LWT - Food Science and Technology 69 (2016) 280–286

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Effect of formulation on rice noodle quality: Selection of functional ingredients and optimization by mixture design

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A R T I C L E I N F O

Article history:
Received 12 July 2015
Received in revised form
22 January 2016
Accepted 23 January 2016
Available online 26 January 2016

Keywords:
Rice pasta
Hydrocolloids
Mixture design
Planetary ball milling
Tensile strength test

Chemical compounds studied in this article:
Hydroxy propyl methyl cellulose (PubChem CID: 57503849)
Xanthan gum (PubChem CID: 7107)
Corn starch (PubChem CID: 24836924)

A B S T R A C T

The aptitude of seven functional ingredients was evaluated by applying the tensile strength test on cooked noodles. Each formulation included the functional ingredient; modified rice flour obtained by planetary ball milling; and water. Gelatinized rice flour and its blends with gelatinized corn starch; xanthan gum; and guar gum provided a satisfactory mechanical behavior. Pasta formulation was optimized by mixture design, which included seven combinations of gelatinized corn starch, xanthan gum and guar gum. Each combination (8.5%) was blended with modified rice starch (86.7%) and gelatinized rice flour (4.8%) as dry ingredients. Synergistic effects between gums could be detected. Optimum mixture (7.8% gelatinized corn starch, 0.7% guar gum without xanthan gum) obtained by maximizing strain at break (17.9%) and simultaneously minimizing cooking loss (13%) also showed satisfactory values of water absorption (58.7%) and stress at break (31.5 kPa). The capacity of gelatinized rice flour and gelatinized corn starch to induce starch network formation was enhanced by the pre-gelatinized character of modified rice flour. The use of gums in pasta formulated with thermo-mechanical modified rice flour could be significantly reduced by substituting them partially with gelatinized corn starch, without reduction of noodle quality.

1. Introduction

Rice flour is a convenient ingredient to perform gluten-free foods due to its organoleptic and hypoallergenic characteristics (Molina-Rosell, 2013; Osella, de la Torre, & Sánchez, 2014). Rice noodles based on rice starch or rice flour obtained by wet-milling are a popular food in Asia. In a traditional process, a milk layer (aqueous dispersion of flour or starch) is cooked by steam to obtain gelatinized sheets which are then partially dried and cut to noodle strips. The procedure is similar to that of edible rice paper (Cham & Suwannaporn, 2010; Yeh, 2004). However, Western consumers prefer noodles which emulate those obtained by lamination or extrusion of wheat flour (Molina-Rosell, 2013).

Production of gluten-free pasta requires a uniform and cohesive matrix able to withstand the cooking process and to provide good quality attributes to cooked pasta, such as good water absorption capacity, low stickiness, low cooking losses and high extensibility, among others (Huang, Knight, & Goad, 2001; Mariotti, Iametti, Cappa, Rasmussen, & Lucisano, 2011). Therefore, in order to confer appropriate viscoelastic properties to the gluten-free dough, different hydrocolloids, gums, emulsifiers, enzymes have been used (Heo, Lee, Shim, Yoo, & Lee, 2013; Kim, Kee, Lee, & Yoo, 2014; Susanna & Prabhasankar, 2013).

Several authors have also reported that the gelatinization increases the binding capacity of flour particles, improving the noodle quality (Cham & Suwannaporn, 2010; Hormdok & Noomhorm, 2007; Lorlowhakarn & Naivikul, 2006). In fact, different hydrothermal treatments have been successfully applied to enhance the functionality of rice flours (Sozer, 2009).

In recent studies, pre-gelatinized flours of amaranth and rice were obtained by planetary ball milling (Loubes & Tolaba, 2014; Roa, Santagapita, Buera, & Tolaba, 2014). High impact milling of polished rice produced rice flours of variable granulometry (D50 among 96 μm and 262 μm) which presented a gelatinization degree (36–88%) dependent on milling conditions (Loubes & Tolaba,

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http://dx.doi.org/10.1016/j.lwt.2016.01.055
0023-6438/

2014). The particle size of rice flour plays a key role in the flour properties; the fine fraction (<150 μm) is traditionally used for rice noodles (Yeh, 2004). Rice flour obtained by planetary ball milling could be useful to produce rice noodle with suitable stability and texture upon cooking, due to its particle size. Nevertheless, this has not been studied yet.

