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Micronized bran enriched fresh egg tagliatelle: significance of gums addition on pasta technological features

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Abstract

The aim of the work was to produce fibre enriched fresh pasta based on micronized wheat bran and durum wheat semolina with appropriate techno-functional properties. Wheat semolina was replaced with fine particle size (50% below 75 μm) wheat bran -up to 11.54% (w/w). A Box–Behnken design with randomised response surface methodology (RSM) was used to determine a suitable combination of carboxymethylcellulose-CMC, xanthan gum-XG and locust bean gum-LBG to improve pasta attributes: minimum cooking loss, maximum values for water gain and swelling index, as well as better colour and texture characteristics before and after cooking. The proximate chemical composition of wheat semolina and bran was determined and the microstructure of uncooked pasta was observed as well. From the RSM analysis, it is recommended to use: (i) XG over 0.6% w/w as it lead to bran enriched pasta with a better developed structure and superior cooking behaviour, (ii) a combination of XG (0.8% w/w) and CMC (over 0.6% w/w) to enhance uncooked pasta yellowness.

Practical applications

The aim was to produce a healthier pasta product with higher content on fibre, minerals and vitamins and suitable quality. This work recommends an alternative formula and bran milling technology to prepare fresh pasta in the food industry.

Introduction

Nowadays, consumers are much more concerned than in the past about the role of foods in health. Food production seeks not only to satisfy hunger and provide necessary nutrients for humans, but also to prevent nutrition-related diseases and improve consumers' physical and mental well-being (Menrad, 2003; Mastromatteo et al., 2011). Thus, in the 1990s, dietary fibre (DF) was especially recognized for human consumption and a great deal of interest was paid to cereal fibre. Several epidemiological studies have demonstrated a relationship between diets with inadequate fibre intakes and the development of certain so-called "Western" diseases, such as colon cancer, cardiovascular disease and intestinal transit alterations (García & Velasco, 2007). At present, eating more vegetable products (fruits, cereals, pulses) and producing fibre-enriched products is recommended. The daily recommended DF intake for adults is 25-38 g. (Romo et al., 2008).

Pasta is a staple food consumed worldwide and 13.5 million tons of pasta were produced in 2013 (IPO, 2014). It is considered a low glycaemic index food as it progressively releases sugars during digestion (Aravind et al., 2012a; Brennan & Tudorica, 2008), which leads to low postprandial blood glucose and low insulin responses. The WHO and FDA consider pasta to be a good vehicle for adding nutrients (Chillo et al., 2008).

Pasta is traditionally made by using only durum wheat semolina, but it is possible to use non-durum wheat ingredients to produce specifically-labelled blended pasta. Several authors have attempted to improve the nutritional properties of pasta by incorporating other plant source flours (pea, oat, teff, quinoa, maize, soy, amaranth), mainly for the protein enrichment of gluten-free products (Mastromatteo et al., 2011; Torres et al., 2007; Borneo & Aguirre, 2008; Chillo et al., 2009; Hager et al., 2012; Larrosa et al., 2013). Other authors have studied the effect of adding soluble and insoluble fibre, vitamins and minerals on pasta quality (Aravind et al., 2012a; Knuckles et al., 1997; Aravind et al., 2012b). The addition of dietary fibre can further reduce the glycaemic index and introduce other health benefits (Aravind et al., Yokoyama et al., 1997). Recently, Kaur et al. (2012) analysed the functional properties of pasta enriched with a variable content of cereal bran. The results are promising as 15% (wheat, rice and oat) or 10% (barley) replacement levels can be achieved without negatively affecting the physicochemical, sensory and cooking properties of dried pasta. Wheat bran is composed of a large amount of dietary fibre in the form of insoluble cellulose, hemicellulose, pentosans and lignin(Hemery et al., 2007). These outer layers of cereal grains are also rich in vitamins, minerals and antioxidants. And it is becoming increasingly evident that the synergestic action of several bioactive compounds contributes to health protection (Ciccoritti et al., 2017). The main physiological benefit of bran is an improvement in gut peristalsis, which is related to water holding capacity and its effect on gut viscosity. It can also slow carbohydrate absorption by reducing glycaemic and insulinemic responses (Aravind et al., 2012b). The negative effects of bran on the techno-functional and sensory properties of food structure are the main difficulties that appear when formulating high-fibre products (Kaur et al., 2012). It is known that bran particles can physically interfere with gluten development (Kaur et al., 2012; Manthey & Schorno, 2002) and that the colour, cooking and sensory characteristics of whole-wheat or bran-enriched pasta are inferior to those of pasta made only from semolina (Aravind et al., 2012b; Edwards et al., 1995). However, it should be important to introduce this healthy ingredient into pasta formulation as long as the techno-functional and sensory quality of the pasta is ensured (Chillo et al., 2008). Pasta of “ideal” physical and sensory quality is characterized by a cohesive and elastic dough, minimal cooking loss, no stickiness and reasonable firmness after cooking (Howard et al., 2011). To solve this challenge, the use of innovative technological processes, such as micronization, has been proposed (Ciccoritti et al., 2017). The micronization process consists of a particle size mechanical reduction of the matrix into a fine powder, which improved the technological functionality and increased the bioaccessibility of bioactive compounds in bread (Hemery et al., 2010). The literature also reports that substances that swell in water -e.g. hydrocolloids- can be used to mimic the viscoelastic properties of gluten by improving its structural mouth-feel, acceptability and shelf life (Lazaridou et al., 2007). Its film-forming properties also act as a lubricant in batter and protect the other formulation ingredients from being damaged by mixing, particularly starch granules (Alamprese et al., 2009). Carboxymethylcellulose (CMC) is a derivative of cellulose that is widely used to modify the viscosity of several food matrices, such as dairy products, jellies and cake mixes (Chillo et al., 2009). The addition of CMC (soluble fibre) to cereal-based food has also shown beneficial effects on blood glucose regulation and fasting plasma cholesterol (Brennan et al., 1996). Non-starch polysaccharides, such as xanthan gum (XG) and locust bean gum (LBG), have a significant effect on pasta's viscoelastic properties and can be used to improve its elastic texture, as well as enhancing the firmness and mouth feel of end products (Larrosa et al., 2013). The synergistic effect of XG and LBG can boost its rheological properties due to increased solution viscosity or gel formation.

