Improvement of the texture and quality of cooked gluten-free pasta

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ABSTRACT

The effects of egg-proteins and water content on viscoelastic and quality properties of cooked gluten-free pasta were analyzed. Cooking properties included the determination of optimum cooking time (OCT = 10 min), water absorption, cooking loss, and total organic matter. Cutting force and texture profile parameters were also evaluated. Springiness, resilience, and adhesiveness were mainly controlled by the egg-protein content in the dough, while cooked pasta hardness and the plateau modulus were negatively correlated with dough moisture. The obtained results were mathematically modeled, and a multi-response optimization process was performed using individual desirability functions based on target properties of wheat flour pasta. These functions were combined into a single composite response (global desirability) to determine the precise amount of the different components in the formulation to obtain high quality gluten-free cooked pasta. Optimized dough was prepared, cooked, and the predicted properties were experimentally validated.

1. Introduction

Pasta manufacturing industry, like all industries, caters to the wants and needs of their consumers. High quality cooked pasta from durum wheat semolina maintains good texture, resists surface disintegration, does not release an excessive amount of organic matter into the cooking water, retains a firm structure, and does not show surface stickiness (Liu, Shepherd, & Rathjen, 1996). This is clearly related to the fact that gluten in wheat flour is the main structure-forming protein, thus its absence in gluten-free (GF) pasta results in technological and quality problems.

The technological process adopted in GF pasta production has a significant influence on the quality of the final product as well as the raw materials used. One of the usual methodologies to produce GF pasta is to obtain pregelatinized starch through heat and cool stages, thus forming a rigid network based on the retrograded starch (Cabrera-Chávez et al., 2012; Marti, Caramanico, Bottega, & Pagani, 2013; Marti, Seetharaman, & Pagani, 2010).

However, despite the great efforts made in the last few decades to produce GF pasta with sensory characteristics similar to durum-wheat products, the GF pasta currently on the market is still far from what the consumer is looking for (Marti & Pagani, 2013). Basically, in GF pasta, the role of gluten could be replaced by choosing suitable formulations and recipes using the correct amount of proteins, hydrocolloids and moisture to achieve the desirable quality attributes after the traditional hydrothermal treatment, but also making the dough easy to handle under industrial conditions (Larrosa, Lorenzo, Zaritzky, & Califano, 2013).

Starch has to assume a structuring role, which is related to the tendency of its macromolecules to re-associate and interact after gelatinization, resulting in newly organized structures that retard further starch swelling and solubilization during cooking. Protein quantity and quality have received considerable attention as the most important factors affecting both wheat pasta properties (D'Egidio, Mariani, Nardi, Novaro, & Cubadda, 1990), and GF pasta (Marti et al., 2014). In some cases, also low amounts of emulsifiers (Chillo, Laverse, Falcone, & Del Nobile, 2008) and hydrocolloids (Singh, Raina, Bawa, & Saxena, 2004) are added. Nowadays, the most used ingredients in gluten-free pasta production are: rice and corn flours (Arendt, Morrissey, Moore, & Dal Bello, 2008; Larrosa, Lorenzo, Zaritzky, & Califano, 2012), flours from pseudo cereals (Chillo et al., 2008; Fiorda, Soares, da Silva, Grosmann, & Souto, 2013) starches of different origin (Huang, Knight, & Goad, 2001),

dairy products and vegetable proteins (Marti et al., 2014; Mirhosseini et al., 2015).

The amount of water used in pasta processing should be optimized to achieve pasta color and textural characteristics according to market preferences (Fu, 2008; Hou, Otsubo, Okusu, & Shen, 2010). It has been informed that insufficient water produce streaky and/or flaky dough sheet surfaces (diminishing pasta color), resulting in softer cooked pasta texture (Hou et al., 2010). Using above optimum levels of water in the formulation also has adverse quality effects, as doughs will be stickier to handle and difficult to sheet tending to produce poor quality finished pasta (Fu, 2008; Hatcher, Kruger, & Anderson, 1999; Hou et al., 2010).

In previous works, Larrosa et al. (2013) optimized gluten-free (GF) pasta dough composition to achieve the desirable textural and rheological properties of the uncooked dough, evaluating its handling properties such as extensibility, ease of processing, smoothness, and non-adhesiveness. The aim of the present work was to improve the GF pasta dough formulation previously proposed (Larrosa et al., 2013) by studying cooked quality attributes at the optimal cooking time. To fulfill this global objective three steps were completed: i) the relationship between egg-proteins and water contents and quality features of cooked GF pasta was analyzed; ii) the precise amount of components to obtain a high quality GF cooked pasta was predicted based on the response of those characteristics that were significantly affected by composition; iii) the predicted optimal formulation was prepared and the cooked GF pasta was characterized, to validate the procedure.