Several studies have been reported on the selection of functional ingredients, optimization of formulations and methods to produce gluten-free food with a high sensorial and textural quality (Cappa, Lucisano, & Mariotti, 2013; Gallagher, Gormley, & Arendt, 2004; Lazaridou, Duta, Papageorgiou, Belc, & Biliaderis, 2007; Rosell, Moita Brites, Pérez, & Gularte, 2007; Sánchez, Gonzalez, Osella, Torres, & de la Torre, 2008; Velázquez, Sánchez, Osella, & Santiago, 2012). In comparison to bakery products, however, little information exists in literature concerning rice-based pasta (Lai, 2002; Marti, Caramanico, Bottega, & Pagani, 2013; Marti, Seetharaman, & Pagani, 2010). There is even less information about laminated rice noodles designed to match preferences of Western consumers.

The objectives of this work were a) to produce laminated rice noodles from blends of modified rice flour (obtained by planetary ball milling) and different hydrocolloids. Several formulations based on xanthan gum, guar gum, espina corona gum, HPMC, cassava starch, corn starch and gelatinized rice flour were evaluated; b) to select the best hydrocolloids based on tensile strength tests of cooked rice noodles; c) to perform a mixture design including the selected functional ingredients in order to optimize pasta formulation based on mechanical and cooking attributes of cooked rice noodles. Synergistic effect between hydrocolloids was also investigated.

2. Materials and methods

2.1. Materials

A local variety of long-grain polished rice with 23.7 g/100 g amylose content (dry basis) was milled 20 min in a planetary ball mill (model PM100, Retsch GmbH, Haan, Germany) at 550 rpm to obtain modified rice flour, using the method described by Loubes and Tolaba (2014). Grain composition was determined in duplicate by standard methods (AOAC, 1995), the results expressed in wet basis were: moisture (11.7 g/100 g), starch (79.5 g/100 g), fat (0.5 g/100 g), protein (7.8 g/100 g; N × 5.75), and ash (0.4 g/100 g).

Durum wheat semolina (Carrefour, Buenos Aires, Argentina) was purchased from a local market and it was adopted to prepare the control sample. Flour samples were kept in tightly sealed package, protected from light and moisture, and stored at room temperature for a few weeks prior to being tested.

Xanthan gum, guar gum, cassava starch and corn starch, were purchased from a local market (Doña Clara, Buenos Aires, Argentina), hydroxy propyl methyl cellulose (HPMC) was provided by Sigma–Aldrich (St. Louis, USA) and espina corona gum (hydrocolloid from *Gleditsia amorphoides* seed) was donated by Nature Gum Co. (Chaco, Argentina).

2.2. Pasta formulations

Seven formulations which included modified rice flour, distilled water and the functional ingredient were prepared according to Table 1. The ingredients evaluated were gelatinized corn and cassava starches, gelatinized rice flour and binary blends of gelatinized rice flour and one of the following hydrocolloids: HPMC, xanthan gum, guar gum, espina corona gum. Pasta based on durum wheat semolina and water was adopted as control. Each formulation was conducted in duplicate.

2.3. Preparation of fresh noodles

Rice noodles were prepared according to the procedure of Kim et al. (2014) with modifications. Prior to the preparation of dough, gelatinized fractions of rice flour, corn starch or cassava starch were obtained by heating the corresponding aqueous dispersion (11.1 g/100 ml) in a water bath with stirring at 90 °C for 30 min. The complete starch gelatinization was verified by DSC calorimetry. The total amount of water was added in this step which was determined for each formulation (Table 1) from preliminary experiments in order to achieve an optimum lamination of dough.

Gelatinized fraction was joined on the screened and blended dry ingredients (MRF, MRF and gums or MRF and HPMC), and kneaded by hand for 5 min. The dough (80 g) was placed in a tightly sealed container and kept at 25 °C for 30 min to let the starches hydrate. The dough was sheeted on a noodle machine (rollers diameter: 35 mm, Shule, Changzhou, China) at the minimum setting to smooth and firm it, and fed another five times between the rollers, decreasing the gap between rollers each time. Finally, noodles were cut manually into strips (20 mm × 50 mm) and were stored in hermetically sealed containers at 4 °C until used, to prevent moisture loss.

Wheat pasta (F8) adopted as control, was prepared following the procedure described above.

2.4. Cooking of noodles

Rice noodles were cooked in boiling water using pasta to water ratio of 1 g: 10 ml (distilled water without salt added). The optimum cooking time of rice pasta was evaluated as the time required for disappearance of the dry central core when gently squeezed between two glass plates (AACC, 1995).