Nevertheless, most works in food technology literature are about dried pasta. Despite the increasing demand for fresh pasta, to the authors' knowledge, no research has been conducted on composite fresh egg pasta, based on replacing wheat semolina with wheat bran and supplementing it with a combination of structure agents such as CMC, XG and LBG. This work was undertaken to find a suitable combination of these hydrocolloids in order to obtain a high quality -“source of fibre”- fresh egg tagliatelle. The most significant technological properties of pasta (water absorption ratio, swelling index, cooking loss, firmness, elasticity, consistency and colour attributes) were all evaluated.

Materials and Methods

Raw materials

Commercial durum wheat semolina (DWS) and micronized wheat bran (MWB) were supplied by Harinas Villamayor S.A. (Huesca, Spain). According to the manufacturer, the wheat bran was produced by using an improved milling method and sieving technology (micronization based on compression coupled to air fractionation) in order to obtain a small particle size which could lead to a more uniform and better hydrated blend. Both DWS and MWB were analysed for their moisture content, ash, fat, protein and fibre, according to the American Association of Cereal Chemists approved methods (AACC, 2000). The digestible carbohydrates were determined by difference (100 – per cent estimated proximate chemical composition). Table 1 summarizes the particle size distribution (information from supplier) and the proximate chemical composition of DWS and MWB. Pasteurised liquid egg was provided by Avícola Llombai S.A. (Llombai, Valencia, Spain). Carboxymethylcellulose CMC-3500-4000 cps, xanthan gum XG-1400 cps and locust bean gum LBG-2800 cps were supplied, respectively, by Quimica Amtex, S.A. (Mexico), Shandong Fufeng Fermentation Co., Ltd. (China) and Lbg Sicilia Srl (Italy). This same batch of materials was used for all the experiments.

Experimental design

The CMC, XG and LBG amounts were selected as factors (3 independent variables) to obtain fresh egg pasta (based on wheat bran and wheat semolina) with suitable techno-functional characteristics (response variables): minimum cooking loss, maximum values for water gain and swelling index, as well as better colour and texture characteristics before and after cooking. The experimental design and statistical analysis were performed using Statgraphics® Centurion XVI statistical software, version 16.1.17 (StatPoint Technologies, Inc., 2011). A Box–Behnken design with a quadratic model was used to analyse the effect of the different factor combinations on the various response variables (randomised response surface methodology (RSM)). The levels of the factors were chosen taking into account preliminary trials (data not shown) and ranged from 0 to 0.8% w/w (coded as 0=0%, 1=0.4%, 2=0.8%). The statistical design resulted in 15 runs including three replicates of the central point (Table 2). A multiple regression analysis was performed to assess the significance of the linear, quadratic and interactive effects of the factors (amounts of CMC, XG, LBG) on the response variables (Y): water absorption index (WAI), cooking loss (%CL), swelling (ΔV), CIEL*a*b* colour coordinates, chrome (C^*_{ab}), tone (h^*_{ab}), firmness (F), elasticity (S_i) and consistency (A). Such parameters were measured in the uncooked (subscript *o*) and cooked (subscript *c*) pasta samples. The regression model is described by a second-order polynomial equation (Eq. 1), where each response variable (Y) is related to the obtained linear (β_i), quadratic (β_{ii}) and interactive (β_{ij}) regression coefficients, that is, to the relative weight of each analysed effect (G_1-CMC, G_2-XG and G_3-LBG, either alone or combined). Constant Y_o represents the response when no gum is considered.

$$\mathbf{Y} = \mathbf{Y}_0 + \sum_{i=1}^{3} \beta_i \cdot G_1 + \sum_{i=1}^{3} \beta_{ii} \cdot G_i^2 + \sum_{i=1}^{3} \sum_{j=i-1}^{3} \beta_{ij} \cdot G_i \cdot G_j \qquad (1)$$

For the models, three-dimensional graphs were used to visualize the overall trends. Each formulation was carried out in duplicate.

The pasta formulation was prepared for the 15 runs according to the following reference recipe: durum wheat semolina (65% w/w), tap water (22% w/w) and pasteurised liquid egg (13% w/w). The amount of added water was adjusted in previous tests to obtain a dough that was easy to handle and process. Wheat semolina was replaced by wheat bran –of up to 11.54% (w/w)- to obtain a product of approximately 4% fibre content, labelled "source of fibre" (>3 g dietary fibre/100 g food), according to the Nutritional Requirements for Dietary Fibre Foods (Official Journal of European Union, 2006). The fibre content was estimated considering the chemical composition of the raw materials (Table 1). The obtained values for the 15 runs ranged from 3.7 to 5.2 g/100 g of pasta.

Fresh egg pasta preparation

After being weighed (0.001 g accuracy, PFB 300-3, Kern & Sohn GmbH, Balingen), the dry (semolina/wheat bran/gums) and liquid (egg/water) ingredients were premixed at speed number 4 in a medium speed electric cooking device (Thermomix TM-31, Vorwerk Spain M.S.L., S.C., Madrid). The mixing order was established to obtain a uniform blend: first, the egg and water were mixed for 15 s; secondly, the gums were added and mixed for 40 s; finally, the wheat semolina/bran mix was incorporated and mixed for 45 s. The obtained blends were then kneaded for 2.5 min in the same cooking device. The dough was left to stand for 20 min inside a plastic bag, to allow sample relaxation. Afterwards, the tagliatelle were formed with a domestic pasta-making machine (Simplex SP150, Imperia, Italy) coupled to a specific motor (A2500, Imperia, Italy). The dough was laminated to obtain a 1-mm thick sheet and then cut into 4 mm-wide tagliatelle. Prior to cooking, the tagliatelle was allowed to stand for 10 min in order to prevent stickiness. The tagliatelle samples were made and immediately tested for their mass, water content, dimensions, volume, colour and mechanical properties (analysis explained below). Three replicates (and five for the mechanical properties) were obtained for each pasta formulation.