2. Materials and methods

2.1. Materials

Corn flour and corn starch were purchase from Herboeste (Bs As, Argentina) and Saporiti (Bs As, Argentina), respectively. Dry egg and dry egg-white were kindly provided by Ovobrand SA (Brandsen, Argentina). Used hydrocolloids were food-grade commercial xanthan (XG) and locust been gums (LBG) obtained from Sigma—Aldrich Co. (St. Louis, MO). Analytical grade NaCl, sunflower oil (AGD, Bs As, Argentina), and cold distilled water were also used.

2.2. Experimental design

A two-way factorial design was employed to analyze the effect of water and protein content on the quality of cooked pasta (Larrosa, Lorenzo, Zaritzky, & Califano, 2015). Three levels for moisture content (34.8 g/100 g, 36.13 g/100 g, and 37.5 g/100 g) and two for egg-proteins (2.7 g/100 g and 6.6 g/100 g) were adopted (Table 1). An additional central point was included and replicated three times to better interpret the interaction of components and evaluate curvature in the mathematical models (W2EP2).

Water plus egg-proteins contents (dry whole-egg + dry egg-

white, 10:1) ranged between 37.5 g/100 g and 44.1 g/100 g, thus the corn starch and corn flour mixture varied from 56.2 g/100 g—49.6 g/100 g, accordingly. The ratio between corn starch and corn flour was 4:1 in all formulations.

As a control, wheat pasta formulated with 67 g/100 g of commercial wheat flour (Molino Cañuelas, Bs As, Argentina) and 33 g/100 g fresh eggs was also prepared.

2.3. Pasta dough sample preparation

The basic formulation of the dough was taken from a previous work where composition was optimized to obtain a good quality uncooked pasta dough (Larrosa et al., 2013): 1 g/100 g NaCl, 2.8 g/100 g sunflower oil, 2.5 g/100 g of a mixture of XG and LBG in a 2:1 ratio.

The mixing protocol adopted to prepare GF dough was previously described by Larrosa et al. (2013). Once the laminated dough was obtained, representative subsamples were cut from these sheets and kept in airtight polystyrene containers to avoid moisture loss until assessment of their functional characteristics. Ambient temperature was kept at 20 °C throughout dough preparation.

Two different geometries were used: band pasta (tagliatelle, $8 \times 2 \times 150$ mm) and lasagna sheet ($80 \times 80 \times 2$ mm). Tagliatelle shaped pasta was used to analyze texture and the other quality parameters, while rheological properties were determined using circles (35 mm diameter) cut from the lasagna sheet, to entirely cover the measuring surface of the sensor.

2.4. Cooking properties

2.4.1. Pasta quality evaluation
The optimal cooking time for each formulation was determined using method AACC 66-50 (AACC, 2000). The cooking tests were performed for various cooking times for each pasta sample in order to determine the optimal cooking time (OCT). Briefly 25 g of tagliatelle was cooked in 300 ml of boiling distilled water. OCT was when the white core in the pasta was still present but disappeared after squeezing between two glass slides. Once the OCT was evaluated, the pasta sample was optimally cooked and the solid loss and water absorbed during cooking were determined by triplicate.

Cooking loss (g loss/100 g initial dough) was measured by evaporation of the cooking water to dryness in an oven-tray (100 °C). Absorbed water was measured as the weight increase of tagliatelle before and after cooking, and was expressed as percent weight gain with respect to the weight of uncooked pasta (Bonomi et al., 2012).

2.4.2. Total organic matter (TOM)
Total organic matter (TOM) is the amount of organic matter released from the cooked pasta during exhaustive rinsing. 25 g drained pasta was washed with 500 ml water to remove the substance coating the surface of cooked pasta. Then the washing water was analyzed for TOM (D'Egidio et al., 1982) using a commercial test for Chemical Oxygen Demand analysis (Hach Cat. N° 24159, Hach Co., CO, USA). Water samples digestion (2 h, 150 °C) was performed in a Hach COD Reactor 45600, and absorbance was measured (Hach DR 2000 photometer). TOM value was expressed as g starch/100 g dough. Measurements were done in triplicate.

2.5. Color analysis

The color of raw and cooked pasta was measured using a Minolta Chroma Meter (CR-400, Minolta Co., NJ, USA). CIE color parameters lightness (L*), redness (a*), and yellowness (b*) were determined. At least three different regions of the lasagna sheets

Table 1
Composition of the studied formulations. Protein and water contents are given as percentages of the total fresh dough.

