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Optimization of bread quality with quinoa flour of different particle size and degree of wheat flour replacement

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Abstract

The study aimed to assess the influence of quinoa flour of different particle size and degree of wheat flour replacement on dough and bread characteristics. Dynamic rheology and farinographs were used to describe the dough parameters. Specific volume, texture, porosity, color, overall quality and chemical assessment were performed as well. It could be observed that the degree of wheat flour substitution by quinoa flour significantly influenced the G' and G" values in linear and quadratic terms ($p \leq 0.01$ and $p \leq 0.05$). Particle size played a significant role in increasing G' and G" only in quadratic terms. Increasing quinoa substitution of wheat flour and interaction of PS and QS significantly increased the porosity of breadcrumbs. Moisture content was mainly affected by the particle size of quinoa flour and increased the values of this parameter. The optimization revealed that the most suitable combination would be the composition of bread with 219 μm and 5.41% of substitution.

Keywords: quinoa; bread; particle size; response surface methodology.

Practical Application: Optimal particle flour size could help to produce bread with enriched nutritional value.

1 Introduction

Quinoa (*Chenopodium quinoa*) is widely known as an endemic crop of the Andean region. Nowadays, it is an essential part of the diet in Latin America, Africa, and Asia (Alvarez-Jubete et al., 2010a). Quinoa is not a popular pseudocereal in breadmaking technologies, however, the usage of quinoa flour for consumers that have celiac disease is increasing day by day (Giménez et al., 2013). Quinoa is one of the pseudocereals that are perceived as a complete food because of its high protein content and its quality. Not only does it have high protein content (over 15%), but it is also highly nutritional due to its amino acid profile (Nascimento et al., 2014). It is known that quinoa has a high quality and level of protein content. The composition of amino acids is characterized by a high content of methionine and lysine. In addition, phytosterols, polyphenols and flavonoids, that can benefit human health, can also be found (Alvarez-Jubete et al., 2010b). The high content of phenolic compounds in quinoa seeds is advantageous for using it as a recipe ingredient with antioxidant activity (Abderrahim et al., 2015).

Wheat (*Triticum aestivum*) is the best-known and best-studied grain. It started to be popular in confectionary and breadmaking due to gluten which can give structure and some rheological properties to baked products. Wheat bread is an easy source of energy because of the high level of starch, and it can contain a wide range of vitamins and minerals, dietary fiber (Dewettinck et al., 2008). There were studies that showed that there is a solution to use 10% quinoa flour instead of wheat flour. Such a substitution did not have a detrimental effect on the sensory characteristics (taste, color, structure) and dough stability, loaf volume and weight (Enriquez et al., 2003). Commercial gluten-free bread recipes show the opportunity to incorporate quinoa flour in gluten-free baked products in up to 20-30%, as was mentioned in several research works (Turkut et al., 2016). Some work presents the ability to add quinoa seeds into wheat bread. It is known that incorporating even 20% of quinoa seeds can get an excellent result which shows acceptable characteristics of bread (Stikic et al., 2012). Even leaves can increase its functional and potential biological properties (Świeca et al., 2014).

Adding flour, which is not generally used for bread production, causes a deterioration of baking performance and final product quality. Therefore, several methods like high hydrostatic pressure, germination or particle size reduction are used for improving the breadmaking properties of flour. Particle size influences hydration as a result of rheological properties influencing the final product quality (Tsatsaragkou et al., 2017).

Some studies evaluated the effect of mixing quinoa flour and wheat flour on the nutritional and functional properties of food products. These blends had a certain impact on the technological process of breadmaking as well (Alvarez-Jubete et al., 2010a; Calderelli et al., 2010; Valcárcel-Yamani & Lannes, 2012). Obviously, the quality of bread or any baked goods will change with the addition of nontraditional pseudocereals, and it will significantly transform all characteristics of products. The breadmaking ability of wheat flour mixed with quinoa flour with different particle size has not been studied yet. Therefore, this study aims to clarify the role of particle size on the breadmaking property of quinoa flour.