Pasta cooking

The cooking trial was conducted in triplicate for each pasta formulation. The cooked pasta was prepared by boiling 25 g of 7-cm-long samples in deionised water (300 ml). The water volume was maintained at 90% of its initial volume by adding boiling water and covering the flasks to avoid loss through evaporation. At 4 min (the optimal cooking time for 100% semolina fresh egg tagliatelle), cooking time determined by the method AACC 16-50 (AACC. 2000), the pasta was removed from the flasks and cooled down with 50 ml of cold deionised water. Afterwards, the samples were drained for 2 min and then analysed. The tagliatelle pieces were weighed (0.001 g accuracy, PFB 300-3, Kern & Sohn GmbH, Balingen) and analysed for their water content, cooking properties -water absorption index (WAI) and cooking loss (%CL)-, swelling index, colour attributes and mechanical properties (analysis explained below).

Technological properties of the tagliatelle

The water content (x_w, g water/ g product) of the uncooked and cooked samples was determined according to the AACC 44-40 method (AACC. 2000). The tagliatelle dimensions (thickness, length and width) were measured with a calliper (PCE-DCP 200N, PCE Ibérica S.L., Albacete, Spain). The water absorption index (WAI, g/g) was calculated taking into account the mass gain and increase in water content after cooking (Eq. 2).

$$WAI = \frac{m_c \cdot x_{wc} - m_o \cdot x_{wo}}{m_o} \qquad (2)$$

where m_c is the weight of cooked tagliatelle, x_{wc} is the water content of cooked tagliatelle, m_o is the weight of uncooked tagliatelle and x_{wo} is the water content of uncooked tagliatelle.

Cooking loss (amount of solid substance lost to cooking water, %CL) was determined according to the AACC approved method 16-50 (AACC. 2000). After the cooking process, the cooking and rinse waters were collected in an aluminium vessel and evaporated to dryness in an air oven at 100ºC to constant weight. The residue was weighed and reported as a percentage of the starting material. Pasta swelling (SI) was expressed as the relative volume changes between the uncooked and cooked samples. The tagliatelle colour was measured throughout the surface reflectance spectra, obtained by a spectrocolorimeter (Minolta CM-3600D), between 400 nm and 700 nm (illuminant D65, 10° standard observer), using a white background. For each pasta formulation, determinations were made in triplicate before and after cooking. The CIE $L^*a^*b^*$ colour coordinates were obtained from the reflectance spectra: L^* (lightness), a^* (redness-greenness) and b^* (yellowness-blueness). The results were expressed in terms of both chromatic magnitudes and colour saturation ($C_{ab}^* = \sqrt{a*^2 + b*^2}$), and hue angle ($h_{ab}^* = arctg \frac{b^*}{a^*}$).

The mechanical properties were determined through a Texture Analyzer (TA.XT2, Stable Micro Systems, Godalming, UK). The tests were performed following the AACC Method 16-50 (AACC. 2000; Gallegos-Infante et al., 2010). Five 7-cm-long adjacent strands were cut at 0.17 mm/s. To assess changes in the pasta texture during cooking, three parameters were considered: (i) maximum cut force (F) -used as a measure of firmness-, (ii) the area compressed under the force-time curve from the initial test time to the maximum cut force- which represents dough consistency and (iii) the initial slope of the force-time curve (S_i), which is related to the elasticity modulus and, therefore, provides an idea of the product’s solid nature.

Scanning electron microscopy

The microstructure of uncooked pasta tagliatelle was observed by Field emission scanning electron (SEM) (JEOL®, model JSM-5410, Japan). Field emission scanning electron observations were carried out on the pasta cross section. To prepare the samples, samples were frozen in liquid N_2 at -210°C and cryofractured. Two replicates per formulation were fixed on copper stubs, gold coated, and observed using an accelerating voltage of 15 kV.

Statistical analysis

Statgraphics® Centurion XVI.I, version 16.1.17 (StatPoint Technologies, 2011), was used to adjust the multiple regression models to the experimental data, which enabled us to evaluate the linear, quadratic and interactive effects of hydrocolloids' CMC, XG and LBG on the selected dependent variables ($p < 0.05$) and optimise the pasta formulations. The same statistical software was used to generate surface response plots.

Results and Discussion

Raw material characteristics are extremely important for determining the cooking quality of pasta. In Table 1, it is possible to observe that proteins, which contribute significantly to the structure conformation of dough and, thus, to texture, are slightly lower in wheat bran (9.6 g/100 g) compared to durum wheat semolina (12 g/100 g). Along with proteins, starch plays an important role in determining pasta quality as starch granules absorb water, swell and gelatinise during cooking. Certain leaching to cooking water occurs as a result of starch solubilisation when proteins coagulate. Replacement of wheat semolina for wheat bran will reduce dough starch content, as digestible carbohydrate content is fairly inferior in wheat bran (25% compared to 67% w/w for wheat semolina).

As expected, wheat bran is rich in dietary fibre (45 g/100 g), ash (8.5 g/100 g) and fat (4.07 g/100 g), which improved the nutritional quality (fibre, vitamins and minerals) of the resultant product. It is also noteworthy that the used wheat bran presented a 50% particle size below 75 μm, while the wheat semolina particle size mainly ranged between 250 and 180 μm (50%) or was below 180 μm (35%). This bran particle size was chosen in order to obtain a more uniform and better hydrated blend.

Eggs are traditionally used in pasta, mainly to achieve flavour effects, but can also help structure formation promoting a tighter protein network (Hager et al., 2012). The pasteurised liquid eggs used in this study presented a high protein content (11 g/100 g).

Table 2 presents the experimental cooking, mechanical and optical property values obtained for each run of the experimental design. The results from the 15 runs were fitted to a second order polynomial equation (Eq. 1) and the removal of non-significant terms ($p > 0.05$) was applied. The goodness of the fitted model was evaluated through an analysis of variance, mainly based on the F-test and the R^2adj, which provides a measurement of how much variability in the observed response values could be explained by the experimental factors and their interactions (Granato et al., 2010). In practice, a model is considered adequate in describing the influence of the variable(s) when the coefficient of determination (R^2) is at least 80% (Yaakob et al., 2012) or the R^2adj values go over 70% (Cruz et al., 2010).