Formulation	Composition (g/100 g)			Coded levels	
	Dry egg	Dry egg-white	Water	Egg-protein (EP)	Water (W)
W1EP1	2.45	0.25	34.8	−1	−1
W2EP1	2.45	0.25	36.13	−1	0
W3EP1	2.45	0.25	37.5	−1	1
W2EP2	4.23	0.42	36.13	0	0
W1EP3	6	0.6	34.8	1	−1
W2EP3	6	0.6	36.13	1	0
W3EP3	6	0.6	37.5	1	1

were measured.

2.6. Rheological analysis: viscoelastic oscillatory measurements

Dynamic oscillatory tests were performed on lasagna sheets cooked until the OCT in a RS600 Rheometer (Haake, Germany) with parallel plate geometry (PP35S, 1.6 mm gap), following the protocol adopted by Larrosa et al. (2015). Three replicates of each sample were analyzed.

To analyze the effect of composition on the rheological characteristics of cooked GF pasta, an empirical time–concentration superposition method was applied, using the plateau modulus (G_N^0) as the normalization factor. This parameter can be considered as a characteristic parameter of this region and it was evaluated for each formulation as follows: first the discrete relaxation spectra (G_i, λ_i) described by the generalized Maxwell model was calculated from the mechanical spectra using the software IRIS (Rheo-hub 2007); afterwards, the plateau modulus (G_N^0) was computed as the sum of the relaxation moduli (Larrosa et al., 2015).

2.7. Texture analysis

Texture analysis were performed in a TAXT2i Texture Analyzer (Stable Micro Systems,UK). For every formulation at least ten repeated measurements were done and mean values were reported. Measurements were carried out on cooked samples dipped in cool water soon after cooking in order to stop the cooking process.

2.7.1. Cutting force

This test was used to determine the maximum force (N) needed to cut the cooked pasta (100% compression). Each analysis was carried out on five strands of cooked tagliatelle at room temperature (25 °C) using the Light Knife Blade A/LKB probe to simulate the bite action of incisive teeth (speed = 0.5 mm/s).

2.7.2. Texture profile analysis (TPA)

The texture of cooked pasta was determined with two compression cycles test using a 25 mm diameter flat-ended cylindrical probe (P/25). The experimental procedure was as follows: 5 tagliatelle were placed on the base and were compressed twice to give a two complete compression-relaxation-tension profile curve. The test speed was set on 0.5 mm/s and the compression distance was 30% of the original size (Olivera & Salvadori, 2009). From the force–time curve, hardness, cohesiveness, adhesiveness (negative force of the first compression cycle), springiness, chewiness, and resilience were obtained (Szczesniak, 2002).

2.8. Statistical analysis

A second order complete polynomial equation was used to fit the behavior of each measured variable as a function of dough composition (Myers, Montgomery, & Anderson-Cook, 2009):

$$\widehat{Y} = \beta_0 + \beta_1 C_1 + \beta_2 C_2 + \beta_{11} C_2^2 + \beta_{22} C_2^2 + \beta_{12} C_1 C_2 + \beta_{112} C_1^2 C_2 + \beta_{122} C_1 C_2^2 \tag{1}$$

where $\widehat{Y}$ is the response variable, β_0 is the constant term, β_1 and β_2 are the linear coefficients, β_{11}, β_{22}, β_{12}, β_{112}, β_{122} are quadratic and interaction coefficients. C_2 and C_1 are the water and egg-protein contents expressed as coded variables.

Data were modeled adopting backward stepwise analysis and only the variables significant at P < 0.05 were selected for the model construction.

To validate the assumptions used in the analysis of variance (ANOVA), residual analysis was performed after model fitting was done. The adequacy of the model was verified using a "lack of fit" test and the "Adequate Precision" coefficient (Montgomery, 2012).

After all the variables have been regressed as a function of egg-proteins and water concentration in the dough, optimal formulation of GF pasta was obtained by Derringer's desired function methodology (Derringer, 1980). The method involves transformation of each predicted response, $\widehat{Y}$, to a dimensionless partial desirability function, d_i, which includes the researcher's priorities and desires when building the optimization procedure. The partial desirability functions are then combined into an overall desirability function D, defined as the geometric mean of d_i values (Derringer, 1980; Larrosa et al., 2013). The formulation that gives the highest D was considered as the "optimum".

Quality attributes similar to those of cooked wheat pasta were considered as target values for the optimization process to establish the best formulation to produce cooked gluten-free pasta. The attributes considered were: cooking loss, TOM, cutting force, hardness, springiness, adhesiveness, and resilience.

Once the optimal formulation was computed, a batch of GF pasta was prepared using the optimal ingredient levels and quality characteristics were determined as described above. Finally results were statistically compared to the values predicted by the mathematical model.

