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Quinoa as gelling agent in a mortadella formulation

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Abstract

The aim of the present work was to determine the possibility of replacing soybean flour in a mortadella formulation with high levels of quinoa flour, as gelling agent, to obtain a product with the required binding effect and good level of acceptance. The investigated variables were cooking temperature (70, 75 and 80°C), cooking time (1.5, 2.0 and 2.5 h) and the replacement level of soybean flour with quinoa flour in the formulation (80, 90 and 100%). The response variables were taste, colour, smell, hardness, chewiness and gumminess as well as the overall impression of quality from a sensory evaluation on the obtained formulations. Models for each evaluated attribute were fitted. The thermo-mechanical behaviour of the quinoa flour indicated its possible use in the formulation considered from reaching the required gelling effect. The operational conditions of 80°C, 2.5 h and 86% of soybean flour replacement corresponded to the greatest acceptance of the formulation. Soybean flour replacement was the operational variable having the greatest influence. The quality of the formulated product was comparable to a commercial product.

Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a pseudo-cereal. It has been cultivated in South America since pre-Columbian times. It has a well-balanced nutritional composition including proteins, starch, lipids, dietary fibre and minerals. In addition to these nutritional characteristics, it also contains vitamins and bioactive compounds with health-promoting properties (Leenhardt *et al*., 2006; Abugoch James, 2009; Hirose *et al*., 2010; Steffolani *et al*., 2013; Nascimento *et al*., 2014; Mota *et al*., 2016). These nutritional characteristics have led to an increasing interest in research for this pseudo-cereal. Several papers have reported the inclusion of quinoa in food formulations (Jacobsen, 2011; Delgado and Albarracín, 2012; Wang *et al*., 2015; Li and Zhu, 2017a).

Quinoa has been used as a supplement (Correia and Mittal, 2000; Delgado and Albarracín, 2012; Petracci *et al*., 2013) for the substitution of lean meat or fat-like raw material (Peña *et al*., 2015; Wang and Zhu, 2016). In those cases, however, the required binding effect in the meat emulsions has been obtained from other component included in the formulations, for example soybean protein (Liu *et al*., 2008; Asgar *et al*., 2010). The inclusion of quinoa flour as gelling agent in meat formulations should achieve the required binding effect of the emulsion in order to guarantee a product with hydration properties of starch and proteins under cold conditions as well as a complete gelation of starch/protein matrix (Petracci *et al*., 2013).

The aim of the present work was therefore to determine the possibility of replacing soybean flour in a mortadella formulation with high levels of quinoa flour as gelling agent to obtain a product with the required binding effect and good level of acceptance.

Materials and methods

Mortadella formulation and preparation

The product formulation was as follows: lean beef (270 g), lean pork (330 g), porcine dorsal fat (180 g), flour (50 g), iced water (170 g), sodium chloride (20 g), sodium nitrite (0.125 g), phosphate (3 g), monosodium glutamate (1 g), ascorbic acid (0,5 g), white pepper (1 g), black pepper (0.5 g), oregano

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(1.5 g), garlic (2 g), onion (3 g), cinnamon (1.5 g) and nutmeg (2 g). The product preparation was as follows: chopping up of meat (segments: 5 - 10 cm) and fat (segments: 1 - 3 cm); milling of meat (disc: 7 mm in diameter) and fat (disc: 9 mm in diameter); cutting up the meat; adding salt, phosphates, nitrites, iced water (50%) spices, seasoning, monosodium glutamate, ascorbic acid, flour and the iced water remaining; stuffing; cooking (temperature and time according to the experimental plan); refreshing in cold water; cooling storage. Cooking was carried out by immersion in hot water. A jacketed pot with a water temperature control was employed for this. The process was carried out by natural convection.

During cooking, the temperature in the thermal centre of the product was measured by means of a needle thermometer (Checktemp Hl, Hanna Instruments Ltda., Bedfordshire, UK). The shape of the products was cylindrical with 10 cm diameter and 30 cm length, and a mass of 2 kg. The product was stuffed in a synthetic gut for mortadella.