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2 Materials and methods

2.1 Material

The local supplier provided wheat and quinoa flour. The basic composition of 100 g of wheat flour was 68.2 of carbohydrates, 9.1 g of protein, 2.9 g of dietary fiber 1.9 g of fat, while the 100 g of quinoa flour were 64.2 of carbohydrates, 14.1 g of protein, 7.1 g of dietary fiber and 6.1 g of fat. Just different particle size of quinoa flour was prepared with the application of ultra-centrifugal grinder with a sieve with 0.1, 0.2 and 0.5 mm diameter holes (Retsch, ZM 200, Germany). Then, they were sieved using vibrating sieve shaker and collected as presented in Table 1 (Retsch, AS 200, Germany).

2.2 Particle size analysis

The obtained flours were analyzed to determine the particle size. The measurement of their particle size was carried out using the microscope provided with static automated imaging (Morphology G3S, Malvern, England). The obtained results were expressed as 4.3. diameter after volume transformation and presented in μm.

2.3 Bread preparation

The dough formulation contained the following ingredients: wheat flour, quinoa flour with a different particle size (73, 106, 186, 265, 298 μm), dry yeast (1.80 g), salt (1.50 g) and water. The quantity of the quinoa flour was correlated with 100 g of dry blend matter due to the experiment plan (Table 1). The dough ingredients were placed into a bowl of kneading machine (RM Gastro, HTF 10, Italy) where the water was added, knead time was 6 min. After that, the big dough ball was formed and left for fermentation for 15 min. The dough was divided into pieces (220 g) that were put into aluminum form for proofing in the dough proofer for 40 min at 30 ± 1 °C, humidity - 85% (CPE 110, Kuppersbuch, Germany). The loaves were baked for 17 min at 180 ± 5 °C in a laboratory oven (CPE 110, Kuppersbuch, Germany). The baked loaves of bread were taken off from the pans and left at room temperature (24 °C) for 3 h for cooling.

Table 1. The experimental design of bread with different particle size and degree of wheat flour substitution.

	Particle size (μm)	Degree of substitution (%)
1	298	9.3
2	186	1.1
3a	186	9.3
4	106	3.5
5	186	17.4
6a	186	9.3
7a	186	9.3
8	73	9.3
9	265	3.5
10	265	15.0
11a	186	9.3
12	106	15.0
13a	186	9.3

a = center points.

2.4 Rheological measurements

Dynamic rheological measurements were conducted with a Mars III rheometer (Thermo Haake, Germany). The rheological examination was done using standard dough preparation, but without yeast, to avoid the influence of fermentation on the results. The forced oscillation test was conducted in the plate-plate geometry with a 2-mm gap. The parameters were chosen after a set of measurements had been performed to determine the viscoelastic region. The frequency of oscillation was 1 Hz, shear stress 600 Pa, angle rotation sensor 2°, and temperature of the measurement 15 °C. Measurements were performed in triplicate, and the measured parameters were: *G'* (elastic modulus, in Pa), *G"* (viscous modulus, in Pa).

The dough prepared from controlled wheat flour and mixtures of wheat flour and quinoa flour were examined on the rheological characteristics by Brabender farinograph model RSM65NG (Brabender OHG, Duisberg, Germany) due to American Association of Cereal Chemists (2000) method.

Sample weight on 14% moisture basis (mb) was calculated using the Equation 1:

$$Flour\ weight\ onmb = \frac{100-14}{100-M} \times flour\ weight \quad (1)$$

where: M = flour moisture content in %.

The farinograph water absorption is the volume of water that was expressed in mL per 100 g of flour at 14.0% moisture content and needed to make a dough with the highest consistency of 500 FU.

2.5 Physical parameters

Cooking loss, specific volume, moisture content

Cooking loss was assessed as the difference of weight between the dough and cooled bread loaf expressed in percentage. Bread loaves were cooled down after baking and weighted. Their volume was assessed with rapeseed displacement method. The specific volume was calculated as volume/bread weight and expressed in cm^3/g. Moisture content was analyzed as the difference of ground bread samples before and after 24 h of drying at 105 °C (CPE 110, Kuppersbuch, Germany). The difference was then divided according to the initial mass and expressed in percentage.