Regression analysis, optimization, and response surfaces were accomplished using the software Design-Expert® (Stat-Ease Inc., Minneapolis, USA). ANOVA and pairwise comparisons (Tukey's test) were computed using the SYSTAT software (SYSTAT, Inc., Evanston, IL). Differences in means were considered significant when P < 0.05. Standard errors of the mean values are shown between parentheses.

3. Results and discussion

Cooking process is a critical step in the perception of good quality pasta. Several reactions are produced during pasta cooking as a result of the heat effect and water uptake (for example protein swelling, starch gelatinization, increase in pasta weight and volume). In the present work 10 min were established as the OCT for all the assayed gluten-free formulations. These results agree with those reported by Yalcin and Basman (2008) for GF rice starch spaghetti prepared with different proportions of gelatinized starch.

3.1. Rheological analysis

Mechanical spectra of GF cooked pasta always showed a "gel like" behavior with a storage modulus (G′) scarcely dependent on the frequency and a minimum in the loss modulus, G″. This type of behavior is typically observed in elastic solids. The existence of both a plateau region in the G′ or a minimum in the G″ vs. frequency curves, indicate the formation of a gel structure due to the cross-linking by intermolecular interactions.

The normalized dynamic master-curves of G′ and G″ can be seen in Fig. 1. All data fell into a single master-curve in reasonable approximation. The plateau modulus (G_N^0), used as a normalization factor, is a viscoelastic parameter defined for polymers as the extrapolation of the entanglement contribution to the viscoelastic functions at high frequencies (Larrosa et al., 2015). The fact that these master-curves could be achieved by applying an empirical vertical superposition method implies that the different compositions did not modify the overall microstructural pattern of systems, but mainly influenced the level of interactions among macromolecular components.

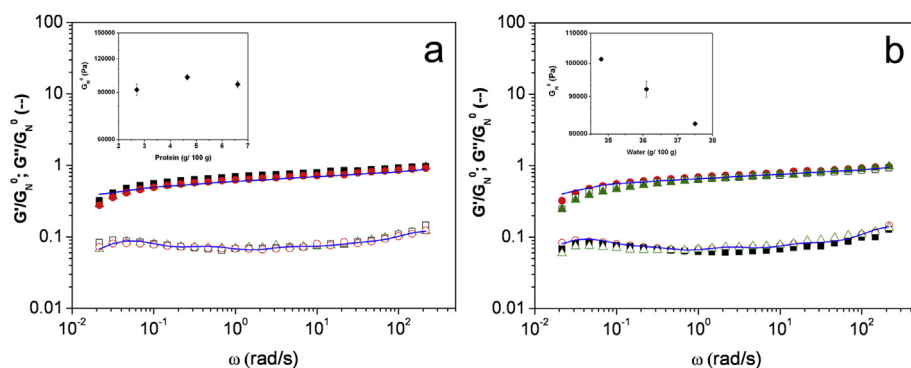When formulations prepared with the same water content and

Fig. 1. Normalized dynamic master curves of the elastic (G'/G_N^0, filled symbols) and viscous (G''/G_N^0, empty symbols) moduli for cooked pasta. (a) water: 36.1 g/100 g and (■ □) 2.7, ●○ 4.65, and ▲△ 6.6 g/100 g egg-protein; (b) egg-protein: 2.7 g/100 g and (■ □) 34.8, ●○ 36.1, and ▲△ 37.4 g/100 g water; Continuous lines represent the fitting using Maxwell model. Inset plots correspond to G_N^0 values used to normalize the mechanical spectra.

different protein concentrations were analyzed (W2EP1, W2EP2, and W2EP3) the shift factors were practically coincident since the plateau modulus did not significantly differ among samples (Fig. 1a). However, G_N^0 diminished when initial water content increased as could be observed in the example shown in Fig. 1b. This behavior revealed a decrease in the elasticity of the pasta when the dough contained larger amount of water.

3.2. Cooking properties and color

The weight of a cooked pasta indicates the water uptake and corresponds to a macroscopic event involving a complex molecular modification of starch and proteins, mainly hydration (Nouviaire, Lancien, & Maache-Rezzoug, 2008; Sozer, Dalgic, & Kaya, 2007). Water absorption was not significantly affected by formulation; average value was 61.6(2.2) g/100 g, similar to the water absorption informed by Vijayakumar and Boopathy (2012) who worked with pasta prepared with wheat, cassava, and soy flours.

Total organic matter lost (TOM), expressed in terms of starch is shown in Table 2 for all the studied formulations. For GF pasta TOM ranged between 0.18 and 0.49 g/100 g (dough basis), which according to D'Egidio et al. (1982) corresponds to a good quality cooked pasta (TOM<1.4 g/100 g). According to Alamprese, Iametti, Rossi, and Bergonzi (2005), the heat treatment of pasta causes denaturation of proteins, leading to a stiffening of pasta structure, with a consequent reduction in the mass loss during cooking.