Mechanical properties of the uncooked and cooked fresh egg pasta

It has been widely recognized that an instrumental analysis is useful for estimating textural pasta characteristics, and has been acknowledged as being important for consumers, which-consequently- affects product acceptability (Brennan & Tudorica, 2007). These properties are firmness, stickiness and elasticity. High-quality cooked pasta must maintain a good texture, be resistant to surface disintegration and stickiness, and have a firm but elastic and consistent structure (“al dente”).

Table 3 summarizes the estimated regression coefficients (Y_o, β_i, β_{ii} and β_{ij}) of the second order model obtained for the mechanical properties of the uncooked and cooked tagliatelle, in which fitted parameters from the analysis of variance are included.

With regards to the fitted model, the lack-of-fit parameter was not significant ($p > 0.05$) and the p-value of the Durbin-Watson statistic was greater than 0.05, meaning that there is no indication of serial autocorrelation in the residuals at the 5% significance level. The predictive models developed for the consistency of the uncooked (A_o) and the firmness (F_c) and consistency (A_c) of the cooked pasta were considered adequate, as the R^2adj values and model significance obtained satisfactory levels. Nonetheless, the model was less suitable (R^2adj = 60.9%) for the cooked pasta elasticity (S_{ic}) and an explanatory analysis of the data was undertaken because it offered a reasonable initial solution to describe the tendency of this parameter.

Figure 1 shows the Response Surface plots for the different mechanical parameters of the uncooked (a) and cooked pasta (b-f). As can be observed, the influence of factors on the mechanical behaviour of the pasta was affected by the cooking process. For the assayed gum concentration range, the β and p values in Table 3 indicate that the presence of XG had a significant and positive effect on the mechanical fresh pasta properties. Both the uncooked and cooked pasta consistency increased linearly with the XG concentration. This was probably the result of a better structured dough with a continuous protein matrix entrapping starch granules, which can absorb water and gelatinise without major loss occurring during cooking. In fact, as discussed below, this gum reduced cooking loss. Indeed, Figures 1a and 1b show that adding 0.8% XG to the pasta formulations based on durum wheat semolina and wheat bran led to increases of 110.7% and 92.7% (values calculated from the models) in the consistency of the uncooked (A_o) and cooked (A_c) tagliatelle pieces, respectively. The cooked pasta firmness was also enhanced (up to 72.3%; see Figure 1c).

Similar results were reported by (Brennan & Tudorica, 2007), who showed improved pasta firmness when xanthan gum was added at levels of 2.5-10%. The results of

(Larrosa et al., 2013) for corn-based pasta also indicated that pasta firmness increased when a high gum proportion (XG/LBG) was used. These authors proposed that the formation of a network by the soluble fibre around starch granules would lead to a stronger cohesiveness between the starch and protein in the pasta structure. Scanning electron microscopy (Figures 2a-b) showed, in fact, the tightly embedded starch granules (slightly swollen) in a well formed gluten network of uncooked tagliatelle with supplemented with wheat bran and 0.8% xanthan gum. Plain wheat semolina samples (Figures 2c-d) are included as a reference. The contribution of xanthan gum to the structural strength could also be linked to the lower cooking loss values obtained (as discussed below), which indicates a well-formed structure from which small amounts of solids are released during cooking. The cooked pasta firmness (F_c) was negatively affected when CMC and LBG were used together. Therefore, this combination does not seem to be convenient.

In the uncooked pasta, neither firmness nor elasticity were significantly ($p>0.05$) affected by the incorporation of the various gums. And as commented before, only the consistency of the uncooked pasta seemed to be affected by the addition of XG ($p<0.05$). This could be attributed to the poor interactions established by the hydrocolloids used when solved in cold water environments.

Significant interactions between CMC and XG on A_c (negative) and $S_{i,c}$ (positive) were also found (Table 3). Therefore, when combining both hydrocolloids, the cooked pasta elasticity significantly -although slightly- increased. However, consistency of cooked pasta decreased up to 15.99% when combining 0.8% w/w of CMC and XG (Figure 1b). LBG affected only the cooked pasta elasticity and, although this linear effect was slight, a positive tendency was observed (Figure 1e), with an increase from 0.213 (0% w/w) to 0.257 N/s (0.8% w/w). Thus, it would be interesting to raise the LBG concentration in the pasta formulation even more. CMC used alone not only had no effect on the mechanical response of the uncooked and cooked pasta, but also had a negative quadratic effect on the cooked pasta elasticity (Table 3, Figures 1e and 1f). Chillo et al. (2009) did not find a significant effect on the elastic modulus of fresh amaranth tagliatelle when 0.1-0.3% CMC was incorporated into standard wheat semolina dough. Aravind et al. (2012a) observed no significant impact on cooked pasta firmness when adding 0.25-1.5% of CMC to durum wheat semolina pasta. The results obtained for elasticity in this work differ somewhat from those reported by Larrosa et al. (2013) and Brennan & Tudorica (2007), who obtained a more elastic dough when adding gums, yet they used higher concentrations of hydrocolloids.

From these results, it can be concluded that only xanthan gum implies a better texture on ready-to-eat tagliatelle within the analysed concentration range. It also seems that LBG should be used at higher levels than those employed in this work. No synergistic effect was observed between XG and LBG.

Cooking quality and colour attributes of the uncooked and cooked fresh egg pasta

The regression summary and ANOVA for cooking quality (WAI and %CL) and colour attributes of the uncooked pasta are shown in Table 4 (only the significant variables at the 95% confidence level were selected for model construction). In this case, the water absorption index (WAI) adequately fitted the multiple regression model with gums used as the independent variables, explaining 97.7% of the variation in the experimental data (R^2adj). From the regression coefficients, it can be observed that LBG had a slightly negative quadratic effect on WAI, but water gain significantly decreased when the XG concentration increased from 0 to 0.36% w/w, and it rose up again when more of this hydrocolloid was added to the pasta formula. In fact, it seems from Figure 3a that this growing tendency when using XG concentrations above 0.36% will continue from 0.8%

w/w. The observed interactive effect of CMC and XG also implied a WAI 21.9% higher than that obtained when using XG alone (considering the highest assayed gum concentrations (0.8% w/w) for the calculus). This effect is observed in Figure 3a. A synergistic interaction between CMC and XG was also observed, which had a relative weight on the WAI response (β = 0.29, Figure 3a). Finally, the XG and LBG combination also showed a positive but less important (β = 0.1) interaction (Figure 3b). CMC had no effect on this parameter when used alone, as other authors have previously observed when replacing 0.25-1.5% wheat semolina with CMC (Aravind et al., 2012a). In contrast, Komlenic et al. (2006) found reduced water absorption when adding 0.15-0.75% CMC, suggesting that CMC absorbs available water speedily to inhibit starch swelling. However, in the last cited work, wheat flour was used instead of durum wheat semolina.

