Title: The cooking behavior of rice pasta: the effect of thermal treatments and extrusion conditions

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Abstract

The effects of pre-gelatinization, mild and severe parboiling processes on paddy rice and the utilization of the corresponding flours (PGF, MPF, and SPF) for gluten-free (GF) pasta-making were investigated. Flour from native rice (NF) was considered as a control. Two pasta-making processes (extrusion-cooking and conventional extrusion) were carried out and seven GF pasta samples, with different thermal treatments but without the addition of additives, were obtained. The thermal treatments affected the physical properties and the susceptibility to α-amylase hydrolysis of rice flours to different extents. The loss of starch granule integrity during the pre-gelatinization process promoted high viscosity at 30°C and dramatically increased the mass of absorbed water, the amount of soluble components leached out from the granules and the fraction of starch quickly hydrolyzed by α-amylase. Compared to pre-gelatinization, both parboiling processes induced lower pasting viscosity at any temperature, enzymatic susceptibility, and hydration. The magnitude of these changes significantly increased with the severity of the parboiling treatment. The lowest value for cooking loss was detected for samples prepared by 100% SPF (extrusion-cooking) or by mixture of SPF and PGF (50:50) (conventional extrusion). Nevertheless, the extrusion-cooking process promoted a firm texture when applied to parboiled flours.

Keywords: rice, pre-gelatinization, parboiling, gluten-free pasta, cooking quality

Abbreviations: BD, breakdown; BU, Brabender units; FV, final viscosity; GF, gluten-free; IV, initial viscosity; MPF, mild parboiled rice flour; NF, native rice flour; PaMPF_A, pasta from mild parboiled rice flour (extrusion-cooking); PaMPF_B, pasta from mild parboiled rice flour (conventional extrusion); PaNF_A, pasta from native rice flour (extrusion-cooking); PaPGF_B, pasta from pregelatinized rice flour (conventional extrusion); PaSPF_A, pasta from severe parboiled rice flour (extrusion-cooking); PaSPF_B, pasta from severe parboiled rice flour (conventional extrusion); PaSPF+PGF_B, pasta from severe parboiled and pregelatinized rice flour (50:50) (conventional extrusion); PGF, pregelatinized rice flour; PT, pasting temperature; PV, peak viscosity; SB, setback; SP, swelling power; SPF, severe parboiled rice flour; WAI, water absorption index; WSI, water solubility index.

1. Introduction

Rice flour is widely used as a raw material to prepare gluten-free (GF) products for its bland taste, white color, high digestibility, and hypoallergenic properties (Rosell&Marco, 2008). However, in spite of its advantages, rice is low in protein and has relatively poor technological properties for interacting and developing a cohesive network.

Up to now, GF pasta made from rice flour has usually been prepared in one of two ways (Pagani, 1986). In the first, native rice flour is treated with steam and extruded at high temperatures (more than 100°C) for promoting starch gelatinization directly inside the extruder-cooker. The second method focuses on the use of pre-gelatinized flours, in which starch is already partially gelatinized; the pre-treated flour can be formed into pasta by the continuous extrusion press commonly used in durum wheat semolina pasta-making. In this regard, annealing and heat-moisture treatments have been proposed for rice flour and/or cereal starch to induce new physiochemical properties. Because it is easy to use, pre-gelatinized flour is the most commonly used in industrial GF pasta production. Even if the effects of pre-gelatinization on starch from different sources (cassava, corn, rice, etc.) have been extensively investigated (Nakorn, Tongdang&Sirivongpaisal, 2009; Lai&Cheng, 2004; Anastasiades, Thanou, Loulis, Stapatoris&Karapantsios, 2002; Vallous, Gavrielidou, Karapantsios& Kostoglou, 2002; Lai, 2001; Perez-Sira&Gonzalez-Parada, 1997), there is not much information about the relationship between the induced starch arrangement and rheological properties of pre-gelatinized flour or its suitability for pasta-making or its cooking behavior.

