, Kochanski.

TABLE 2.
SWELLING POWER AND MINIMUM COOKING TIME OF MILLED RICE VARIETIES WITH SHORT, MEDIUM AND LONG GRAINS*

Characteristics	Short grain		Medium grain										Long grain
	No. 51	R-ka	M-lli	No. 69	O-ka	M-sa	Biser-2	SA	P-ska	R 76/6	N-115	Drago	K-ski
Length (L15), mm	8.69d,e	8.67d,e	8.56d,e	9.17c,d	10.27a	8.28e	9.07c,d	8.56d,e	9.51b,c	9.87a,b	8.44e	9.30b,c	9.12c,d
SD ($n = 20$)	0.494	0.447	0.369	0.220	0.788	0.803	0.581	0.431	0.61	0.889	0.429	0.678	0.499
Width (W15), mm	4.01a,b,c	4.19a,b	3.75c	4.25a	4.11a,b	3.91b,c,d	4.05a,b	4.14a,b	4.14a,b	4.11a,b	3.66d	3.92b,c,d	3.93b,c,d
SD ($n = 20$)	0.223	0.214	0.389	0.290	0.326	0.451	0.295	0.229	0.146	0.315	0.185	0.180	0.230
Elongation ratio (L15/Lo)†	1.65b	1.63b	1.55b,c	1.62b	1.79a	1.43c,d	1.46c	1.37c,d	1.51b,c	1.54b,c	1.30d	1.42c,d	1.38c,d
SD ($n = 20$)	0.132	0.118	0.118	0.242	0.186	0.098	0.154	0.110	0.104	0.165	0.107	0.120	0.095
Expansion (W15/Wo)	1.18e,d	1.30a,b	1.33a	1.22c,d,e	1.25b,c	1.24b,c,d	1.21c,d,e	1.29a,b	1.25b,c	1.29a,b	1.16e	1.32a	1.25b,c
SD ($n = 20$)	0.046	0.043	0.060	0.073	0.077	0.118	0.075	0.065	0.019	0.069	0.041	0.072	0.072
Min. cooking time(MCT), min	19.61e,f	22.5a	17.5g	21.7b,c	20.3d,e	22.3a,b	21.4c	19.2f	20.5d	21.7b,c	22.0a,b	20.5d	19.2f
SD ($n = 30$)	0.508	0.994	0.907	0.681	0.750	0.957	0.888	0.771	0.701	0.831	0.538	0.942	0.654
Elongation ratio (Lt/Lo)‡	1.97b	1.93b,c	1.65d,e	1.90b,c	2.17a	1.67d,e	1.96b	1.80c,d	1.89b,c	1.94b,c	1.53e,f	1.43f	1.67d,e
SD ($n = 20$)	0.105	0.136	0.108	0.167	0.156	0.151	0.161	0.158	0.151	1.140	0.128	0.174	0.160

* Means and standard deviations (SD) with different superscripts across the rows are significantly different ($P < 0.05$).
† (L15/Lo) – elongation ratio after 15 min cooking.
‡ (Lt/Lo) – elongation ratio after min cooking time.
R-ka, Ranka; M-lli, Monticelli; O-ka, Osogovka; M-sa, Montesa; SA, San Andrea; N-115, Nada-115; K-ski, Kochanski.

TABLE 3.
CHEMICAL AND PASTING CHARACTERISTICS OF MILLED RICE VARIETIES WITH SHORT, LONG AND MEDIUM GRAINS AND THEIR FLOUR*