2.5. Mechanical properties of cooked noodles

Uniaxial tensile strength tests were performed according to Arismendi, Chillo, Conte, Del Nobile, Flores, and Gerschenson (2013) with slight modifications. Mechanical behavior was determined by using a universal testing machine (Instron 3345, Norwood, USA), calibrated for a load cell of 100 N. The average value of at least ten specimens per sample was reported. Each cooked noodle strip (20 mm × 50 mm × 1.65 mm) was mounted between grips (cat 2710-105 Instron, USA). Initial grip separation and crosshead speed were 30 mm and 10 mm/min respectively. The stress σ (F/A, being F the force and A = 33 mm^2 the area of the specimen; kPa) and the strain ε (ΔL/L_0, being ΔL the crosshead displacement occurred and L_0 = 30 mm the initial effective length of the sample; %) were recorded. The stress (σ_b) and strain (ε_b) at break were evaluated. For strains lower than 10% the σ–ε curves were fitted to a linear model and the Young's modulus (YM, kPa) was evaluated from the slope.

2.6. Cooking quality

Cooking loss (CL) was evaluated by following the AACC (16-50) standard method (AACC, 1995). Five strips of pasta (4 g) were cooked in 150 ml of boiling water for 8 min. Cooking water was dried to constant weight at 100 °C in order to determine dry matter. The residue was weighed and CL was reported as percentage of the uncooked product (% w/w, dry basis). Water absorption (WA) was evaluated by weighing pasta before and after cooking (Tudoricâ, Kuri, & Brennan, 2002). WA was expressed as the ratio percentage among the weight increase and the weight of uncooked pasta. The average value of at least three replicates for each sample was reported.

Table 1
Formulations of fresh rice noodles for the selection of functional ingredients.

Ingredients (g/100 g dough)	Formulations							
	F1	F2	F3	F4	F5	F6	F7	F8
Rice flour	47.37	46.45	50.00	46.45	50.00	46.45	46.45	–
Gelatinized rice flour	5.26	5.16	–	5.16	–	5.16	5.16	–
Xanthan gum	–	1.94	–	–	–	–	–	–
Gelatinized cassava starch	–	–	5.00	–	–	–	–	–
HPMC[a]	–	–	–	1.94	–	–	–	–
Gelatinized corn starch	–	–	–	–	5.00	–	–	–
Guar gum	–	–	–	–	–	1.94	–	–
Espina corona gum	–	–	–	–	–	–	1.94	–
Durum wheat semolina	–	–	–	–	–	–	–	60.24
Water	47.37	46.45	45.00	46.45	45.00	46.45	46.45	39.76
Total	100	100	100	100	100	100	100	100

[a] Hydroxy propyl methyl cellulose (E464).

2.7. Statistical analysis

Descriptive statistics was applied on mechanical parameters (σ_b, ε_b, MY) and cooking attributes (CL, WA). The data was subjected to analysis of variance (ANOVA) or non-parametric Kruskal–Wallis test when the assumption of homogeneity of variance was not verified, in order to determine significant ($p < 0.05$) differences between formulations. All statistical analysis was accomplished using SPSS (version 11.5.1, Statistical Package for the Social Sciences, USA) and GraphPad Prism (version 5, GraphPad Software Inc., USA) software packages.

2.8. Mixture design

Simplex centroid design with constraints which included seven combinations of three selected hydrocolloids was performed to optimize pasta formulation (Hu, 1999). Percentages of rice flour and gelatinized rice flour were maintained constant (86.7% and 4.8% respectively), therefore the sum of the three functional ingredients was set at 8.5%. In order to define the experimental region the following constraints were adopted based on previous tests: x_2 (lower bound) = 0%, x_3 (upper bound) = 3.7%, x_2 (upper bound) = 3.7%. Mass balance equations were solved to determine the composition for each vertex of the triangle (experimental region) defined by the adopted constraints. Table 2 shows the composition of each mixture calculated from the experimental design. Distilled water was added to obtain approximately 0.9 g water/g (dry basis) in accordance with literature reports (Heo et al., 2013; Kim et al., 2014). The water content of each mixture, also included in the table, was determined from preliminary experiments in order to obtain a good lamination of dough.

2.9. Surface response analysis

Models for analyzing data from mixture design are usually obtained by combining traditional Scheffé type models for the mixture variables with response surface models for the design variables (Scheffé, 1958). The following special cubic model was fitted to the data:

$$Y = \sum_{i=1}^{3} \beta_i x_i + \sum \sum_{i<j}^{3} \beta_{ij} x_i x_j + \sum \sum \sum_{i<j<k}^{3} \beta_{ijk} x_i x_j x_k \tag{1}$$

Where Y is the response variable, β_i, β_{ij}, and β_{ijk} are the coefficients of mixture variables in the regression model and x_i, x_j, x_k are the coded concentrations of each mixture component. Model fitting was performed by regression analysis and a stepwise methodology was followed to determine the significant terms in Eq. (1). Differences in the computed parameters were considered significant when the computed probabilities were less than 0.05 ($p < 0.05$).