Quinoa flour characterisation

The quinoa flour was of Ingapirca variety. The contents of protein, moisture, starch, ash and fibre were characterised and expressed as percentage (AOAC, 2000). The functional properties such as water retention capacity (WRC) (Rodríguez-Sandoval *et al*., 2012) and fat retention capacity (FRC) (Lin *et al*., 1974) were also determined and expressed as g water/g flour and g fat/g flour, respectively. A granulometric analysis was carried out based on sieves of 295 µm (Mesh 48), 248 µm (Mesh 60) and 208 µm (Mesh 65) according to Tyler scale.

Quinoa flour was also characterized in terms of thermo-mechanical behaviour by using a Mixolab device (ChopinTechnologies, Mixolab 2, France) (Kang *et al*., 2015; Schmiele *et al*., 2017; Malegori *et al*., 2018) under controlled temperature and also with a temperature increase followed by a cooling step. For the assays, a certain amount of quinoa flour with known moisture content was placed into the Mixolab. After tempering the solids, the water required for the dough to produce a torque of 1.1 Nm was added. The settings used in the test were as follows: (1) the temperature was kept constant at 30°C for 8 min; (2) the temperature was raised to 90°C at a rate of 4°C / min, and held for 7 min; (3) cooling to 50°C at a rate of 4°C /min, holding for another 5 min. The mixing speed during the entire analysis was 80/min. The processes were repeated three times.

The parameters evaluated were water absorption, WA (water required for the dough to produce a torque of 1.1 N.m); stability time, ST (elapsed time at which the torque produced remained at 1.1 Nm); minimum torque, MT (minimum value of torque produced by dough subjected to mechanical and thermal constraints); pasting temperature, PT (temperature at the onset of this rise in viscosity); peak torque, PkT (maximum torque produced during the heating stage); peak temperature, PTt (temperature at the peak viscosity); breakdown torque, BT (minimum torque reached during cooling to 50°C); setback torque, SbT (difference between final torque, FT, and breakdown torque, BT) (Hadnađev *et al*., 2011; Zhou *et al*., 2018; Schmiele *et al*., 2017).

Experimental design

The variables investigated were cooking temperature (70, 75 and 80°C), cooking time (1.5, 2.0 and 2.5 h) and the replacement level of soybean flour with quinoa flour in the formulation (80, 90 and 100%). The variable replacement level of soybean flour represents the percentage of the soybean flour mass replaced in the original product formulation. The soybean contents in the formulation described was the only modification on the original formulation. The replacement levels of soybean flour were selected from tests conducted prior to the investigation. The investigated cooking temperatures were established from the gelatinisation temperature of quinoa flour considering the high levels of this material in the investigated formulations.

A D-optimal design of twelve experimental points with three replicates at the central point was implemented. The variables were coded.

A sensory evaluation was done for each formulation. The assessed variables were taste, colour, smell, hardness, chewiness and gumminess employing a continuous scale of 10 cm (0: uncharacteristic and 10: characteristic), as well as the overall impression of quality (considered as overall acceptance and hereinafter briefly referred as quality) also on a scale of 10 cm (0: awful and 10: excellent). Each evaluation was performed by a panel of seven experts. For each assessed variable, the statistical model below was fitted:

$$y = b_0 + b_1 A + b_2 B + b3\ C + b_4 A\hat{\ }2 + b_5 B^2 + b_6 C^2 + b_7 AB + b_8 AC + b_9 BC$$

where y = assessed attribute; A = time; B = temperature; C = percentage of replacement of soybean flour.

The values of the independent variables that yielded the highest value of the response variables were considered as the operational variables. Those values were determined from the model optimisation by means of the statistical program. Three productions corresponding to these operational variables were made in order to validate the results obtained from the models. The product was assessed by the panel of experts from the aforementioned characteristics, and the issued scores were compared with those obtained from the models. In addition, an affective test with 80 potentially consumers of this type of meat sausage based on whether or not they would consume the obtained product was performed. Sensory profile of both, the experimental product (EP) and a commercial product with a recognized trademark (CP) (with soybean flour and without quinoa flour in its formulation) was carried out by the same panel of experts. The evaluated variables were taste, colour, smell, hardness, chewiness and gumminess on the scale of 10 cm.