Characteristics	Short grain		Medium grain										Long grain
	No. 51	R-ka	M-lli	No. 69	O-ka	M-sa	Biser-2	SA	P-ska	R 76/6	N-115	Drago	K-ski
Alkali spreading value	4.50d	3.75a,d,f	2.50g	3.00f	4.34d	4.75cd	3.00f	6.25a,b	5.25c,d	4.25c,d	6.50a	5.50b,c	4.33d
SD (n = 18)	0.534	0.707	0.534	0.756	0.754	1.581	0.926	0.088	0.089	0.463	0.756	0.534	0.715
Amylose (%)	17.22c	12.00g	19.41b	14.62e	23.35a	15.35c,d	13.13f,g	13.54f	18.74b	16.35c,d	13.55f	15.68d	13.52f
SD (n = 3)	0.041	0.273	0.731	0.574	0.382	0.714	0.428	0.646	0.669	0.434	.385	0.816	0.554
Protein (Pr) (Nx5.95) (g/100 g dry mass)	8.93b,c	9.47a,b	8.72c,d,e	8.81c,d	8.86b,c	7.91f	9.12a,b,c	8.06e	8.18d,e,f	9.72a	7.82f	7.95f	8.20d,e,f
SD (n = 3)	0.383	0.178	0.197	0.439	0.535	0.266	0.374	0.142	0.322	0.226	0.417	0.382	0.346
To (C)	60.5c	71.17a	60.0c,d	62.5b	58.0e,f	57.5f	60.5c	59.5c,d,e	55.5g	58.5d,e	60.0c,d	57.5f	58.0f
SD (n = 3)	0.500	1.04	1.322	0.866	1.322	0.866	1.322	1.322	0.500	0.866	0.866	0.866	0.500
Tmax (C)	78.5b	83.0a	76.0c,d	74.5d,e	75.0c,d	68.5g	75.0c,d	75.5c,d	71.0f	76.5b,c	75.5b	74.0d,e	73.0e
SD (n = 3)	0.500	0.500	1.000	0.866	0.500	0.866	1.322	0.500	1.000	0.500	0.866	0.866	0.866
Viscosity, (AU)	600.0f	110.0g	690.0e	610.0f	1,035.0a	980.0c	970.0c	1,020.0a,b	1,020.0a,b	1,015.0a,b	910.0d	990.0b,c	980.0c
SD (n = 3)	21.794	5.000	18.027	13.228	21.79	18.027	18.028	20.000	20.000	13.229	18.028	13.229	18.027
Paste stability, min	5.4a	0.00g	3.0c	4.5b	2.4d,e	1.8f	1.8f	2.5d	1.7f	2.0e,f	2.0e,f	1.9f	2.8c,d
SD (n = 3)	0.14	0.00	0.046	0.173	0.265	0.132	0.050	0.436	0.265	0.132	0.278	0.132	0.36

* Means and standard deviations (SD) with different letters across the rows are significantly different ($P < 0.05$).
R-ka, Ranka; M-lli, Monticelli; O-ka, Osogovka; M-sa, Montesa; SA, San Andrea; P-ska, Prima riska; N-115, Nada-115, K-ski, Kochanski; To, onset temperature; Tmax, maximal temperature.

determined after 15 min of cooking (L15, W15), and then after attaining a minimum cooking time (Lt, Wt), Table 2. The data was used for calculation of elongation ratios (L15/Lo) and (Lt/Lo) of the grains cooked for 15 min and time established as minimum for cooking, respectively. The lowest elongation ratio (1.3) after 15 min of cooking (L15/Lo) was established for the grains of Nada-115, and the greatest elongation ratio (1.79) for grains of Osogovka. The varieties with shorter grains had attained a higher elongation ratio during 15 min cooking. The expansion of the grains (W15/Wo) during 15 min cooking was less than their elongation, varying in the range of 1.16–1.29. However, the grains of cultivar Drago have attained the same values of expansion as well as elongation ratio (1.42).

The MCT for all milled rice varieties was greater than 15 min and varied among the cultivars. The shortest MCT (17.5 min) was established for grains of cultivar Monticelli, while the longest MCT (22.5 min) for grains of Ranka. During prolonged cooking from 15 min to attaining of MCT, additional elongation of the grains occurred. The greatest (2.17) elongation ratio (Lt/Lo) was attained by grains of cultivar Osogovka, while the smallest (1.43) elongation ratio was attained by grains of cultivar Drago. It has to be pointed out that the grains of Drago had negligible increases in elongation ratio (1.43) after MCT compared to the elongation ratio (1.42) after 15 min cooking. The grains of cultivars Osogovka and Drago, although have almost the same MCT, 20.3 min and 20.5 min, respectively, they have shown completely different gelatinization behavior during cooking due to their different chemical composition.