Recently, the use of flour from parboiled rice as a raw material for pasta products was proposed (Grugni, Mazzini, Viazzo&Viazzo, 2009), by obtaining GF pasta with a good cooking behavior (Marti, Seetharaman&Pagani, 2010) due to the particular starch arrangements in the product (Marti, Pagani&Seetharaman, 2011).

The first objective of this study was to investigate the effects of three heating processes (pre-gelatinization and two parboiling processes differing in their steeping conditions) on rice flour properties, with particular attention to starch arrangements; the latter were evaluated by enzymatic and rheological approaches. Then, the relationship between starch properties and cooking behavior of the pasta samples was studied. The experimental products were prepared according to the two technologies currently used in the GF field, avoiding the addition of any additives (modified starches, gums, emulsifiers, etc.) to determine if physical treatments of raw rice materials can induce effective macromolecular organization, thus assuring the formation of a cohesive and regular starchy network.

2. Experimental

2.1 Rice flours and pasta production

Four types of rice flours were produced with different thermal treatments (Figure 1). Starting from Indica type cultivar of commercial origin, a native flour (NF; total starch: 84%db, AACC 76-13; amylose: 25%, UNI ISO 6647; protein: 6.8%db, AOAC 920.87; ash: 0.66%db, AACC 08-12) was produced by directly grinding the milled (or white) rice (particle size<500 μm). The pre-gelatinized flour (PGF) was obtained by heating with steam (3.5atm, 115°C, 45min). Moreover, the same paddy rice was subjected to two parboiling treatments, namely “mild” (steeping: 60°C; steaming: 1.1atm, 100°C) and “severe” (steeping: 70°C; steaming: 1.1atm, 100°C) parboiling. Both parboiled rice types were milled and then ground (particle size<500μm) for obtaining mild (MPF) and severe (SPF) parboiled rice flour.

Pasta from NF was prepared by using the extrusion-cooking process (Process A), as shown in Figure 2a. NF-water mixture (40% moisture) was heated by steam at 2.5atm for 10min in a gelatinization tank at 120°C. After that, the pre-treated dough was subjected to a first extrusion at 120°C (extrusion-cooking) and formed into pellets (small cylinders of 2-3mm diameter). After this first extrusion step, the pellets were transferred into a lab-scale extruder for semolina pasta (20kg/h; MAC 30, Italpast, Parma, Italy), for the second extrusion step at 50°C. Samples were formed into macaroni shape (7mm external diameter) and dried in an experimental drying cell using a low-temperature drying cycle (50°C max; 14h).

Pasta from PGF was prepared using the conventional extrusion process for semolina (Process B; Figure 2b). PGF and water (40% dough moisture) were formed into pasta in the lab scale extruder used for Process A, keeping the extrusion temperature at 50°C. Pasta drying was carried out in the same manner for Process A. Only the presence of partially disorganised starch, such as in MPF and SPF, guarantees the formation of pasta by using either Process A or B.

Another sample was prepared by adding the PGF to the SPF at a level of 50% and the mixture was extruded by using Process B.

To summarize, starting from the same commercial rice type, seven pasta samples (all of the same shape) were prepared and stored at room temperature until analyzed.

2.2 Rice flour characterization

Damaged starch content was determined according to AACC 76-31 official methods. A color meter (CR 210, Minolta Co., Osaka, Japan) was used to measure the lightness (L*) and saturation of the color intensity value (a*, redness-greenness; b*, yellowness–blueness) of flours. Hydration properties were expressed as water absorption index (WAI), water solubility index (WSI), and swelling power (SP) and were measured according to Lai&Cheng (2004). Pasting properties of rice flours were measured according to Marti, Seetharaman&Pagani (2010) by a Brabender Micro-Visco-AmyloGraph (Brabender, Duisburg, Germany).