Texture profile analysis

A texture profile analysis (FTM50 computerized Texture/Firming analyser, Spain) was conducted on both products. Samples were cut as a cube with 2 cm in length. They remained at room temperature for 1 h inside a polyethylene bag to prevent moisture loss. A double compression was performed to 75% of deformation and a head speed of 1 $mm.s^{-1}$. The analysed characteristics were hardness ($kg.m.s^{-2}$), gumminess ($kg.m.s^{-2}$), adhesiveness ($kg.m2.s^{-2}$), chewiness ($kg.m.s^{-2}$), cohesiveness and elasticity.

Chemical composition

Both EP and CP were chemically characterised for ash, proteins, moisture, fat and fibre contents, and the results were expressed in percentage (AOAC, 2000).

Statistical analysis

All measurements were performed three times. The results were expressed as mean with standard deviation. Statistical analyses were done using the program Statgraphics-Plus version 5.1 (Statistical Graphics, Rockville, MD, USA). A mean comparison test was used to determine significant differences among samples based on the student t-test ($p < 0.05$). Moreover, a principal component analysis (PCA) was carried out using Unscrambler 8.0 (CAMO ÅS, Trondheim, Norway).

Results and discussions

Quinoa flour characterisation

The proximate composition (moisture: 9.12%; proteins: 11.25%; fibre: 6.15%; ash: 2.09%; fat: 6.12%; starch: 57,40%) obtained agrees with the data reported in literature (Steffolani *et al*., 2013; Nascimento *et al*., 2014; Padrón *et al*., 2014; Navruz-Varli and Sanlier, 2016; Srichuwong *et al*., 2017). The quality of products with addition of quinoa flour can be greatly determined by the properties of starch (Wu *et al*., 2014; Wang *et al*., 2015). Starch is the most abundant macro-component and major energy source of quinoa (Repo-Carrasco *et al*., 2003; Steffolani *et al*., 2013; Li and Zhu, 2017a).

The granulometric analysis indicated a narrow particle size distribution (0.8%, 2.80%, 96% and 0.4% passed through the 295, 240, 208 and smaller than 208 μm sieve, respectively). The superficial mean diameter (0.229 mm) ensured adequate texture for the product.

WRC (2.94 g water/g flour) is related with the protein ability to hydrate (Ogunwolu *et al*., 2009) with effects on food taste and texture (Yu *et al*., 2007). It is due to the formation of large clusters of protein molecules (Ahn *et al*., 2005; Dogan *et al*., 2005). The presence of quinoa flour in the formulation might contribute to the retention of water in the product thereby maintaining its quality during storage (Abegunde *et al*., 2013). The WRC value (2.94) obtained in the present work was higher than 2.65 (Wang *et al*., 2015), 2.31 (Rodríguez-Sandoval *et al*., 2012) and 1.46 (Peña *et al*., 2015) reported elsewhere. WRC is determined by a narrow particle size distribution, lower amylose content and the molecular structure of amylose and amylopectin in quinoa starch (Wang *et al*., 2015). The hydrophilic character of quinoa proteins (globulins and albumin) also favours water retention (Wolter *et al*., 2014). The WRC values of soybean flour have also been reported. Most of them were between 2.72 (Dogan *et al*., 2005) and 3.12 (Ahn *et al*., 2005). The quinoa flour assessed in the present work yielded WRC value within this range.