Considering the restrictions adopted to limit the experimental region, the following linear relationships among coded variables (x_i, x_j, x_k) and concentrations of mixture components (c_i, c_j, c_k) can be established

$$x_1 = (c_1 - 4.8)/3.7 \quad x_2 = c_2/3.7 \quad x_3 = c_3/3.7 \tag{2}$$

Therefore Eq. (1) can be rewritten in terms of the concentrations of mixture components as:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i c_i + \sum \sum_{i<j}^{3} \beta_{ij} c_i c_j + \sum \sum \sum_{i<j<k}^{3} \beta_{ijk} c_i c_j c_k \tag{3}$$

All statistical analysis, mixture design, generation of response surfaces, desirability functional analysis, and optimization were accomplished using Statgraphics Centurion version XVI (Statistical graphics Corporation, USA) statistical software.

Table 2
Mixture design applied for the optimization of cooked rice noodle.

Mixtures	Ingredients[a] (g/100 g, dry basis)					Total	g water/g (dry basis)
	c_1	c_2	c_3	Rice flour	Gelatinized rice flour		
M1	4.80 (0)	-(0)	3.70 (1)	86.70	4.80	100	0.86
M2	4.80 (0)	1.85 (½)	1.85 (½)	86.70	4.80	100	0.86
M3	8.50 (1)	-(0)	-(0)	86.70	4.80	100	1.20
M4	6.65 (½)	1.85 (½)	-(0)	86.70	4.80	100	1.03
M5[b]	6.03 (1/3)	1.23 (1/3)	1.23 (1/3)	86.70	4.80	100	0.97
M6	6.65 (½)	-(0)	1.85 (½)	86.70	4.80	100	1.03
M7	4.80 (0)	3.70 (1)	-(0)	86.70	4.80	100	0.86

[a] Coded values between brackets, c_1: gelatinized corn starch, c_2: guar gum, c_3: xanthan gum.
[b] Central point of experimental design (triplicate).

3. Results and discussion

Modified rice flour presented the following physicochemical characteristics: median particle size (131.1 ± 1.6 μm); damage starch content (8.4 ± 0.1 g/100 g db) according to AACC (76-30A) standard method (AACC, 1995); crystallinity degree (28.1%); starch gelatinization degree (62.1%); starch gelatinization temperature within the range 64.3–76.9 °C (Loubes & Tolaba, 2014).

Several of these characteristics matched the requirement for a suitable rice noodle production: particle size was within the recommended range (100–150 μm); its intermediate amylose content together with its pre-gelatinized character are necessary to obtain a product with fibrillar structure (Yeh, 2004).

3.1. Selection of functional ingredients

The composition of the seven formulations studied are listed in Table 1 together with the wheat-based pasta formulation (F8) used as control. The effect of formulation on mechanical behavior of cooked noodle can be appreciated in Fig. 1, in which the experimental values of stress at break (Fig. 1A), strain at break (Fig. 1B) and Young's modulus (Fig. 1C) are shown. Wheat control exhibited average values of 28 ± 4 kPa (σ_b); 27 ± 4% (ε_b); and 211 ± 24 kPa (YM), while the different formulations ranged between 7–29 kPa (σ_b), 6–21% (ε_b) and 98–266 kPa (YM). The highest levels of stress and strain at break were found in formulations with guar gum and xanthan gum respectively. In comparison with wheat control, a significant decrease ($p < 0.05$) in strain at break was observed for cassava starch (55%), corn starch (59%), HPMC (55%) and espina corona gum (73%). In relation to formulation F1, which only includes modified rice flour, gelatinized rice flour and water; the addition of gums or gelatinized corn starch caused an increase of mechanical parameters. The opposite effect was observed when HPMC, gelatinized cassava starch or espina corona gum were used as functional ingredients.

Thus, the addition of xanthan or guar gums had a good effect on mechanical properties of gluten free pasta in accordance with literature findings (Huang et al., 2001; Larrosa, Lorenzo, Zaritzky, & Califano, 2013; Marti et al., 2010; Sozer, 2009). Susanna and Prabhasankar (2013), who studied gluten free-pasta based on soybeans, sorghum and whey proteins; have found that HPMC was as effective as xanthan gum or guar gum to enhance the shear stress behavior. This finding is different from the results of this work. The reason for such controversy may be the different dough composition, which affects the intermolecular interactions between dough components and functional ingredients.