2.3 Pasta characterization

Color, susceptibility to α-amylase hydrolysis and pasting properties were measured in ground pasta (particle size<500 μm) as described for flour. Cooking losses were evaluated by determining the amount of solid dispersed in the cooking water (g of matter lost/100 g of dry pasta (D’Egidio, Mariani, Nardi, Novaro&Cubadda, 1990), at a pasta:water ratio = 1:10 and no salt. After cooking for the optimum cooking time (OCT; D’Egidio, Mariani, Nardi, Novaro&Cubadda, 1990), the pasta was drained, the original quantity of water was restored, and an aliquot was dried to constant weight at 105°C. The weight increase in pasta due to water absorption during cooking was evaluated gravimetrically. The textural characteristics of cooked pasta were determined by using the Texture Analyzer TA.HD-plus (Stable Micro System Ltd., Godalming, United Kingdom), equipped with Kramer cell, according to Marti, Seetharaman&Pagani (2010). The cooking behavior of pasta samples was compared to those of commercial semolina pasta (Barilla brand) with the same shape.

2.4 Statistical analysis

One-way analysis of variance (ANOVA; LSD, Least Significant Differences) was performed using STATGRAPHIC®*Plus* (StatPoint Inc. Virginia, U.S.A.).

3. Results and Discussion

3.1 Effect of thermal treatments of rice flours

No significant differences in starch or protein content were observed between NF and heat-treated flours (data not shown). As expected, total ash was significantly higher ($p<0.05$) in parboiled flours (0.88%db) compared to NF (0.63%db) because of the diffusion of water-soluble constituents into the endosperm during parboiling (Bhattacharya, 2004).

3.1.1 Color

The thermal treatments carried out on rice kernels affected the color of the flours, causing an overall decrease in luminosity (Table 1). A decrease in redness and yellowness was detected in PGF; whereas, regardless of the severity of treatment, parboiling increased not only the darkness (decreasing in L* value), but also the a* and b* color parameters, confirming the observations of Elbert, Tolaba&Suarez (2001). The darker and more yellow color after parboiling is a consequence of the migration of pigments from the husk and/or bran to the endosperm (Bhattacharya&Ali, 1985), non-enzymatic browning (Dendy, 2000), and enzymatic actions occurred during soaking (Lamberts, Brijs, Mohamed, Verhelst&Delcour, 2006). SPF flour exhibited higher yellowness and redness compared to MPF, confirming the role of both soaking and steaming conditions, as well as drying methods, in changing color parameters (Lamberts, Rombouts, Brijs, Gebruers&Delcour, 2008).

3.1.2 Hydration properties

The high degree of associative forces in the starch granules of NF accounted for its insolubility in cold water and, consequently, for the low WAI, WSI, and SP values (Table 1). Starch hydration properties were greatly affected by heating treatments as a consequence of macromolecular disorganisation and degradation (Nakorn, Tongdang&Sirivongpaisal, 2009). The significant increase in WAI and SP values after pre-gelatinization may represent the macroscopic result of the greater ability of "exposed" hydrophilic groups to bind water molecules and to form a gel, as suggested by Lai&Cheng (2004). Only severe parboiling conditions significantly changed the hydration properties of flour.

The WSI value is generally used as an indirect index of the loss of starch organisation during heat-treatments. Pre-gelatinization seemed to promote a partial break-up of molecular components, as compared to that of NF. On the contrary, parboiling did not induce the formation of soluble components, a behavior due to the re-association of amylose and/or amylopectin, resulting in an increased rigidity of the starch molecules (Lai&Cheng, 2004).

3.1.3 Susceptibility to α-amylase hydrolysis and pasting properties

The measure of starch susceptibility to α-amylase hydrolysis (expressed as damaged starch) may represent an indirect tool for obtaining information about the starch organisation resulting from heat-treatments on rice flour. The percentage of α-amylase susceptibility increased in flours which had undergone heat-treatments (Table 2). This index was almost 20 times higher in PGF than that for NF, as steam treatment induced a high degree of starch gelatinization (Alamprese, Casiraghi&Pagani, 2007). This trait accounted for the great hygroscopicity of the flour (Table 1), as reported by Colonna, Tayeb&Merciers (1989). After both parboiling processes, starch granules became a little more accessible to enzymatic hydrolysis than NF. However, the modest susceptibility to amylase in parboiled flours may be due to the cooling stage after heat-treatments of the kernels, which promotes retrogradation and recrystallization of the gelatinized starch granules (Ong&Blanshard, 1994).