The FRC value (2.76 g fat/g flour) obtained in the present work was close to 2.73 mentioned by Morales *et al*. (2015) for soybean flour. FRC is related with the non-polar chains of proteins which bind with hydrocarbon chains of fat thereby retaining the flavours and smoothness of products (García *et al*., 2012). Chau and Cheung (1998) reported FRC value of soybean flour of 1.93 whereas Ahn *et al*. (2005) reported 1.59. Both values are lower than that obtained in the present work. The FRC increase can be attributed to the physical entrapment of oil (Siu *et al*., 2002). Lin and Zayas (1987) suggesting that the ability of protein to bind fat depends on non-polar side chains binding hydrocarbon chains, thereby contributing to increased oil absorption. Considering those results, it can be expected that quinoa flour bounds water and fat similarly to soybean flour.

It should have a good influence on the texture and mouthfeel product when quinoa flour is applied in such a product.

Table 1. Mixolab parameters of quinoa flour.

Parameter	Value
Water required, WA (%)	67
Stability time, ST (min)	8
Minimum torque, MT (N.m)	0.68
Pasting temperature, PT (°C)	58
Peak torque, PkT (N.m)	1.54
Peak temperature, PTt (°C)	70
Breakdown torque, BT (N.m)	1.32
Final torque, FT (N.m)	2.14
Setback torque, SbT(N.m)	0.82

Table 1 shows the rheological parameters obtained from Mixolab when the quinoa flour was subjected to dual mechanical shear and temperature constraints. WA, ST and MC Mixolab parameters are used to evaluate the dough development during mixing, and stability at constant mechanical shear (Schmiele *et al*., 2017). During the initial mixing, the distribution of the material, the disruption of the initially spherical protein particles and the hydration of the flour compounds occur together with the stretching and alignment of the proteins, leading to the formation of a three-dimensional viscoelastic structure with retaining properties (Angioloni and Collar, 2009; Rodríguez-Sandoval *et al*., 2012). WA of quinoa flour (67%) obtained in the present work was lower than the soybean flour (101.4%) (Hadnađev *et al*., 2011). These hydration levels are in accordance with the respective WRC values reported earlier and it might be partly due to the formation of large clusters of protein molecules (Dogan *et al*., 2005).

ST is an indicator of the deformation resistance ability (Rosell *et al*., 2011). ST of quinoa flour (8 min) obtained in the present work was close to that (7 min) reported by Torbica *et al*. (2010). However, the obtained value was lower than 9.45 min reported for soybean flour (Hadnađev *et al*., 2011).

MT indicates the weakening when flour was subjected to dual mechanical shear and heating. This weakening is a consequence of aggregation and denaturation of proteins. Proteins underwent structural changes due to denaturation which contributed to modify the meat emulsion consistency (Robin and Palzer, 2015). Moreover, upon heating starch granules absorb the available water in the medium and the amylose chains leach out into the aqueous intergranular phase, promoting an increase in viscosity (Rosell *et al*., 2011; Fu *et al*., 2015; Robin and Palzer, 2015; Schmiele *et al*., 2017; Srichuwong *et al*., 2017; Zhou *et al*., 2018). MT values of 0.65 and 0.49 N.m have been reported for soybean flour by Torbica *et al*. (2010) and Hadnađev *et al*. (2011), respectively.

The quinoa flour assessed in the present work showed the highest gelling ability which was manifested by the value of PkT (1.54 N.m). Hadnađev *et al*. (2011) reported a PkT value of 0.78 N.m for soybean flour. The higher peak viscosity of quinoa flour has been associated with its higher starch content (Torbica *et al*., 2010).

PT and PTt of quinoa flour were 58°C and 70°C, respectively. The low temperature of gelatinisation might be related with a high content of amylopectin (Petracci *et al*., 2013). The obtained gelatinisation temperature intervals agree with those reported for different quinoa varieties (PT: 44.6 - 53.7°C; PTt: 50.5 - 61.7°C) (Lindeboom *et al*., 2005). Romo *et al*. (2006) established the interval 55 - 65°C whereas Arzapalo *et al*. (2015) reported 66 - 69°C. Jan *et al*. (2017) established 64.32°C - 76.98°C depending on quinoa variety. Srichuwong *et al*. (2017) reported 53.9°C and 60.6°C. Hadnađev *et al*. (2011) reported PT and PTt values for soybean flour of 72.4°C and 79°C whereas Ahn *et al*. (2005) established 99.5°C and 103.5°C, respectively. The quinoa flour values obtained in the present work were lower than these. So, it can be considered favourable regarding a lower energetic requirement for obtaining starch gelatinisation.