Amylose and Protein Content

All rice samples were varieties with high protein contents (7.82–9.72%), Table 3. Generally, the protein content among the rice varieties is 6–10% (Morita and Kiriyama 1993). The high protein content in rice is especially important when rice flour is used in preparing baby food or is the main nutrient source. Rice flour possesses unique nutritional properties. It is hypoallergenic, colorless and has a bland taste. Compared with other cereals, rice has a higher lysine content (3–4%) and more balanced amino acid profile (Shih and Daigle 1997). However, besides the nutritional value, specific proteins associated with the starch granules have some influence on viscoelastic properties of the cooked grains and flour. Low protein rice samples are more tender than high protein samples of the same cultivar (Hamaker and Griffin 1993; Kadan *et al.* 1997). High protein rice has been shown to absorb water at a slower rate during cooking. It has been hypothesized that more protein forms a thicker barrier around the starch granule, thus slowing water uptake and retarding gelatinization and swelling.

The properties of cooked rice mainly depend on the amylose content (Hamaker and Griffin 1993; Lii *et al.* 1996). Amylose content of the rice varieties evaluated has varied from 12–23.3%. On the basis of amylose content, rice varieties could be grouped into waxy (1–2% amylose), low-amylose (8–20%), intermediate-amylose (21–25%) and high-amylose (>25%) cultivars. The estimated rice cultivars, with exception of Osogovka, which was intermediate-amylose type (23.3% amylose), were low-amylose varieties with 12 to 19.4% amylose. Usually low-amylose varieties are moist and glossy when cooked, and tend to disintegrate easily while swollen and extensively overcooked. High-amylose varieties are more rigid and not easily ruptured. They cook dry and fluffy, but become hard upon cooling (Tester and Morrison 1990).

Gelatinization Characteristics of Rice Grains and Flour

Alkali test was used as indirect method for estimation of approximate gelatinization temperature of rice grains because it is an indicator of rice endosperm compactness. It refers to cooking temperature at which water is absorbed and the starch granules swell irreversibly. According to the results of alkali spreading test, Table 3, the rice cultivars Monticelli, No. 69 and Biser-2 are with high gelatinization temperatures, cultivars San Andrea and Nada-115 are with low gelatinization temperatures, while the rest of the rice cultivars are with intermediate gelatinization temperatures. Comparatively, gelatinization temperature was determined on 10% rice flour slurry using a Brabender Amylograph. The results of Amylograph, Table 3, have shown that only flour of cultivar Ranka had an intermediate (71C) onset gelatinization temperature. The flours of the rest of the rice cultivars have shown lower onset gelatinization temperatures (55.5–62.5C). These results are not in agreement with the data of the alkali-spreading test. An additional gelatinization property, which is a very important property in preparing food, is the viscosity of gelatinized rice flour. The evaluated rice varieties could be grouped into three categories according to the data for Brabender peak viscosity: with low viscosity (<700 AU), No. 51, No. 69 and Monticelli, with high viscosity (700–1000 AU), Nada 115, Biser-2, Montesa, Kochanski and Drago, and the rest of the cultivars, with the exception of cultivar Ranka, were with very high viscosity (>1000 AU). The flour of Ranka was with very specific low value of max viscosity (110 AU).

The time needs to decrease maximum viscosity for 100 AU during continuous heating of gelatinized slurry, denoted as stability of paste consistency, also varied among the investigated rice cultivars in the range of 1.8–5.5 min.

Correlation between Physico-chemical Characteristics of Milled Rice and its Behavior during Cooking

The results of performed correlation analyses between physico-chemical characteristics of evaluated rice cultivars are given in Table 4. Significant

TABLE 4.
CORRELATION COEFFICIENTS BETWEEN PHYSICO-CHEMICAL CHARACTERISTICS OF MILLED AND COOKED RICE GRAINS

Variable	Lo	Wo	Thc	Lo/Wo	L15/Lo	(L/W)15	MCT	Lt/Lo	ASV	Amy	Pr
Lo, mm	1.00	−0.48	−0.63*	0.89*	−0.72*	0.43	0.05	−0.46	0.50	−0.24	−0.40
Wo, mm		1.00	0.62*	−0.83*	0.60*	−0.09	0.11	0.88*	−0.48	0.17	−0.61*
Thc, mm			1.00	−0.72*	0.66*	−0.30	0.36	0.73*	−0.27	0.14	0.64*
Lo/Wo				1.00	−0.75*	0.35	−0.03	−0.74*	0.57*	−0.22	−0.60*
L15/Lo					1.00	0.18	−0.04	0.77*	−0.51	0.61*	0.65*
L15/W15						1.00	−0.17	0.05	0.01	0.63	0.05
MCT, mins							1.00	−0.36	0.13	−0.42	0.17
Lt/Lo								1.00	−0.36	0.36	0.69*
ASV, number									1.00	−0.13	−0.64*
Amy (%)										1.00	0.07
Pr (%)											1.00

* Significant at $P < 0.05$.