The model developed for cooking loss (%CL) and the uncooked pasta colour attributes (b^* coordinate and chrome) proved less predictive (with an R^2adj of 54.1 and 51.5%, respectively). This is partially explained by the narrow range of the experimental response variables (18.18-20.21 for b^* and 18.97-21.16 for C^*_{ab}). Nevertheless, regression coefficients and surface plots were also generated for these models because they offer a reasonable initial solution to describe the quality response of these parameters. In Figure 3c, we can see a significant drop in %CL when XG over 0.4% was incorporated into the pasta formula. The obtained negative quadratic effect could lead to a 16.7% lower cooking loss if XG was used at the 0.8% concentration. However, LBG had a positive quadratic effect (β = 0.63, Figure 3c) on this variable as it increased %CL, and its use, therefore, is not recommendable from this point of view. CMC had no significant effect on this parameter at the concentration range used in the experiments, as previously reported by Aravind et al. (2012a) when replacing durum wheat semolina with 0-1.5% CMC for spaghetti formulations. However, Komlenic et al. (2006) observed a rise in this parameter when incorporating 0.15-0.75% CMC into *Triticum aestivum* wheat semolina pasta. The colour parameters that presented statistically significant relationships ($p<0.05$) with the hydrocolloids employed within the studied range were the yellowness (coordinate b^*) and chrome (C^*_{ab}) of the uncooked tagliatelle samples. Both were affected in the same way and by the same gums (Table 4, Figures 3d and 3e). A positive quadratic effect of CMC on $b*$ and chrome was observed. Therefore, the higher the CMC concentration, the greater the yellowness and colour saturation of the tagliatelle dough. Both characteristics are highly appreciated by consumers, as they usually link the yellow colour with the presence of egg (Alamprese et al., 2009). Aravind et al. (2012a) obtained similar results when using CMC concentrations from 0 to 1.5% on durum wheat semolina formulations. A negative effect on $b*$ and chrome was reported in the interaction of CMC and XG. These parameters fell by 3.8% when they were combined at 0.8% w/w in the pasta formulation. As yellowness reduction is not welcomed in this product, this combination is not recommended.

Conclusions

“Source of fibre” fresh egg tagliatelle with good technological properties can be prepared with a combination of wheat semolina, wheat bran and gums. An experimental design was conducted to assess the effects of carboxymethylcellulose (CMC), xanthan gum (XG) and locust bean gum (LBG) on pasta quality. The results highlight that the incorporation of XG into the pasta formula at the 0.8% level results in lower cooking loss, better textural characteristics and minimal impact on colour characteristics, compared to the values obtained without additives. CMC only significantly increased the yellowness and colour saturation of uncooked pasta, both of which are desirable characteristics for consumers. The cooked pasta elasticity and water absorption also improved when CMC was used at a concentration over 0.6% and in combination with XG. However, this combination led to less consistent cooked pasta and poorer colour characteristics. Therefore, the use of XG above 0.8% to improve textural properties -and the employment of CMC to enhance yellowness in formulate composite wheat bran-based pasta are recommended. A significant, but slight, increase in the cooked pasta elasticity was linked positively to LBG concentration.

Conflict of interest

The authors declare that they have no conflict of interest.

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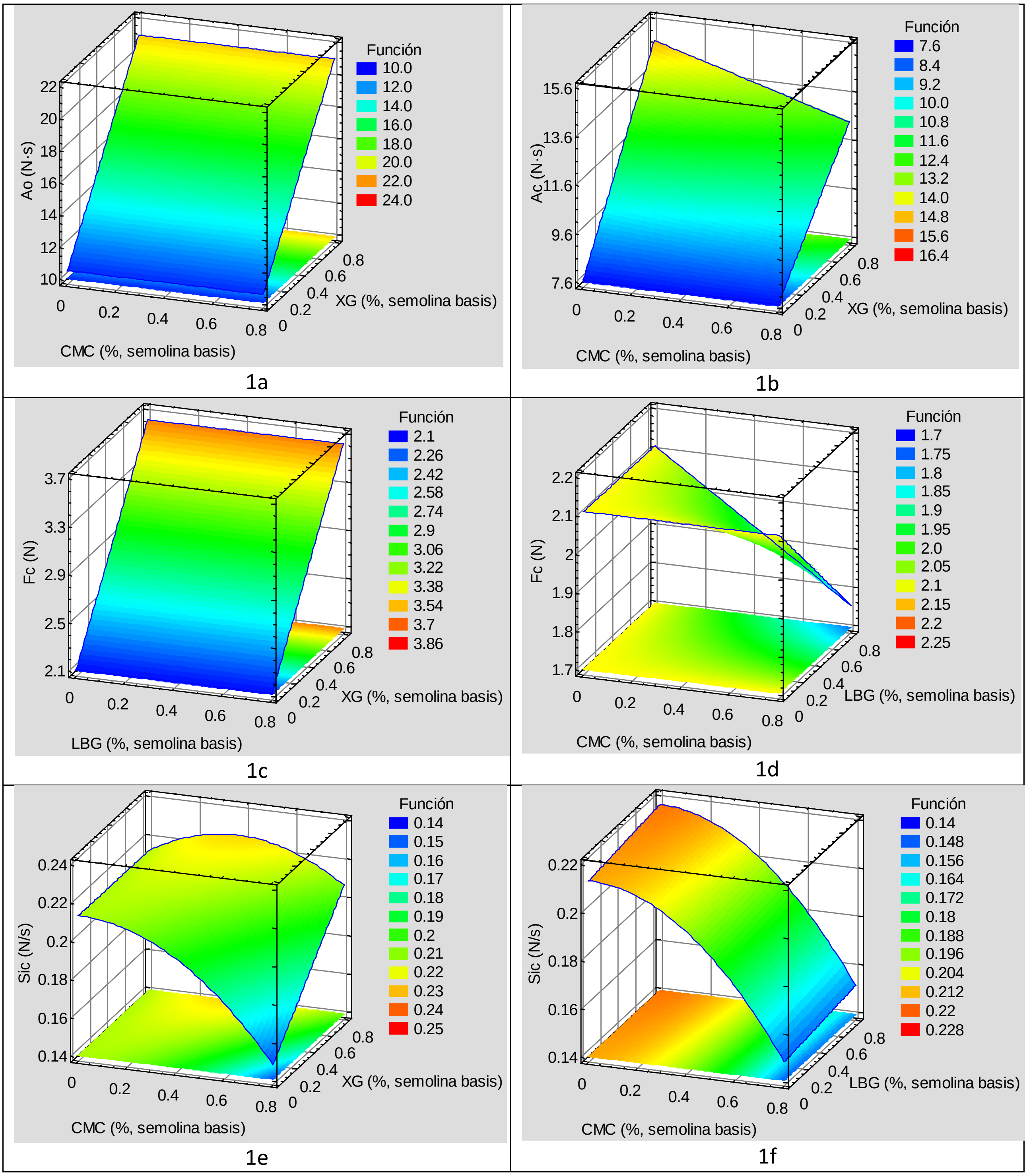