Heo et al. (2013) developed rice-based noodles using xanthan gum as a functional ingredient. They have reported values of strength and deformation at break of 1.1 N and 6.5 mm respectively. Similar values of strength (σ A = 0.8 ± 0.1 N) and deformation (L_0 ε = 5.4 ± 0.9 mm) at break were calculated from stress and strain values obtained in the present work using the same functional ingredient (formulation F2). It must be noted that the use of different types of extensibility test and milling methods makes the comparison between the literature data difficult.

Finally, a multiple comparison test was performed to determine significant differences between studied formulations and wheat control. It can be appreciated, from the results shown in Fig. 1, that the formulations F1, F2 and F6 do not differ significantly from wheat control. In addition, the formulation F5 showed a good performance. Therefore, combinations of gelatinized rice flour with gelatinized corn starch, xanthan gum and guar gum were selected as suitable functional ingredients. The strategy was to perform a mixture design with seven combinations of gelatinized corn starch, xanthan gum and guar gum. These combinations were added to a basic mixture with fixed amounts of gelatinized rice flour and modified rice flour as dry ingredients.

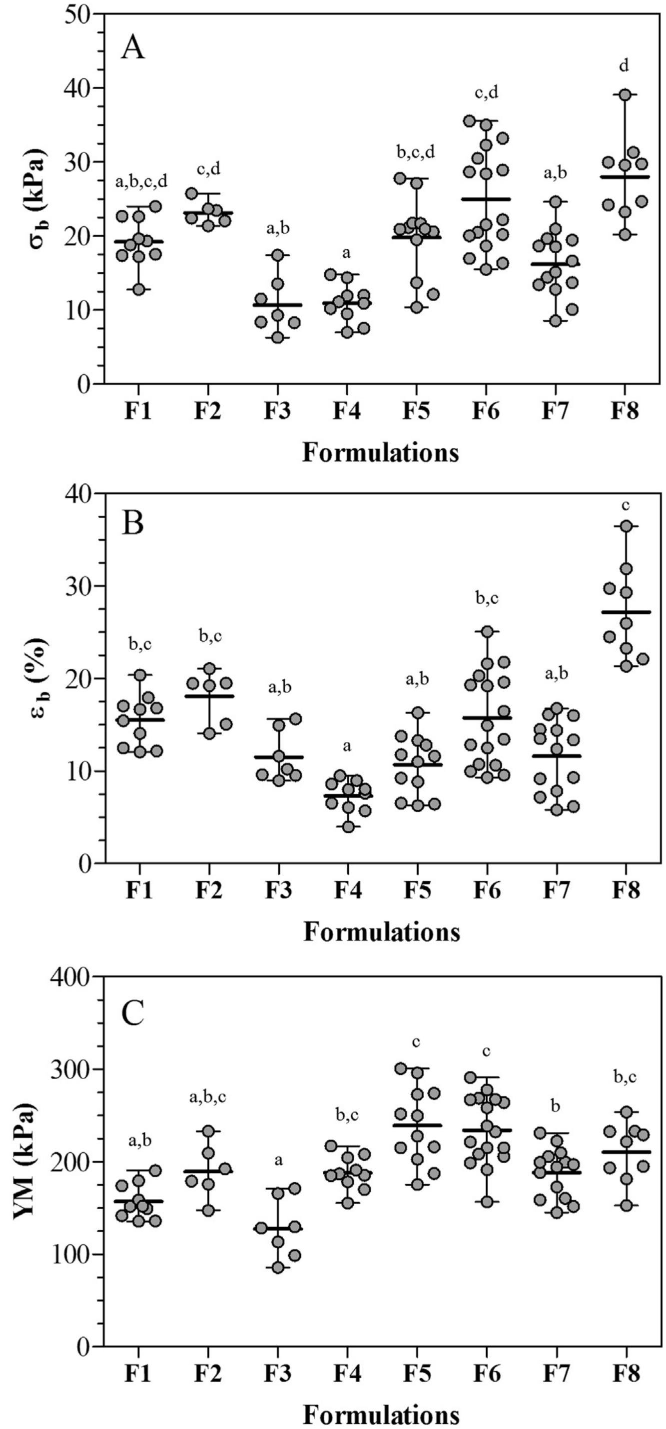

Fig. 1. Mechanical properties of cooked rice noodle as function of pasta composition (F1: gelatinized rice flour, F2: gelatinized rice flour and xanthan gum, F3: gelatinized cassava starch, F4: gelatinized rice flour and HPMC, F5: gelatinized corn starch, F6: gelatinized rice flour and guar gum, F7: gelatinized rice flour and espina corona gum, F8: control). A) stress at break (σ_b), B) strain at break (ε_b), C) young modulus (YM).