SbT represents starch retrogradation. Soybean flour values of 0.23 N.m (Torbica *et al*., 2010) and 0.20 N.m (Hadnađev *et al*., 2011) have been reported. Quinoa flour exhibited the highest retrogradation (0.82 N.m) due to the higher degree of starch gelatinisation in the heating phase (Fu *et al*., 2015; Schmiele *et al*., 2017). Starch consists of amylose and amylopectin. They play different roles during the retrogradation process (Li and Zhu, 2017b). The diversity in gelatinisation behaviours of both flours might be due to the differences in amylopectin fine structure (Bertoft, 2004; Li and Zhu, 2017b), amylose content (Kaur *et al*., 2002; Lindeboom *et al*., 2005), starch granule size, and the presence of minor components such as proteins and lipids (Srichuwong and Jane, 2007; Li *et al*., 2016), in addition to the differences between starch contents. Moisture content has been also reported with significant effect on this stage (Lund and Lorenz, 1984; Singh *et al*., 2003). The reached torque at the retrogradation ending indicates the contribution to the maintenance of the food consistency such as meat products (Steffolani *et al*., 2013).

Table 2. Statistical models and optimal values of the independent variables ($p < 0.01$).

Terms	Quality	Colour	Taste	Hardness
Independent terms	7.1	4.9	5.9	7.5
A: Time	2.2	1.4	2.3	1.2
B: Temperature		-1.2		
C: Replacement	-2.8	-1.2	-1.9	-2.7
A^2				
AB				
AC	-1.8	-1.4		-2,5
B^2	2.7			
BC				
C^2	-5.3			-4.1
R^2	93.0	88.6	75.9	92.7
Mean absolute error	0.4	0.3	0.5	0.4
A optimum	2.5 h (1.0)	2.5 h (1.0)	2.5 h (1.0)	2,5 h (1.0)
B optimum	80°C (0.99)	70°C (-1.0)	80°C (1.0)	74°C (-0.25)
C optimum	86% (-0.44)	80% (-1.0)	80% (-1.0)	84% (-0.64)
Optimal value	9.5	6.3	7.7	9.1

The SbT exhibited by the employed quinoa flour together with the other analysed parameters may be an indicative of a good performance. Its use as gelling agent in a mortadella formulation could be considered promising.

Modelling of process

Table 2 shows the results of the fitting models obtained. Smell, chewiness and gumminess did not fit into the models. The obtained models indicated that quality and the other attributes increased over time. A cooking time of 2.5 h (optimum value) reported a product with the greatest acceptance by the judges with an increasing on colour, taste and hardness. This may be associated with the necessary time to achieve the changes in the meat emulsion and its complete cooking (Wu *et al*., 2014; Arzapalo *et al*., 2015). The attributes, especially quality, were influenced by temperature. Temperature at the thermal centre of the product was 70 - 72°C. This result supports the best results obtained at 80°C as cooking temperature since gelatinisation was completed at 70°C (Table 1).

The increase of quinoa in the formulation caused an adverse effect on the quality product. Colour, taste, and hardness also showed the same behaviour. Regarding quality, the optimum value (Table 2) corresponded to 86% of replacement, while hardness was 84%. Moreover, the best results for taste and colour were obtained at the lowest level (80%). It may be concluded that the best results were closed to the lowest level of the considered replacement (80%).

The influence on the colour may be related to the presence of pigments like carotenes and phenolic compounds (Wang *et al*., 2004; Mir *et al*., 2016) as well as the quinoa ash content. However, the quinoa flour colour itself may influence on the product colour and luminosity (Wang *et al*., 2015). Some judges appreciated a light opaque tonality of the product.