Pasting properties of rice flours before and after each heat-treatment are shown in Figure 3 while viscosity data is summarized in Table 2. NF exhibited the typical pasting behavior of Indica varieties. Heat-treatments significantly modified these traits. The viscosity profile indicates that the starch granules in PGF are already swollen and highly susceptible to hydration, as the initial cold paste viscosity demonstrates. This result is consistent with the greater enzymatic susceptibility and high water absorption capacity of the PGF previously discussed (Table 1). The high initial viscosity and the low PT in pregelatinzed rice may be attributed to the disruption of the molecular order within the starch granules during the treatment, resulting in the loss of granule integrity and destruction of starch crystallinity (Lai&Cheng, 2004; Lai, 2001). During the heating step, PGF reached a peak viscosity similar to that for NF, probably as a consequence of residual starch that was still in the native form. During the cooling phase, PGF exhibited less retrogradation intensity compared to NF (see SB values). Viscosity of MPF and SPF flours was dramatically lower during the whole temperature profile, compared to NF, indicating the presence of relevant compactness among starch macromolecules. After parboiling, no peak viscosities, no breakdown, and low SB were observed, confirming the data of Derycke et al. (2005) and suggesting a type-C pasting profile (Schoch&Maywald, 1968). In addition, SPF flour showed lower viscosity values than those for MPF flour, indicating that the former process caused more retrogradation and, consequently, a greater re-association of starch macromolecules.

3.2 Effect of pasta-making process

3.2.1 Color

Pasta color was strongly affected by the heat-treatment conditions used to produce rice flour (Table 3). PaNF_A and PaPGF_B showed the highest luminosity and the lowest yellowness values. As expected, the use of flour from parboiled rice (alone or mixed to PGF) decreased the lightness of pasta samples, due to the migration of pigments and soluble components towards the endosperm of rice kernels during the parboiling process (Bhattacharya&Ali, 1985). Moreover, regardless of the intensity of the treatment, pasta from parboiled rice showed a luminosity similar to that of commercial samples from semolina (data not shown), improving the overall acceptability of the product. Finally, the pasta-making process (extrusion-cooking *vs* conventional extrusion) carried out on parboiled flours did not change the luminosity and redness of the products, confirming that the major changes in color were associated with the phenomena occurring during parboiling.

3.2.2 Susceptibility to α-amylase hydrolysis and pasting properties

The extrusion conditions promoted changes in starch susceptibility to α-amylase actions (Figure 4). The extrusion-cooking process on NF greatly increased starch susceptibility to enzymatic action as a consequence of the large degree of starch gelatinization induced by the extrusion step with steam, in agreement with Lai (2002). After the first extrusion, the temperature of the pellets was around 60°C; this spontaneous cooling may have promoted a further reorganization of the material (Resmini&Pagani, 1983). A strong decrease in starch susceptibility (from 54% db to 18% db) was measured in PaPGF_B sample, suggesting that part of the gelatinized starch material acted as a binder during the extrusion step, forming a structure less susceptible to hydrolysis. However, this starchy network was unable to counteract starch macromolecule dispersion and minimize cooking losses (see Table 4).

PaMPF and PaSPF showed the lowest values for starch susceptibility, suggesting that the use of parboiled rice flours promoted a further relevant rearrangement in starch macromolecules that was effective in lowering cooking losses. The higher the shear stress and temperature during extrusion, the lower the susceptibility to the enzyme. Compared to Process B (conventional extrusion), Process A, including a heating step, may induce greater gelatinization, which results in more retrogradation (Colonna&Buleon, 1992). This new organization may have reinforced the starchy network, making it less accessible to enzymatic action (Marti, Seetharaman&Pagani, 2010). The addition of PGF, characterized by a great amount of damaged starch, to SPF flour did not modify its starch susceptibility.