Regression coefficients obtained for the predictive models for TOM and cooking loss are shown in Table 3; lack of fit and precision adequacy values revealed that the models were convenient. As EP decreases or water in the dough increases more organic matter is lost from the surface of the cooked pasta; the positive interaction term reflects that the dependence of TOM with water concentration is stronger at higher EP contents. Higher egg-proteins fraction in

the formulation may form a more compact network that does not allow for an easy release of organic matter during cooking, leading to a reduction in the free organic matter released to the rinsing water.

Cooking loss, related to solid leaching during cooking (D'Egidio et al., 1982), is widely used as an indicator of the overall cooking performance considering it as an index of resistance to disintegration during cooking of pasta (Matsuo, Malcolmson, Edwards, & Dexter, 1992). Low amounts of residue indicate high quality cooked pasta (Del Nobile, Baiano, Conte, & Mocci, 2005). In gluten-free pasta starch polymers are less efficiently entrapped in the matrix because of the lack of gluten network, giving a final product with high losses during cooking (Marti & Pagani, 2013). Data in the present paper showed that the highest cooking losses corresponded to W3EP1, which could be attributed to the lack of a well-structured protein reticule, hindering the excessive swelling of the starch granules and the consequent dispersion of components in the cooking water (Alamprese, Casiraghi, & Pagani, 2007). The smallest losses corresponded to formulation W1EP3. These results agree with Malcolmson, Matsuo, and Balshaw (1993), who informed that cooking loss decreased significantly as protein level increased. In gluten-free pasta made from parboiled rice flour, Marti et al. (2014) found that egg albumen was significantly more efficient to decrease cooking loss than using whey protein.

Cooking losses varied from 6.2 g/100 g—13.8 g/100 g (Table 2). Hoseney (1994) informed that good quality pasta should present cooking losses <12 g/100 g; thus it could be concluded that all the formulations assayed could be considered acceptable except W3EP1 (13.8 g/100 g, SEM = 0.81 g/100 g).

It is noteworthy that there was a negative correlation between G', G'' and cooking loss ($R^2 = 0.81$, $P < 0.05$ and $R^2 = 0.79$, $P < 0.05$, respectively). When more solids were leached to the cooking water, elastic characteristics of pasta diminished.

Table 2
Cooking losses, total organic matter (TOM), and main textural parameters of the studied formulations of GF and wheat (control formulation) pasta expressed as mean ± SEM.

Formulation	Cooking loss (g/100 g pasta dough)	TOM g (starch/100 g pasta dough)	Cutting force (N)	Hardness (N)	Springiness	Resilience	Adhesiveness (N)
W1EP1	10.49 ± 0.88	0.288 ± 0.021	12.98 ± 0.17	8.53 ± 1.81	0.913 ± 0.009	0.486 ± 0.021	0.81 ± 0.159
W2EP1	11.60 ± 0.47	0.355 ± 0.019	10.27 ± 0.18	34.18 ± 1.38	0.938 ± 0.007	0.533 ± 0.008	1.41 ± 0.163
W3EP1	13.76 ± 0.57	0.384 ± 0.005	7.00 ± 0.08	26.31 ± 2.92	0.911 ± 0.011	0.498 ± 0.022	1.82 ± 0.177
W2EP2 (r1)	10.55 ± 0.26	0.559 ± 0.011	9.00 ± 0.15	13.76 ± 0.96	0.920 ± 0.007	0.619 ± 0.010	1.12 ± 0.171
W2EP2 (r2)	10.01 ± 0.24	0.511 ± 0.048	9.27 ± 0.26	13.22 ± 1.07	0.926 ± 0.004	0.630 ± 0.018	1.22 ± 0.153
W2EP2 (r3)	10.28 ± 0.42	0.431 ± 0.033	8.97 ± 0.20	14.81 ± 0.79	0.919 ± 0.009	0.628 ± 0.021	1.19 ± 0.106
W1EP3	8.28 ± 0.56	0.183 ± 0.027	8.92 ± 0.19	6.09 ± 1.13	0.809 ± 0.041	0.633 ± 0.026	0.90 ± 0.184
W2EP3	9.90 ± 0.46	0.267 ± 0.009	8.18 ± 0.19	23.49 ± 1.95	0.892 ± 0.017	0.645 ± 0.017	1.18 ± 0.077
W3EP3	6.24 ± 0.20	0.425 ± 0.051	9.51 ± 0.21	20.74 ± 2.05	0.833 ± 0.015	0.524 ± 0.021	0.66 ± 0.072
Wheat control	4.76 ± 0.14	0.15 ± 0.013	29.1 ± 1.04	41.8 ± 1.6	0.95 ± 0.064	0.68 ± 0.043	0.84 ± 0.024

Table 3
Regression coefficients for the predictive models for total organic matter (TOM), cooking loss, cutting force, hardness, springiness, adhesiveness, and resilience. Statistical significance of the models (P), R^2, lack of fit, and "adequate precision" coefficient, are also included.