Figure 1a-1f. Effect of CMC, GX and LBG levels on the uncooked and cooked pasta consistency (A_o and A_c, Figures 1a and 1b, respectively) and on the cooked pasta firmness (F_c, Figures 1c and 1d) and elasticity ($S_{i.c}$, Figures 1e and 1f).

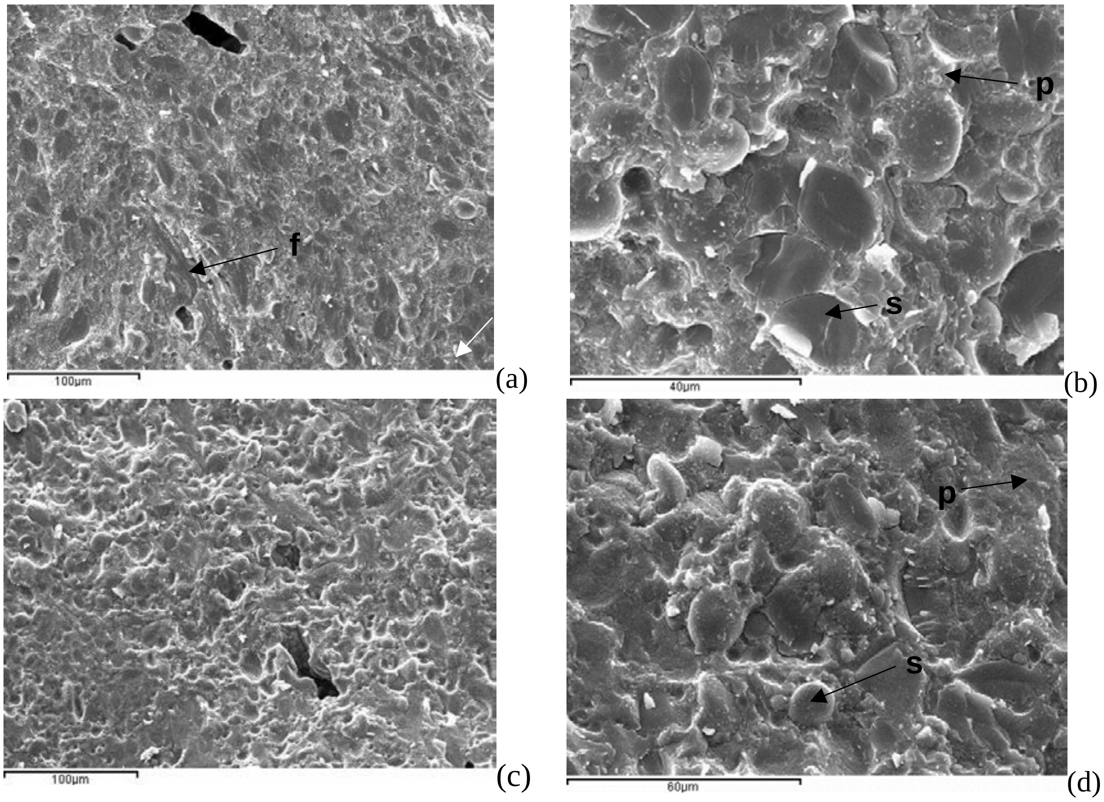
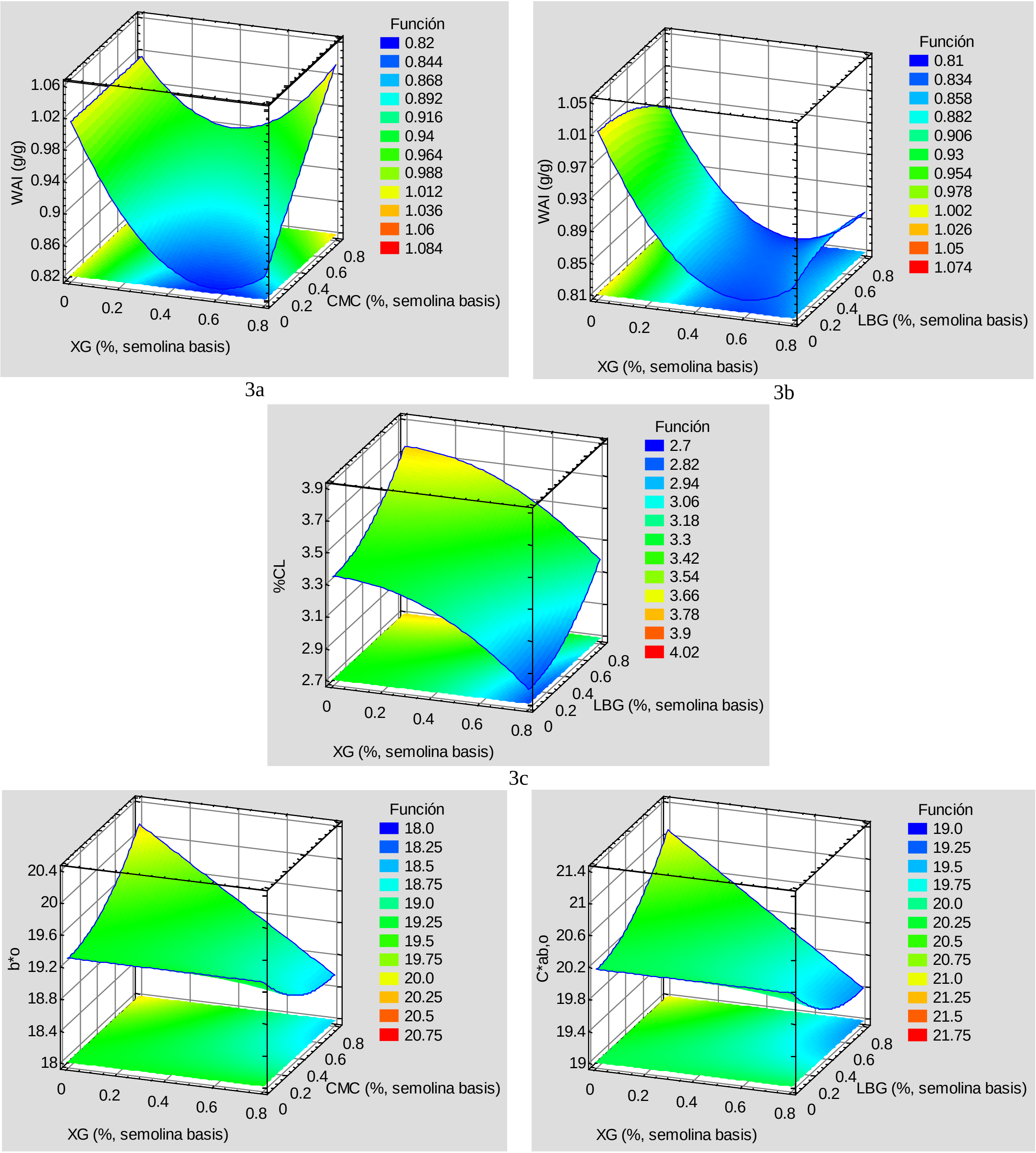