The pasting properties of samples are shown in Figure 5 and viscosity data are presented in Table 3. In PaNF_A, the increase in viscosity associated with starch gelatinization appeared at higher temperatures compared with samples prepared from pre-heated flours. The presence of high amounts of native starch in NF (only 3% is quickly susceptible to hydrolysis, Table 2) delayed gelatinization. Even if starch granules underwent molecular arrangement during raw material heat-treatments, the pasta-making process promoted further structural changes, resulting in a product with new rheological properties as shown in Figure 5. The use of PGF, containing previously gelatinized starch granules, promoted the formation of a structure that had lower pasting temperature, compared to PaNF_A. Moreover, in PaPGF_B starch granules underwent a greater swelling, reaching high viscosity during heating. At the same time, that pasta-making process induced a high stability (low BD) and a low tendency to form a gel during cooling (low setback), in comparison with PaNF_A, confirming the data of susceptibility to α-amylase hydrolysis. These differences may be related to the macromolecular rearrangement in the corresponding flours: starch granules with a high swelling capacity result in a higher peak viscosity. Moreover, the high swelling of the granules promoted a greater tendency to macromolecular bursting during heating, resulting in higher breakdown values (Table 3) and lower ability to withstand heating and shear stress.

Despite the intensity of the parboiling process and the extrusion conditions (extrusion-cooking or conventional extrusion), pasta from parboiled rice flours did not reach a peak viscosity but rather exhibited high stabilities during heating. The pasting behavior of PaMPF and PaSPF samples corresponded to the high level of starch structural organization, as already indicated by their very low enzymatic susceptibility.

The addition of PGF significantly affected the pasting profile of the corresponding pasta sample (Figure 5). PaSPF+PGF_B, in fact, exhibited a higher increase in viscosity during heating, in comparison with PaSPF_B. Moreover, PaSPF+PGF_B reached its peak viscosity at 89.6°C, suggesting that gelatinized starch granules from PGF diluted the reorganized starch granules present in SPF flour.

3.2.3 Cooking quality and textural properties of pasta

The cooking quality and the textural properties of cooked rice pasta are presented in Table 4 and compared with those for commercial semolina. Because of the lack of a gluten network in all GF pasta, starch polymers were less efficaciously entrapped in the matrix, resulting in a product with a high cooking loss, even three-four times more than that of the semolina sample. Nevertheless, severe rice parboiling combined with extrusion-cooking seemed to be an effective procedure to assure the formation of a starchy network, thus lowering cooking losses. The substitution of 50% SPF with PGF improved the quality of the rice pasta, in terms of cooking loss and water absorption. The PGF flour may have acted as a binder, re-polymerizing into a network around the starch granules of SPF during the extrusion step, because of the different gelatinization temperatures of PGF and SPF flours, thereby increasing their tolerance to cooking stress, as suggested by Resmini&Pagani (1983).

Pasta samples showed significant differences in water absorption values. In particular, the use of PGF or parboiled flours promoted the formation of a less hydrophilic starchy structure, resulting in lower water uptake in comparison with PaNF_A (91%) and semolina pasta (99%). For all the experimental rice macaroni significant differences were detected during all the phases of the Kramer test (compression, shear, and extrusion). As expected, the lack of gluten was responsible for the low values of compression energy and firmness that characterize the consistency of the products (Table 4). One exception, pasta obtained from parboiled flours combined with extrusion-cooking, showed a dramatic increase in consistency. The high shear stress and temperature seem to favour the formation of a strengthened starchy network, involving the majority of starch macromolecules (as exhibited by its low cooking loss and pasting viscosity) with a positive effect on the texture of cooked pasta in terms of high consistency parameters. A similar behavior was also found by Wang, Bhirud, Sosulski&Tyler (1999), who investigated the suitability of pea flour for pasta-making using a twin-screw extruder: pasta obtained by extrusion-cooking exhibited superior firmness, flavour, and texture after cooking, compared to pasta-products prepared from the same flour using a conventional extruder. Moreover, in PaSPF+PGF_B, the addition of an aliquot of pre-gelatinized flour was associated with a decrease in consistency, compared to that of a extruded-cooked product.