Model terms	TOM (g starch/100 g pasta dough)	Cooking loss (g/100 g pasta dough)	Cutting force (N)	Hardness (N)	Springiness	Adhesiveness (N)	Resilience
Constant	+0.49	10.08	+9.17	+13.91	+0.92	+1.1	+0.63
Protein	−0.035	–	−1.05	−3.43	−0.038	−0.26	+0.047
Water	+0.069	–	−1.26	+8.23	–	+0.16	−0.023
Water* Protein	+0.051	−1.21	+1.73	–	–	−0.36	−0.028
Water^2	+0.024	–	+0.52	−13.53	−0.046	–	−0.055
Protein^2	−0.18	–	–	+14.84	–	–	−0.037
(Water^2)* protein	–	−2.55	+0.75	–	–	–	–
Model (P)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
R^2	0.611	0.801	0.878	0.761	0.719	0.89	0.654
Lack of fit	0.7437	0.1735	0.442	0.093	0.067	0.085	0.330
Adequate Precision	7.979	17.577	38.89	17.99	9.72	10.57	9.11

Cooking affected color parameters of GF pasta decreasing lightness from 86.04(0.44) to 78.46(0.37), a* from 1.14(0.10) to 0.72(0.08), and b* from 26.29(0.31) to 22.16(0.26). On the other hand these parameters were not influenced by initial dough composition.

3.3. Texture

3.3.1. Cutting force test

Cutting force is directly related to cooked pasta firmness. Table 2 shows the average values of this force, ranging from 6.5 to 13.8 N for GF formulations and a significantly higher value of the firmness for the wheat pasta analyzed (29.1 N). The smallest cutting force corresponded to W1EP1 which contained the lowest water and egg-proteins contents and thus the highest starch concentration.

In Fig. 2 it can be appreciated the influence of both water and egg-proteins contents on the cutting force of GF cooked tagliatelle; the obtained regression coefficients are shown in Table 3. At low EP, firmness showed a strong linear dependence on W content, low water content produced more firm products; conversely, at high EP there was a quadratic dependence on W reaching a minimum force at an intermediate water fraction. On the other hand, at high water content, firmness was directly proportional to EP level.

Regarding the TPA parameters, Table 3 shows the computed regression coefficients for hardness, springiness, adhesiveness, and
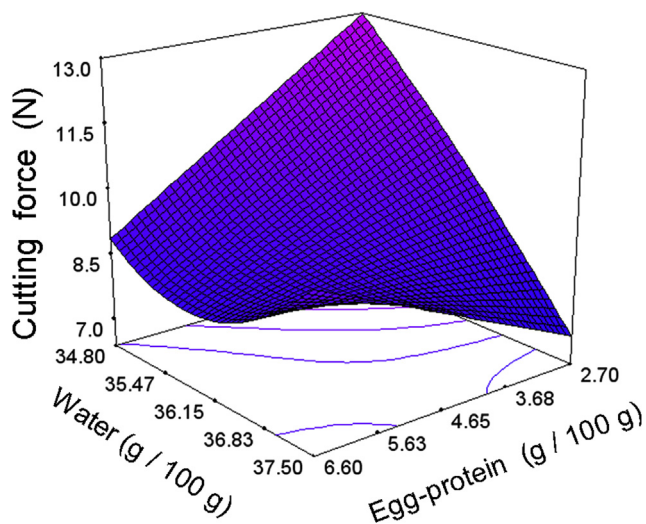
resilience, and Fig. 3 a, b, c, and d the corresponding response surfaces. From the regression coefficients, it can be seen that both water and protein contents strongly affected hardness; maximum hardness corresponded to intermediate water levels while it was minimum for high and low water contents at intermediate protein concentration.

Raw dough initially containing the smallest amount of water also had the largest starch content, which could explain the strong effect of initial water concentration on cooked pasta hardness. Wheat control samples showed higher hardness values (41.8 N, SEM = 1.6 N) than all GF tagliatelles demonstrating the importance of the gluten matrix on tagliatelle texture.

Fig. 3b shows that as protein concentration increased the product became less elastic (smaller springiness), regardless of water content. As smaller EP concentration corresponded to larger amounts of starch in the product; it seems that denatured egg-proteins contributed less to elasticity than the cooked corn-starch. The quadratic dependence of springiness on water content was also noticeable, where intermediate contents corresponded to maximum springiness.