Lo, height; Wo, width; Thc, thickness; Lo/Wo, shape; (L/W)15, shape after 15 min cooking; MCT, minimum cooking time; Lt/Lo, elogation ratio; ASV, Alkali spreading value; AMY, amylose; Pr, protein.

correlations ($P < 0.05$) were found among some parameters of milled rice appearance, their chemical composition, and changes of the grains during cooking. The shape of the grains positively correlated with length ($r = 0.89$) and negatively with width ($r = -0.83$), as a consequence of its relation (Lo/Wo), but also negatively with thickness ($r = -0.72$). Between length and thickness of the grains, negative correlation ($r = -0.63$) was found; however, between width and thickness, positive correlation ($r = 0.62$) was found. The protein content positively correlated with width ($r = 0.61$) and thickness ($r = 0.64$), but negatively with shape ($r = -0.6$). These correlations are very similar to those found among indica rice varieties by Tetens *et al.* (1997). This is useful information to identify varieties of rice richer with proteins.

The rice behavior during cooking is a very important characteristic about consumers and food manufacturers. The results have shown that grains behavior during cooking significantly correlated with some physico-chemical characteristics of milled rice. A significant positive correlation was found between elongation ratio (L15/Lo) attained after 15 min cooking and width ($r = 0.60$), as well as thickness ($r = 0.66$) of the grains; however, it negatively correlated with length ($r = -0.72$) and shape ($r = -0.75$). Besides swelling of the starch during cooking, a part of water is absorbed by the proteins, the elongation ratio after 15 min of cooking has shown a significant positive correlation with amylose ($r = 0.61$) and protein ($r = 0.65$) content. The shape of the grains after 15 min of cooking was positively correlated only with amylose content ($r = 0.63$). The elongation ratio (Lt/Lo) attained during minimum cooking time has shown a significant positive correlation with the width ($r = 0.88$) and thickness ($r = 0.73$) and negative correlation with the shape of the grains ($r = -0.74$). The correlation of elongation ratio (Lt/Lo) with protein content ($r = 0.69$), and also with elongation ratio after 15 min of cooking ($r = 0.77$) is very important. Similar positive correlations were found between elongation ratio of Bangladesh indica rice varieties and width and protein content by Tetens *et al.* (1997). Based on the above-mentioned finding, it can be concluded that amylose content has an influence on elongation ratio after 15 min of cooking, but not on the elongation ratio attained during minimum cooking time. Most probably during 15 min of cooking and swelling of starch granules, amylose was completely dissolved. The results (Table 3) have shown that the evaluated rice cultivars, with exception of one (Osogovka) are with low amylose contents. After dissolving of amylose, penetration of water is facilitated, and in general swelling of proteins contributed to additional elongation of rice grains. As a result of that, elongation ratio (Lt/Lo) after prolonged cooking from 15 min to minimum cooking time correlated only with protein content. Although it is well known that high-protein rice absorbs more water at slower rate and has prolonged cooking time (Kadan *et al.* 1997), among evaluated rice cultivars, any significant correlation between protein content

TABLE 5.
CORRELATION COEFFICIENTS BETWEEN PHYSICO-CHEMICAL CHARACTERISTICS OF MILLED RICE GRAINS AND GELATINIZATION PROPERTIES OF RICE FLOUR

Variable	To	Tmax	Viscosity	Paste stability
Length, mm	0.57*	–0.45	0.74*	–0.28
Width, mm	0.34	0.32	–0.28	0.15
Thickness, mm	0.56*	0.49	–0.48	–0.25
Shape, (length/width)	–0.53	–0.43	0.61*	–0.27
Elongation ratio after 15 min cooking	0.29	0.38	–0.41	0.23
Shape (length/width) after 15 min cooking	–0.54	–0.20	0.54	–0.03
(MCT), mins	0.33	0.03	–0.16	–0.45
Elongation ratio after minimum time of cooking	0.21	0.31	–0.17	0.13
Alkali spreading value (ASV) test (number)	–0.34	–0.20	0.41	–0.14
Amylose (%)	–0.47	–0.20	0.28	0.25
Protein content(g/100 dm)	0.52	0.65*	–0.47	–0.02
To (C)*	1.00	0.81*	–0.91*	–0.24
Tmax (C)		1.00	–0.75*	–0.06
Viscosity (AU)			1.00	0.02
Paste stability (mins)				1.00