Figure 2a-2d. Scanning electron micrographs of cross section of uncooked tagliatelle with (a-b) or without (c-d) wheat bran and 0.8% xanthan gum. Magnification 350 and bar = 100 µm (a, c), 1000 and bar = 40 µm (b) and 750 and bar = 60 µm (d) (s: starch, p: protein, f: fibre).



3a

3b

3c

3d

3e

Figure 3a-3e. Effect of CMC, GX and LBG levels on the cooking properties (WI, Figures 3a and 3b, and %CL, Figure 3c), and the uncooked pasta colour properties (b^*_c and $C^*_{ab,o}$), Figures 3d and 3e, respectively).

Table 1. Proximate chemical composition and particle size distribution of raw materials (means of three replications)

	DWS	**MWB**
Proximate composition (% w/w)		
Water content	14.8 (0.4)	7.4 (0.9)
Protein	12.0 (1.2)	9.6 (0.2)
Fat	1.8 (0.2)	4.07 (0.12)
Dietary Fibre	3.23 (0.02)	45 (3)
Ash	0.90 (0.13)	8.5 (0.2)
DC[a]	67 (2)	25 (4)
Particle size distribution (%)		
> 355 µm	15	-
> 300 µm	-	20
> 250 µm	50	-
> 180 µm	25	20
> 132 µm	10	-
> 75 µm	-	10
< 75 µm	-	50

[a] Digestible carbohydrates calculated by difference

DWS: durum wheat semolina, MWB: micronized wheat bran

Table 2. Response variable values for the different pasta formulations corresponding to the experimental design, as a function of the levels of the three gum concentrations (CMC: carboxymethylcellulose; XG: xanthan gum; LBG: locust bean gum)