Principal components analysis

Two principal components (PC) were extracted from the statistical analysis. They explained 97% of the total variance in the evaluated characteristic. Figures 1a and 1b show the projection of the measured variables in all formulations on the plane defined by PC1 and PC2. No outliers were detected. For PC1, which explained 93% of the experimental variability, all variables showed a positive correlation (Figure 1a). No negative correlations were found for each attribute (colour, taste and hardness). This showed a high correlation with quality. PC2 explained only 4% of the experimental variability. Formulations with the highest replacement level (100%) showed negative correlation with PC1 (Figure 1b). The remaining, with the lowest and middle level of replacement (80 - 90%), showed positive score. This indicated the greatest influence of this operational variable on product quality.

Sensory profile

According to the fitted models, product with the highest quality corresponded to 2.5 h of cooking time, 80°C of cooking temperature and 86% of soybean replacement. It was necessary to validate the model prediction since these conditions were not considered in the experimental plan. The assessment of the EP

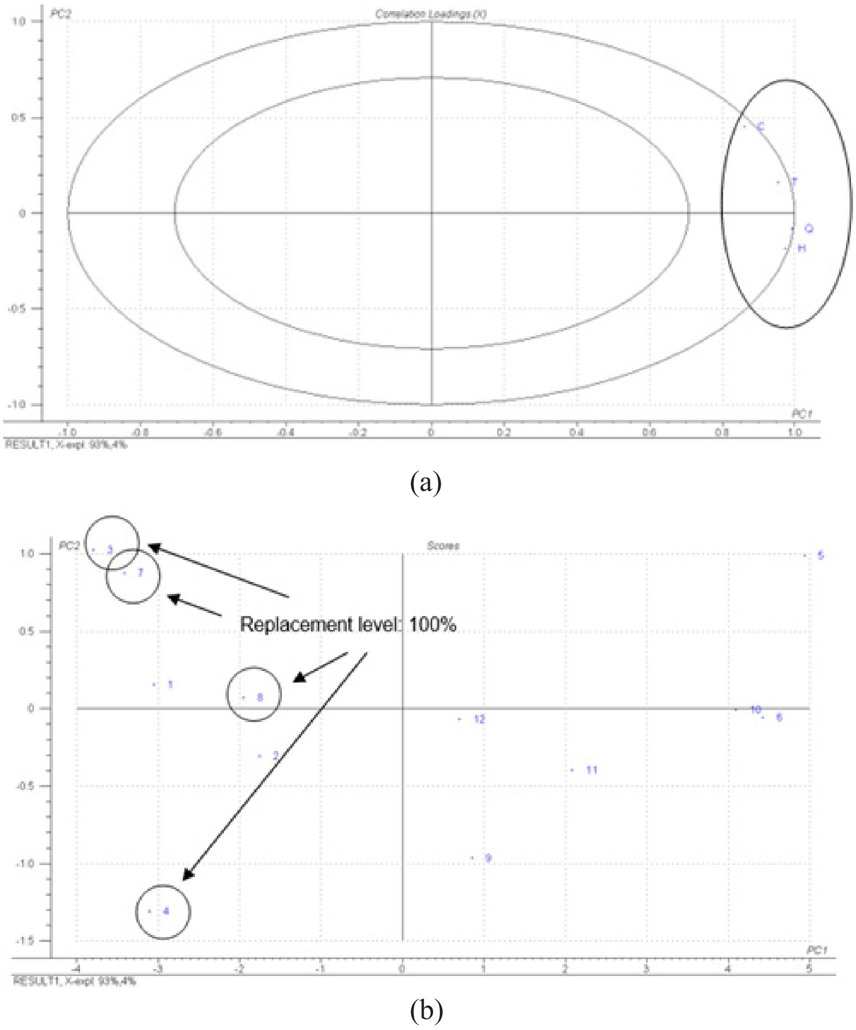

Figure 1. Principal component analysis: PC1 (93%) and PC2 (4%). (a) Correlation scatterplot of the variables: Q, quality; H, hardness; T, taste; C, colour. (b) Representation of the scores.

under such conditions is shown in Table 3 which also includes the results of the assessment of CP taken as a reference. The scale was: 0 - 2, absence to very slight; 2 - 4, very slight to slight; 4 - 6, slight to moderate; 6 - 8 moderate to marked; 8 - 10, marked to highly marked.