* Significant at $P < 0.05$.
MCT, minimum cooking time; To, onset temperature; Tmax, maximal temperature.

and minimum cooking time was not found. Alkali spreading value significantly correlated with the shape of the rice grains ($r = 0.57$) and negatively with protein content ($r = -0.64$). In essential, the shape has positive influence on the rate of water absorption and starch swelling; however, proteins associated with the starch granules by disulfide bonds, according to Hamaker and Griffin (1993), make the swollen granule less susceptible to disruption.

Correlation between Physicochemical Characteristics of Milled Rice and Rice Flour Gelatinization Behavior

Generally, most of the rice is consumed as cooked grain. However, in recent times, there has been a steady increase in new processes and products involving rice flour as an ingredient. It imposes knowledge of relations between physico-chemical properties of rice grains and gelatinization behavior of flours. The onset gelatinization temperatures of rice flours have shown significant positive correlation with thickness ($r = 0.56$), but negative with length ($r = -0.57$) of milled grains, Table 5. Hettiarachchy *et al.* (1997) informed that long grain varieties generally have high amylose content and gelatinization temperature. However, evaluated flours prepared of rice varieties with longer grains had lower onset temperature of gelatinization, but flour of thicker rice grains had higher onset temperature of gelatinization. Viscosity of rice flour slurry has shown a significant positive correlation with the length ($r = 0.74$) and shape ($r = 0.60$) of the rice grains and high negative correlation with onset (To) and maximum (Tmax) gelatinization temperature ($r = -0.91$ and $r = -0.75$), respectively. Hamaker and Griffin (1993) in comparing of three rice varieties, with short, medium and long grains found that viscosity was higher in flour of long grain rice.

Most of the evaluated rice varieties were with medium length. The positive correlation of flours viscosity with lengths of the grains indicated that good paste consistency could be achieved with lower quantity of flour if it is obtained from rice cultivars with longer grains. Reasonably, the temperatures of max gelatinization positively correlated with protein content ($r = 0.65$). There was no significant correlation between stability of paste consistency and any of rice physico-chemical characteristics found.

The above-mentioned results suggested obtaining of quantitative relations as equations of the first order (Eqs. 1 and 2) for predicting of elongation ratio of rice grains, and viscosity of the rice flour during cooking, on the base of physical characteristics of milled rice grains.

$$\text{Elongation ratio (Lt/Lo)} = -1.425 + 0.996\ \text{Width} \quad (r = 0.8806) \qquad (1)$$

$$\text{Viscosity (AU)} = -1{,}671 + 418.06\ \text{Length} \quad (r = 0.7353) \qquad (2)$$

A relatively good correlation of the predicted equations with adequate physical characteristics of the grains have shown that appearance of milled rice grains could be used as an indicator for predicting gelatinization behavior of rice grains and flour during cooking.

CONCLUSIONS

Evaluated rice samples were japonica varieties. Differences in physico-chemical characteristics of different rice varieties were observed. They had high protein (7.82–9.72%) and low amylose (12–19.4%) contents, except one cultivar that had an intermediate amylose content (23.3%). The correlation analyses have shown good correlations exist between some characteristics of milled rice grains and elongation ratio of the grains as well as viscosity of rice flour during cooking.

On the basis of this results could be concluded that appearance of milled rice grains could be used as indicator for predicting their elongation ratio and viscosity of flour during cooking. It means that during cooking of grains with greater width, a larger elongation could be obtained, and pasta with higher viscosity could be expected during cooking rice flour produced of longer grains.

These results indicate that different amounts of rice flour are needed for preparing paste with appropriate good consistency. Thus, the length of grains could be used as criteria in selection of rice variety for flour production. For special applications with lower quantity of rice flour obtained from rice varieties with longer grains would give paste with enough good consistency.

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