3.2. Mixture design

Simplex centroid mixture design was chosen to optimize noodle formulation and to analyze the synergistic effects among the

Table 3
Mechanical parameters of cooked rice noodle as function of mixture composition.

Mixtures[a]	σ_b (kPa)	ε_b (%)	Young Modulus (kPa)
M1	28.6 c	11 c	342 c
M2	32.3 c	9.8 c	430 d
M3	31.8 c	19.8 e	234 a
M4	28.6 c	13.5 d	293 b
M5[b]	21.3 b	10.9 c	245 a
M6	17.9 ab	7.7 b	291 b
M7	17.3 a	5.1 a	421 d
SD[c]	4.5	1.6	35.3

σ_b: stress at break, ε_b: strain at break.
Means ($n \geq 10$) followed by different letters in a column are significantly different at $p < 0.05$.
[a] Mixture composition (gelatinized corn starch: guar gum: xanthan gum): M1 (4.8:0:3.7); M2 (4.8:1.85:1.85); M3 (8.5:0:0); M4 (6.65:1.85:0); M5 (6.03:1.23:1.23); M6 (6.65:0:1.85); M7 (4.8:3.7:0).
[b] Central point of experimental design.
[c] Pooled standard deviation.

selected functional ingredients. Table 2, which shows the mixture formulations, includes the points of experimental design based on selected functional ingredients, as well as the percentages of gelatinized rice flour and modified rice flour to complete the dry ingredients. In addition, water percentages required to proper lamination of dough, were also included. The studied responses were the mechanical and cooking properties of fresh noodle which were matched by equation (3) with percentage (dry basis) of gelatinized corn starch, guar gum and xanthan gum as c_1, c_2 and c_3 respectively.

3.2.1. Tensile strength test

The average values of stress at break (σ_b), strain at break (ε_b), and Young's modulus (YM) of the seven studied mixtures are shown in Table 3. Several mixtures (M1-M4) led to stress values that were consistent with those of wheat noodles (F8). Nonetheless, all the strain values were lower than those of wheat noodle. In Table 4, the coefficients of Eqn. (3), which correspond to mechanical parameters, are shown together with their statistical significance. It can be appreciated that all functional ingredients presented a significant effect on mechanical properties ($p < 0.05$). Contour plot of stress at break (Fig. 2A) and YM (not show) were successfully.

simulated ($R^2 > 0.96$) by a special cubic model. Synergistic effects were detected by combinations of gums. Maximum stress at break (33 kPa) for guar gum to xanthan gum mass ratio of 0.54 and maximum YM (437 kPa) for guar gum to xanthan gum mass ratio of 2.36 were obtained at the lowest concentration of gelatinized corn starch. Contour plot of strain at break (Fig. 2B) was explained by a quadratic model ($R^2 = 0.96$) with significant interaction effects between hydrocolloids, as set forth in Table 4. In Table 5, the maximum and minimum values of mechanical parameters are reported together with the corresponding mixture composition.

The reason for synergistic interaction between polysaccharides is the crosslinking of both polymers, which improves the textural properties. Such improvement has attracted the interest of many researchers (Mao & Rwei, 2006). Larrosa et al. (2013) blended corn flour with xanthan gum and locust bean gum (extracted from carob galactomannan) to obtain gluten free pasta with good extensibility.

In the present work, the mixture M3 without gums showed the greatest strain at break (19.8%, see Table 3). In contrast, the formulation F5, without gums and similar amount of gelatinized corn starch, presented a strain of 10.7% (Fig. 1B). This fact is due to the presence of gelatinized rice fraction in the formulation M3. The combination of gelatinized fractions (gelatinized corn starch and gelatinized rice flour) in mixture M3 was useful to improve the extensibility of cooked pasta as well as to obtain values of stress at break similar to wheat control.

Consistent with this approach, the use of pre-gelatinized starch obtained by successive steps of heating and cooling, which cause starch retrogradation, has been proposed to achieve a rice pasta similar to the traditional wheat pasta (Cabrera-Chávez et al., 2012; Mariotti et al., 2011). This work proposes an alternative method based on the modified rice flour obtained by dry milling in a planetary ball mill. The character that this rice flour gives to the dough is further enhanced with the addition of completely gelatinized fractions of rice flour and corn starch.