FACTORS*				**RESPONSE VARIABLE****																	
Run	**CMC**	**XG**	**LBG**	$\mathbf{Y_{Fo}}$	$\mathbf{Y_{Sio}}$	$\mathbf{Y_{Ao}}$	$\mathbf{Y_{Fc}}$	$\mathbf{Y_{Sic}}$	$\mathbf{Y_{Ac}}$	$\mathbf{Y_{WI}}$	$\mathbf{Y_{\%CL}}$	$\mathbf{Y_{L*o}}$	$\mathbf{Y_{a*o}}$	$\mathbf{Y_{b*o}}$	$\mathbf{Y_{C*ab,o}}$	$\mathbf{Y_{h*ab,o}}$	$\mathbf{Y_{L*c}}$	$\mathbf{Y_{a*c}}$	$\mathbf{Y_{b*c}}$	$\mathbf{Y_{C*ab,c}}$	$\mathbf{Y_{h*ab,c}}$
1	+1	+1	0	6.26	0.33	26.08	3.08	0.22	11.30	0.96	2.88	58.31	5.89	18.91	19.81	1.27	57.66	3.81	14.06	14.56	1.31
2	-1	+1	0	5.70	0.28	22.02	3.59	0.22	14.57	0.87	2.88	57.58	5.60	19.08	19.89	1.29	55.99	3.77	12.67	13.25	1.28
3	0	-1	+1	5.06	0.25	11.55	2.00	0.24	7.40	1.05	3.74	58.19	5.76	19.45	20.29	1.28	55.12	3.78	13.33	13.85	1.29
4	+1	-1	0	5.20	0.21	10.50	1.95	0.17	7.72	1.09	3.44	57.32	6.25	20.21	21.16	1.27	54.88	3.47	13.24	13.69	1.31
5	0	0	0	4.93	0.28	14.94	2.89	0.25	11.03	0.89	3.30	57.19	5.77	18.83	19.69	1.27	56.05	3.60	11.98	12.51	1.28
6	0	+1	+1	5.34	0.28	18.13	3.51	0.28	12.55	0.95	3.18	57.22	5.40	18.18	18.97	1.28	57.79	3.73	13.59	14.10	1.30
7	0	0	0	5.44	0.26	15.29	3.18	0.25	11.77	0.89	3.30	58.41	5.64	18.99	19.81	1.28	55.07	3.74	12.50	13.05	1.28
8	-1	0	-1	4.51	0.21	13.59	2.79	0.22	10.46	0.85	3.20	56.91	6.04	19.35	20.27	1.27	53.86	3.89	12.13	12.74	1.26
9	-1	-1	0	5.53	0.20	10.98	2.00	0.24	7.47	1.00	3.44	56.90	6.06	19.70	20.61	1.27	59.90	4.20	15.13	15.71	1.30
10	0	+1	-1	5.42	0.17	19.15	3.73	0.20	15.04	0.85	2.78	57.72	5.33	18.66	19.41	1.29	59.55	3.79	14.10	14.60	1.31
11	+1	0	-1	5.02	0.10	13.42	2.92	0.21	10.83	0.85	3.20	57.89	5.63	19.36	20.17	1.29	59.82	4.06	15.06	15.60	1.31
12	0	-1	-1	5.13	0.18	10.05	1.88	0.18	7.11	1.01	3.34	57.37	5.90	19.35	20.23	1.28	59.27	3.95	14.99	15.50	1.31
13	0	0	+1	5.468	0.319	18.375	2.607	0.241	9.927	0.916	3.602	58.18	6.14	19.35	20.30	1.26	56.46	3.48	12.65	13.18	1.30
14	+1	0	+1	5.17	0.24	18.22	2.53	0.20	10.30	1.01	3.60	58.48	5.94	19.03	19.93	1.27	54.83	3.80	13.09	13.63	1.29
15	0	0	0	4.93	0.20	14.56	2.92	0.26	11.68	0.89	3.30	57.63	6.06	19.76	20.67	1.27	55.71	3.47	10.36	10.93	1.25

*Factors CMC, XG and LBG stand for Carboxymethylcellulose; Xanthan Gum; Locust Bean Gum: -1 = 0 % w/w; 0 = 0.4 % w/w; +1 = 0.8 % w/w;

**Response variables Y_{Fo},Y_{Fc}, Y_{Sio},Y_{Sic}, Y_{Ao}, Y_{Ac}, Y_{WI}, $Y_{\%CL}$,Y_{L*o}, Y_{a*o}, Y_{b*o}, $Y_{C*ab,o}$, $Y_{h*ab,o}$,Y_{L*c}, Y_{a*c}, Y_{b*c}, $Y_{C*ab,c}$, $Y_{h*ab,c}$ stand for elasticity (S_i), firmness (F) and consistency (A), water absorption index (WI), cooking loss (%CL)), lightness (L*), redness (color coordinate a^*), yellowness (color coordinate b^*), chrome (C^*_{ab}) and hue angle (h^*_{ab}). respectively. Subscripts *o* and *c* refer to uncooked and cooked pasta samples, respectively.

Table 3. Constant values (Y_o) and obtained parameters of the multiple regression model for the mechanical properties elasticity (S_i), firmness (F) and consistency (A). Subscripts o and c refer to uncooked and cooked pasta samples, respectively. Only significant relationships are shown

	A_o (N·s)	**F_c (N)**	**S_{ic} (N/s)**	**A_c (N·s)**
Constant (Y_o)	10.503	2.109	0.213	7.683
CMC	-	-	-	-
XG	13.22	1.905	-	8.902
LBG	-	-	0.055	-
CMC*CMC	-	-	-0.102	-
XG*XG	-	-	-	-
LBG*LBG	-	-	-	-
CMC*XG	-	-	0.0927	-3.699
CMC*LBG	-	-0.549	-	-
XG*LBG	-	-	-	-
p value lack of fit	1.000	1.000	0.996	1.000
R^2	0.774	0.918	0.693	0.890
R^2adj	0.756	0.904	0.609	0.872
Standard error of est.	2.243	0.189	0.020	0.876
Mean absolute error	1.665	0.124	0.015	0.667
Durbin-Watson statistic (p value)	1.187 (0.290)	1.528 (0.145)	2.375 (0.715)	1.991 (0.510)

Analysis of variance at the 95% confidence level;
Independent variables: CMC (carboxymethylcelullose), XG (xanthan gum), LBG (locust bean gum).

Table 4. Constant values (Y_o) and obtained parameters of the multiple regression model for the cooking properties (water absorption index (WAI) and cooking loss (%CL)) and the colour of uncooked pasta (yellowness (color coordinate b^*_o) and chrome ($C^*_{ab,o}$)). Subscript o refers to uncooked pasta samples. Only significant relationships are shown

	WAI (g /g)	%CL	b^*_o	$C^*_{ab,o}$
Constant (Y_o)	1.01267	3.34136	19.2952	20.1591
CMC	-	-	-	-
XG	-0.631424	-	-	-
LBG	-	-		
CMC*CMC	-	-	1.33124	1.44157
XG*XG	0.531295	-0.87169	-	-
LBG*LBG	-0.0829882	0.624838	-	-
CMC*XG	0.287905	-	-2.47099	-2.62642
CMC*LBG	-	-	-	-
XG*LBG	0.100721	--	-	-
p value lack of fit	1.000	0.997	0.996	0.995
R^2	97.65	61.48	60.63	58.47
R^2adj	96.34	55.06	54.07	51.54
Standard error of est.	0.011	0.235	0.334	0.372
Mean absolute error	0.007	0.176	0.234	0.277
Durbin-Watson statistic (P value)	1.968 (0.445)	1.968 (0.445)	1.899 (0.411)	1.894 (0.407)

Analysis of variance at the 95% confidence level;

Independent variables: CMC (carboxymethylcelullose), XG (xanthan gum), LBG (locust bean gum).