4. Conclusions

The cooking quality of GF pasta made from rice flours was greatly affected by the thermal treatments of the raw material. Regardless of extrusion conditions, severe parboiling process on paddy rice promoted new and effective starch networks in flour (highlighted by peculiar hydration and pasting properties), making rice suitable for GF pasta-making. Even if the new starch arrangements in parboiled flours were positive for the texture of the product, it was not efficacious in limiting the leaching of solids during cooking. This disadvantage was alleviated by extrusion-cooking or by adding a certain amount of PGF. The next challenge will be to improve rice pasta cooking properties by modulating the amount of PGF suitable for producing GF pasta with low cooking losses and, at the same time, a consistency similar to that of semolina pasta, without the addition of additives.

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Table 1. Physical characterization of rice flours.

	NF	**PGF**	**MPF**	**SPF**
Luminosity (L*)	100.00 ± 0.00c	93.34 ± 0.35b	89.15 ± 0.50a	88.71 ± 0.53a
Redness (a*)	0.56 ± 0.08b	-0.48 ± 0.09a	0.51 ± 0.05b	0.83 ± 0.06c
Yellowness (b*)	10.57 ± 0.21b	8.81 ± 0.20a	17.68 ± 0.27c	18.85 ± 0.27d
WAI (g/g)	1.65± 0.04a	4.32 ± 0.11c	1.44 ± 0.04a	2.59 ± 0.16b
WSI (%)	1.14 ± 0.28a	3.17 ± 0.15b	1.61 ± 0.26a	1.41 ± 0.07a
SP (g/g)	1.68± 0.04a	4.46 ± 0.11c	1.47 ± 0.04a	2.64 ± 0.15b

Means (n=3) and standard deviation followed by different letters in a line are significantly different at $p<0.05$.

Table 2. Damaged starch and pasting properties of rice flours.

Flour	**Damaged Starch* (g/100g)**	**IV (BU)**	**PT (°C)**	**PV (BU)**	**BD (BU)**	**FV (BU)**	**SB (BU)**
NF	3.05 ± 0.04a	19.5 ± 3.5a	78.0 ± 0.0b	857.0 ± 1.4c	474.5 ± 2.1a	1173.0 ± 15.5d	790.5 ± 14.8c
PGF	54.17 ± 1.28c	45.5 ± 0.7b	54.0 ± 0.1a	832.0 ± 21.2c	592.0 ± 19.8b	662.5 ± 6.4b	420.7 ± 2.5b
MPF	7.04 ± 0.12b	25.0 ± 1.4a	82.5 ± 0.1c	251.5 ± 10.6b**	-	700.0 ± 18.4c	428.0 ± 0.0b
SPF	8.42 ± 0.39b	22.0 ± 1.4a	76.4 ± 3.2b	114.0 ± 1.4a**	-	272.5 ± 9.2a	158.5 ± 7.8a

Means ($n=3$) and standard deviation followed by different letters in a column are significantly different at $p<0.05$.

* Susceptibility to α-amylase hydrolysis

** Viscosity at 95°C

BU, Brabender units; IV, initial viscosity; PT, temperature at which an initial increase in viscosity occurs; PV, maximum paste viscosity achieved during the heating cycle; BD; peak viscosity minus the viscosity after the holding period at 95°C; FV, final viscosity; SB; difference between the final viscosity and the viscosity reached after the first holding period.

Table 3. Color indices and pasting properties of pasta samples.