3.2.2. Cooking properties

Cooking quality is related to high values of WA and low values of CL (Lucisano, Cappa, Fongaro, & Mariotti, 2012). Wheat pasta adopted as reference showed values of WA and CL of 110.5 ± 7.2% and 7.4 ± 1.4% respectively. Cooking parameters of rice pasta (Table 6) were affected by the mixture composition. In comparison with wheat control, water absorption of rice noodles resulted lower and cooking loss was higher. For gluten-free pasta, Susanna and Prabhasankar (2013) have reported values of WA (59–62%) and CL (8.5–12%), which are consistent with the results of this work.

Other authors have obtained slightly lower CL values. Cooking losses of about 5–6% have been reported in noodles made from rice flour obtained by wet or dry milling (Heo et al., 2013); as well as in noodles based on rice flour, which was added rice protein and/or transglutaminase (Kim et al., 2014).

Cooking properties were satisfactorily modeled by Eq. (3) in terms of guar gum, xanthan gum and gelatinized corn starch contents. The results of RSM analysis are shown in Table 4, wherein the polynomial coefficients are presented, together with the corresponding level of significance. A significant cubic interaction effect was found for WA response, while CL was influenced by the

Table 4
Effect of functional ingredients on mechanical and cooking properties of rice noodles.

Coefficients of Eq. (3)	Mechanical properties			Cooking properties	
	σ_b (kPa)	ε_b (%)	Young Modulus (kPa)	Water absorption (%)	Cooking loss (%)
β_o	−41.19	−25.45	−304.9	−68.93	−22.74
β_1 (Gelatinized Corn Starch)	8.58	5.3	63.52	14.36	4.749
β_2 (Guar Gum)	−1.09	−1.6	162.19	9.85	8.5
β_3 (Xanthan Gum)	24.88	12.21	92.6	26.81	7.33
β_{12}	1.2NS	0.61NS	−10.11*	1.60NS	−1.32*
β_{13}	−3.57*	−1.94*	–	−1.40NS	−0.6NS
β_{23}	13.29*	0.84NS	246.83*	30.67*	−6.08NS
β_{123}	−2.2*	–	−48.5*	−6.89*	1.32NS
R^2	0.99	0.97	0.99	0.92	0.94

*Significant at $p < 0.05$; NS: non significant coefficient; –: eliminated coefficient.
σ_b: stress at break, ε_b: strain at break.

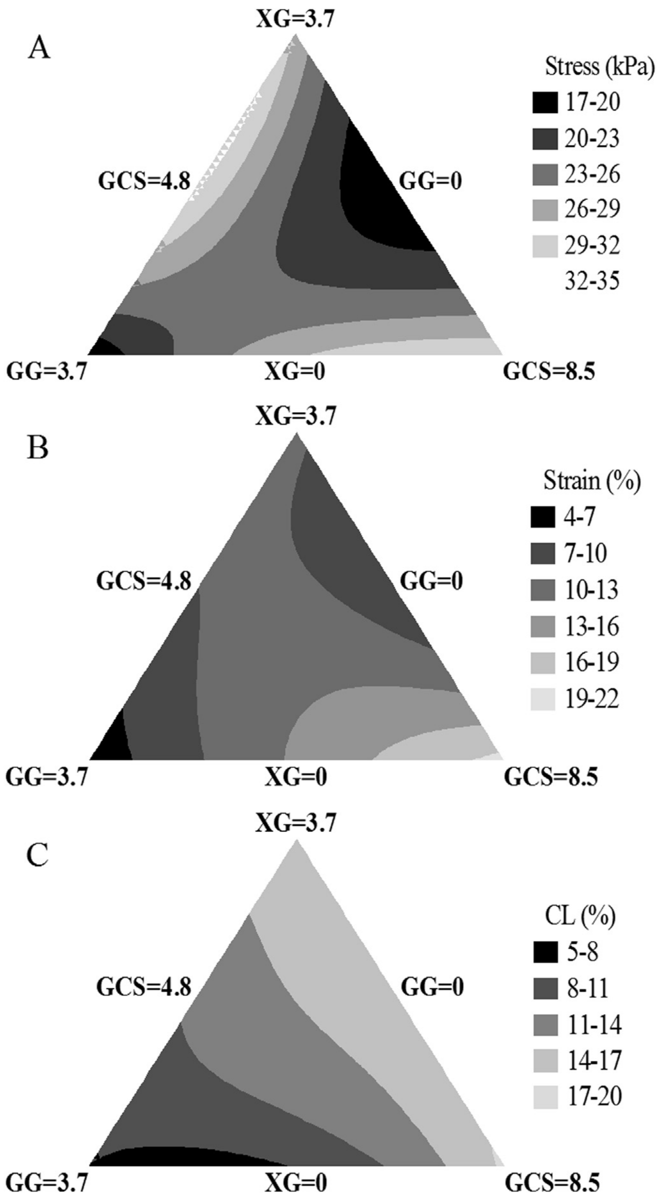

Fig. 2. Contour plots of selected mechanical and cooking properties of cooked rice noodle as function of pasta composition. Gelatinized corn starch (GCS: 4.8–8.5%), guar gum (GG: 0–3.7%), xanthan gum (XG: 0–3.7%). A) stress at break, B) strain at break, C) cooking loss (CL).