Cooked pasta resilience was strongly correlated to EP content and the corresponding response surface is shown in Fig. 3c. The main effect observed was that increasing EP in the formulation resulted in GF pasta with larger capacity of recovery after being subjected to strain. Since interaction between components had a significant effect, pasta resilience exhibited a quadratic dependence on dough moisture enhanced at low EP.

Adhesiveness shows that in those formulations with low protein content there was a strong positive correlation with initial moisture level (Fig. 3d). A marked interaction was found, at high protein concentration lowering water content slightly increased pasta adhesiveness. Pasta adhesiveness is related to the amount of starch granules that exudates from the pasta matrix into the cooking water and coats the surface of the product (Dexter, Matsuo, & MacGregor, 1985). A positive relationship between cooking loss and adhesiveness was observed ($R^2 = 0.96$, $P < 0.05$).

Comparing resilience and adhesiveness it could be concluded that high protein content was necessary to achieve high quality GF pasta. Thus, proteins must maintain enough resilience to cope with starch swelling during cooking. Conversely, when protein content decreased in a high dough moisture, the protein network cannot withstand the starch swelling, and as a consequence, the final cooked pasta resulted stickier and more material was lost during cooking.

Cohesiveness of cooked pasta is mainly dependent on competition between starch and protein molecules to form a continuous network (Riva, Fessas, & Schiraldi, 2000; Sozer et al., 2007). In the present work, cohesiveness ranged from 0.57 to 0.71 for all studied
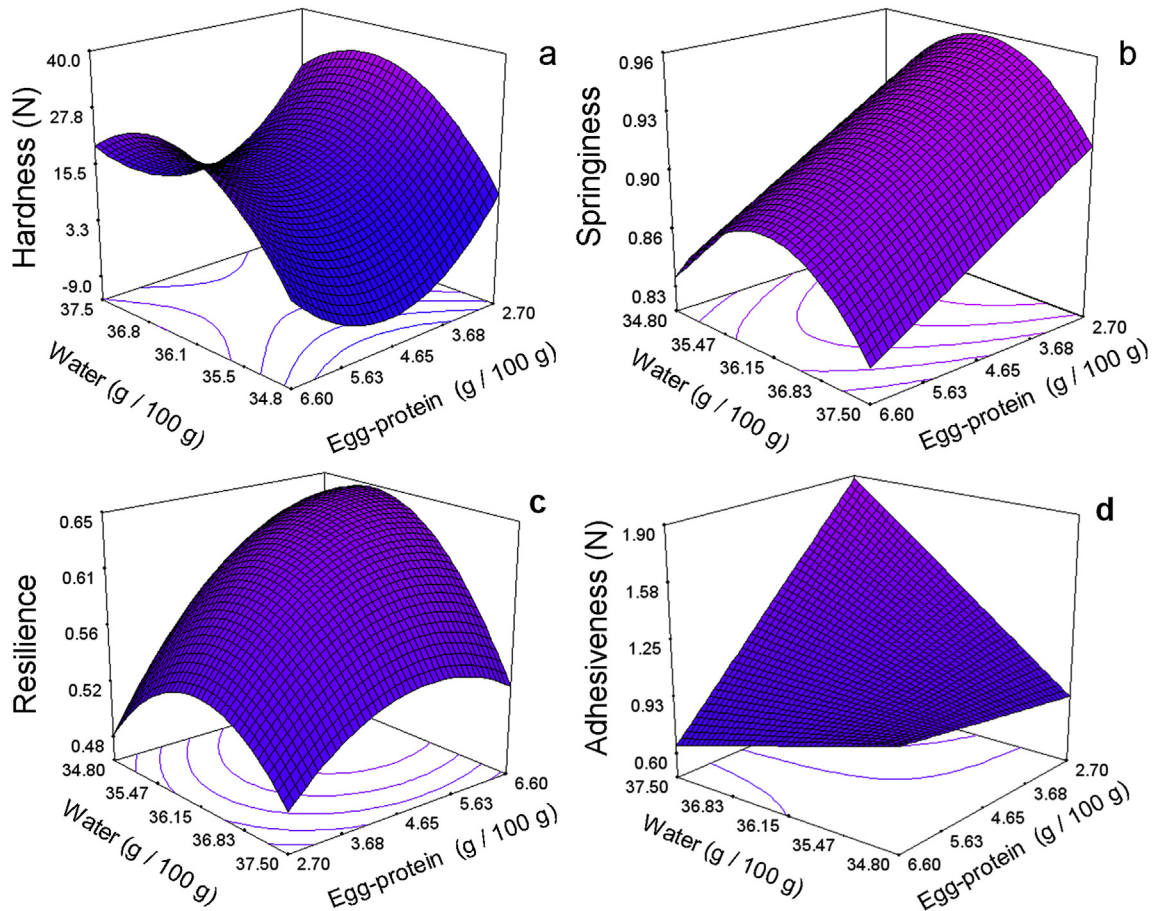
Fig. 2. Effect of egg-proteins and water contents on the cutting force of cooked gluten-free noodles.