	PaNF_A	**PaPGF_B**	**PaMPF_A**	**PaMPF_B**	**PaSPF_A**	**PaSPF_B**	**PaSPF+PGF_B**
Luminosity (L*)	100.3 ± 2.51e	103.97 ± 0.82f	90.82 ± 0.50cd	90.09 ± 0.86bc	88.73 ± 0.73ab	89.76 ± 0.40bc	91.67 ± 0.37d
Redness (a*)	0.85 ± 0.05d	-0.23 ± 0.10a	0.52 ± 0.03c	0.49 ± 0.02c	0.81 ± 0.05d	0.92 ± 0.09d	0.19 ± 0.05b
Yellowness (b*)	15.29 ± 0.51b	-3.31 ± 0.76a	18.12 ± 0.54d	18.49 ± 0.23d	19.34 ± 0.21e	20.43 ± 0.14f	16.25 ± 0.28c
PT (°C)	75.3 ± 0.2e	56.7 ± 0.1a	57.4 ± 0.3b	59.7 ± 0.2c	59.0 ± 0.0cd	56.3 ± 0.1a	59.9 ± 0.1d
PV (BU)	316.0 ± 4.2e	483.0 ± 1.4f	184.5 ± 5.0ab*	248.5 ± 2.1d *	196.0 ± 9.9b *	174.0 ± 15.6a *	229.0 ± 2.8c *
BD (BU)	83.5 ± 4.9b	275.5 ± 2.1c	0	27.0 ± 1.4a	0	0	74.5 ± 6.4b
FV (BU)	887.0 ± 43.8d	584.0 ± 0.7b	760.5 ± 19.1c	812.0 ± 12.7cd	752.0 ± 56.6c	572.0 ± 74.9b	474.0 ± 22.6a
SB (BU)	654.6 ± 43.1c	377.0 ± 2.8a	545.0 ± 12.7b	590.5 ± 12.0bc	556.0 ± 46.7b	398.0 ± 65.0a	319.5 ± 19.1a

Means (n=3) and standard deviation followed by different letters in a line are significantly different at $p<0.05$.

* Viscosity at 95°C

BU, Brabender units; PT, temperature at which an initial increase in viscosity occurs; PV, maximum paste viscosity achieved during the heating cycle; BD; peak viscosity minus the viscosity after the holding period at 95 °C; FV, final viscosity; SB; difference between the final viscosity and the viscosity reached after the first holding period.

Table 4. Cooking quality of experimental rice pasta.

	Optimal cooking time (min)	Cooking loss (g/100 g)	Water absorption (%)	Compression energy (Nmm)	Firmness (N)	Shear force (N)
PaNF_A	9	9.8 ± 0.2c	90.7 ± 4.2b	328.4 ± 6.9a	190.6 ± 6.9a	150.4 ± 4.6a
PaPGF_B	11	10.3 ± 0.7c	78.1 ± 3.6a	552.0 ± 58.3ab	310.0 ± 34.5c	292.9 ± 21.0b
PaMPF_A	15	11.3 ± 0.2d	77.6 ± 2.5a	1970.2 ± 539.9c	832.8 ± 45.7e	520.8 ± 61.0c
PaMPF_B	11	10.0 ± 0.4c	88.7 ± 6.4b	474.5 ± 38.9a	214.6 ± 8.0ab	139.3 ± 14.8a
PaSPF_A	11	5.6 ± 0.1b	77.3 ± 3.5a	1914.8 ± 364.3c	901.6 ± 119.3f	524.7 ± 70.6c
PaSPF_B	10	12.6 ± 0.7e	79.5 ± 3.8a	553.3 ± 30.9ab	275.3 ± 8.2bc	259.1 ± 15.1b
PaSPF+PGF_B	9	6.3 ± 0.3b	87.9 ± 7.6b	371.0 ± 67.5a	187.9 ± 29.2a	159.5 ± 21.7a
Commercial semolina pasta	12	3.5 ± 0.3a	98.7 ± 1.5c	823.7 ± 105.6b	441.9 ± 9.3d	186.4 ± 5.0a

Means (n=5) and standard deviation followed by different letters in a column are significantly different at $p<0.05$.

Compression energy, the area under the part of the curve related to the compression phase;, Firmness, the maximum strength necessary to pack the sample; shear force, the force necessary so that blades pass through the sample.

Figure 1. Milling and heat-treatments on rice to obtain flours for pasta-making.

Figure 2. Processing conditions for experimental rice pasta-making: (a) extrusion-cooking; (b) conventional extrusion.

Figure 3. Pasting properties of rice flours

Figure 4. Starch susceptibility to α-amylase action (or damaged starch) of pasta samples.

Figure 5. Microviscoamylograph curves of pasta samples.