interaction between gelatinized corn starch and guar gum. Water absorption decreased by adding gelatinized corn starch or guar gum to the mixtures with xanthan gum. Fig. 2C shows that cooking loss increased by adding gelatinized corn starch or xanthan gum to the mixtures with guar gum. Table 5 shows that the maximum values of WA and CL were obtained by the maximum amounts of xanthan gum (M1) and gelatinized corn starch (M3) respectively. While minimum CL value was obtained from a binary mixture with a gelatinized corn starch to guar gum ratio of 2 in the absence of xanthan gum. Such mixture also showed a good value of WA (66.1%) in accordance with those reported in the literature for gluten-free pasta (Susanna & Prabhasankar, 2013).

Table 6
Cooking attributes of rice noodles as function of mixture composition.

Mixtures[a]	Water absorption (%)	Cooking loss (%)
M1	74.3 d	16.4 d
M2	61.4 c	11.5 b
M3	53.1 ab	17.5 d
M4	64.5 c	8.2 a
M5[b]	47.8 a	13 bc
M6	58.9 bc	14.9 cd
M7	64.9 c	8 a
SD[c]	3.0	1.2

Means ($n = 3$) followed by different letters in a column are significantly different at $p < 0.05$.
[a] Mixture composition (gelatinized corn starch: guar gum: xanthan gum): M1 (4.8:0:3.7); M2 (4.8:1.85:1.85); M3 (8.5:0:0); M4 (6.65:1.85:0); M5 (6.03:1.23:1.23); M6 (6.65:0:1.85); M7 (4.8:3.7:0).
[b] Central point of experimental design.
[c] Pooled standard deviation.

3.2.3. Multivariable optimization

Finally, a multiple optimization was performed by maximizing the strain at break and, at the same time, minimizing the cooking loss. The resulting optimum composition was 0.7% guar gum, 7.8% gelatinized corn starch without xanthan gum (desirability = 0.96). This mixture had a strain of 17.95% and a cooking loss of 13.0%. Besides, its values of water absorption (58.7%) and stress at break (31.5 kPa) were satisfactory.

It must be noted that good mechanical properties can be obtained avoiding the use of gums as in the mixture M3. However, this mixture presented lower water absorption and higher cooking loss than the optimum mixture.

The results obtained show that the combination of a gelatinized fraction (gelatinized rice flour and gelatinized corn starch) and a small amount of gum confers the cooked pasta a firm quality and it is useful to reduce the soluble material losses during the cooking process.

4. Conclusions

The main contribution of this work is the use of thermo-

Table 5
Optimization of cooked rice noodle formulation.

			Gelatinized corn starch (%)	Guar gum (%)	Xanthan Gum (%)
ε_b (%)	max	19.6	8.5	0	0
	min	4.9	4.8	3.7	0
σ_b (kPa)	max	33.1	4.8	1.29	2.41
	min	17.3	4.8	3.7	0
YM (kPa)	max	437	4.8	2.6	1.1
	min	225	6.9	0.82	0.83
WA (%)	max	74.3	4.8	0	3.7
	min	47.7	6.2	1.09	1.23
CL (%)	max	17.5	8.5	0	0
	min	6.9	5.7	2.83	0

σ_b: stress at break, ε_b: strain at break, YM: Young modulus, WA: water absorption, CL: cooking loss.

mechanically modified rice flour, obtained by high impact milling, as the main ingredient in the production of laminated rice noodles. This rice flour, combined with a convenient proportion of gelatinized fraction (4.8% of gelatinized rice flour and 7.8% of gelatinized corn starch) and a minimum quantity of gum (0.7% of guar gum), results in a satisfactory quality product due to its characteristic particle size and its damaged starch content.

Taking into account that this product usually has 2% of gum, the proposed formulation presents a reduction of 60% of the required amount of this functional ingredient, which is as effective as it is costly.

The obtained rice noodles presented satisfactory cooking attributes as well as a mechanical resistance similar to that of the wheat control. However, its extensibility, though acceptable, resulted a 33% lower than that of the wheat control.

Acknowledgments

The authors acknowledge the financial support from PME-2006-01685 and UBACYT (Project UBACYT 20020130100442BA).

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