Fig. 3. Surface responses of: a) hardness, b) springiness, c) resilience, and d)adhesiveness as a function of egg-protein and water contents (g/100 g dough).

samples and none of the GF formulations significantly differed from the wheat flour control (P > 0.05).

Chewiness of gluten-free pasta could be related to the elastic force of the protein matrix in the sample (Sozer et al., 2007); the highest chewiness value was 39.9(0.8) and corresponded to W1EP3 (highest level of proteins and lowest level of water). Although a polynomial model did not adequately fit experimental data of chewiness, the analysis of variance showed that there was a significant EPxW interaction, at EP = +1 chewiness was inversely proportional to water content in the dough while the opposite effect was found at EP = −1. Control wheat flour dough presented an average chewiness of 26.8(1.0), which was in the range of the values of the GF pasta evaluated.

3.4. Optimization and verification

Individual predictive equations were calculated (Eq. (1), Table 3); computed lack of fit tests were always non significant, and "adequate precision" values were in all cases above 4 indicating a high significance and adequacy of the models.

A good quality pasta product should present certain degrees of firmness and elasticity, appearance uniformity and structural integrity (Edwards, Biliaderis, & Dexter, 1995; Sozer et al., 2007), low TOM, cooking losses, and adhesiveness (Antognelli, 1980; D'Egidio et al., 1982; Dexter, Matsuo, & Morgan, 1983; Pomeranz, 1987). Table 4 shows the optimization criteria for each desirability function. Cooking loss, total organic matter and adhesiveness were minimized. Hardness and cutting force were maximized

since all GF pasta were less firm than wheat control samples. The desirable ranges of springiness and resilience were established according to control pasta (Table 2). The optimum combination of ingredients to add in gluten-free dough formulation corresponded to 6.6 g/100 g egg-protein mix and 35.96 g/100 g water, with an overall desirability D = 0.603 which is acceptable considering the large number of responses optimized simultaneously. Table 4 also shows the predicted responses for this composition and the corresponding d_i function values.

Once the optimum formulation was determined, it was used to manufacture gluten-free tagliatelle which were cooked as described above and all the response variables of this product were analyzed. Experimental values of each response are presented in Table 4. It could be observed that the model obtained using surface response methodology was satisfactory since all textural variables agreed with the predicted values (P > 0.05). Cooking losses and total organic matter were overestimated by the model, but this result is not detrimental to the predictive model because the optimized formulation resulted in a well-structured network enhancing the organic matter retention. This study allowed us to determine a composition to produce high quality cooked gluten-free pasta.

4. Conclusions

The effect of dough composition (water and protein content) of GF pasta on viscoelastic, textural, and quality attributes of the cooked product (water absorption, cooking loss and total organic

Table 4
Criteria used to obtain the desirability functions, predicted responses, and individual desirability functions (d_i).

Parameter	Objective	Predicted response	Individual desirability values d_i	Experimental response
Cooking loss (g/100 g)	Minimum	10.20	0.498	5.02 (1.32)
Total organic matter (TOM, g/100 g)	Minimum	0.99	0.734	0.19 (0.05)
Cutting force(N)	Maximum	8.08[a]	0.217	10.52[a] (1.00)
Hardness (N)	Maximum	23.86[a]	0.576	27.40[a] (1.41)
Springiness (−)	Range (0.88–0.98)	0.880[a]	1	0.94[a] (0.04)
Adhesiveness (N)	Minimum	0.875[a]	0.637	1.05[a] (0.59)
Resilience (−)	Range (0.60–0.75)	0.642[a]	1	0.54[a] (0.12)

Standard errors of the mean are shown between parentheses.
*Experimental responses with the same superscripts than predictive response indicate there are no significant differences (P < 0.05).

matter) was evaluated. Dough moisture mainly affected the elastic behavior of GF pasta leading to a significant decrease in the plateau modulus when water content was increased. Springiness, resilience, and adhesiveness were mainly controlled by the egg-protein content in the dough, while cooked pasta hardness increased when dough moisture decreased and starch content increased.

The statistical methodology was effective and reliable in finding the optimal composition (6.6 g/100 g egg-protein and 35.96 g/100 g water) to obtain high quality gluten-free cooked pasta. Using this optimized composition pasta was prepared and experimental results of the cooked product agreed closely with the predicted values of the parameters.

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