EP and CP smell, hardness, gumminess and quality assessment were not significantly different ($p < 0.05$). CP chewiness, although significantly lower than EP, was in the same range in both cases (4 - 6, among slight and moderate). Colour showed the greatest difference regarding the other attributes. CP colour was evaluated as more characteristic attribute (close to marked: 8) of this type of product than EP (close moderate: 6). Colour, even it could be modified, was not included in this goal. The objective was to make a product without adding other components in order to determine its acceptance. The analysis showed that both products were very similar. The results of the affective test showed that 90% (72 potential consumers) would consume the EP.

Table 3. Sensory profiles of the experimental product (EP) and commercial product (CP).

Parameter	EP	CP
Quality	9.7 ± 0.2^a	9.5 ± 0.1^a
Taste	8.1 ± 0.1^a	7.9 ± 0.1^b
Smell	7.3 ± 0.2^a	7.6 ± 0.1^a
Colour	5.9 ± 0.3^a	7.8 ± 0.4^b
Hardness	8.3 ± 0.3^a	8.1 ± 0.4^a
Gumminess	0.3 ± 0.1^a	0.6 ± 0.2^a
Chewiness	5.4 ± 0.1^a	5.0 ± 0.1^b

Different letters indicate significant difference ($p < 0.05$).

Chemical composition

The EP composition (ash: 3.47%; protein: 13.86%; moisture: 63.39%; fat: 16.36; crude fibre: 1.82%; total carbohydrates: 1.69%) and CP composition (ash: 3.40%; protein: 12.50%; moisture: 59.67%; fat: 14.63; crude fibre: 1.02%; total carbohydrates: 1.66%) indicated that both products had similar nutritional value. The difference in the moisture content might be associated to the highest starch content of quinoa flour and its ability to swell and take up water as previously described. The pH of both products was 5.7.

Texture profile

Table 4 shows the texture profile of both products. EP hardness was significantly lower than that of CP. Judges, however, did not detect this difference (Table 3). The lower hardness of EP may be associated to its higher moisture content than TP (Zapata and Pava, 2018). Ginés *et al*. (2004) stated a direct correlation among hardness and moisture content. Gumminess also showed significant differences. This attribute was determined from hardness multiplied by cohesiveness. Cohesiveness did not show significant differences between the products, so their differences might be mainly associated to the difference in hardness. A relation among the assessed attributes and the moisture content has been reported (Rahman and Al-Farsi, 2005; Jan *et al*., 2016).

Table 4. Texture profile of the experimental product (EP) and commercial product (CP).

Parameter	EP	CP
Hardness ($kg.m.s^{-2}$)	28.3 ± 1.1^a	38.3 ± 2.9^b
Gumminess ($kg.m.s^{-2}$)	15.5 ± 0.7^a	19.2 ± 2.8^b
Cohesiveness	0.6 ± 0.0^a	0.6 ± 0.1^a
Elasticity	0.9 ± 0.0^a	0.9 ± 0.1^a
Chewiness ($kg.m.s^{-2}$)	1.5 ± 0.0^a	1.4 ± 0.0^a
Adhesiveness ($kg.m2.s^{-2}$)	1.4 ± 0.2^a	1.2 ± 0.1^a

Different letters indicate significant difference ($p < 0.05$).

Conclusions

The thermo-mechanical behaviour of the quinoa flour indicated its possible use in the mortadella formulation to obtain the required gelling effect. Although the assessed attributes depended on the process variables, the replacement level of soybean flour had the biggest influence on the product quality. The conditions of 80°C, 2.5 h and 86% of replacement of soybean flour with quinoa flour yielded a product with a quality comparable to that of a commercial product. This high level of quinoa did not impact unfavourably on its acceptance by potential consumers. The use of quinoa flour as gelling agent in a mortadella formulation could be considered promising.

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