Color analysis

The color of bread's crusts and crumbs was assessed using a Minolta CR-400 colorimeter (Konica Minolta Inc., Japan) according to CIELab measuring system (measurement area ø = 8 mm, and a 2° standard observer, illuminant D65). Parameters for color determination were L (analyzed sample was black when L = 0 or white if L = 100), a* (-a* means greenness and +a* redness), b*(– blue; + yellow). The data was collected from three different slices analyzed for color 10 times.

Porosity and texture analysis

Porosity was analyzed with a method presented elsewhere, using a digital camera and computer image analysis from Kaiser company (Germany) (Kurek et al., 2017). Texture parameters were expressed as firmness and springiness measured with TPA. Instron 5965 Universal Testing Machine (Instron, USA) with the maximal load of 500 N, 50% penetration depth with a 40 mm diameter probe and a 20 s gap between cycles on the crumb cubes (20 × 20 × 20 mm) were used as equipment. Measurements were taken 24 h and 72 h after baking. The texture studies were conducted in triplicates for each sample.

Chemical parameters

The kit designed for the measurement of phytic acid (phytate) and total phosphorus measured as phosphorus released by phytase, and alkaline phosphatase was used in the study (Megazyme, Ireland). Dried breads were analyzed for total phenol content (TPC) following the Folin-Ciocalteu method with sample preparation and modifications described in (*17*). Absorbance was measured with an UV-VIS spectrophotometer (Shimadzu UV-1800, Japan). The results of the TPC test were showed as milligrams gallic acid equivalent (GAE) per gram of dry mass.

Organoleptic analysis

The bread quality evaluation was performed by organoleptic assessment tests through a hedonic score system from 1 (the lowest note) to 9 (the highest note). Panelists were selected from postgraduate students and teaching members of the Department of Food Technique and Food Development. All the panel members were experienced and familiar with the hedonic scale test system.

Experimental design and statistical analysis

The response surface methodology was used as the optimization tool for the responses obtained in the experiment. The central composite design was used in the study where two independent variables were selected – particle size (73-298 µm) and quinoa degree of substitution (1.1 to 17.4%). In the experiment 13, runs were conducted as presented in Table 1 with 5 central points. The complete design consisted of 13 combinations performed in random order. In all parameters, the second-degree polynomial model was proposed (Equation 2):

$$y = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1^2 + b_{22}x_2^2 \tag{2}$$

The coefficients were represented as intercept (b_0), linear effects (b_1 and b_2), quadratic effects ($b_{11}$and b_{22}) and interaction effect (b_{11}). Each model was analyzed regarding coefficient of determination (R^2), lack of fit and coefficient of variation (C.V. %). Optimization was performed in numerical technique as presented by Mudgil et al. (2016). The desired goal for selected processing variables was selected. Independent variables were kept in the range, while specific volume, phenolic content, overall acceptability was maximized, firmness and phytic acid content were minimized. Analysis, optimization and response surface graph preparations were conducted with Design Expert 11 Software. Optimized bread was prepared using optimal values and compared to the control sample which was based only on wheat flour.

3 Results and discussion

3.1 Dough parameters

The obtained results are presented in Figure 1 and regression coefficients are presented in Table 2. It can be observed that the degree of wheat flour substitution by quinoa flour significantly influenced the G' and G" values in linear and quadratic terms ($p \leq 0.01$ and $p \leq 0.05$). Particle size played a significant role in increasing G' and G" only in quadratic terms. G' values were higher than the G" values so it can be stated that the dougvh was pseudoelastic. Substitution of wheat flour caused a decrease in G' and G" values.

Water absorption of dough formation was used for determining farinograph parameters of controlled wheat flour and mixtures with different percentages of quinoa flour with varying sizes of the particle. The results have shown that the presence of quinoa in the blend had a marked effect on dough mixing properties, such as water absorption and arrival time (Figure 1). The dough development time was not decreased as significantly as was showed by Chauhan et al. (1992). Water absorption of wheat flour was 61% BF that was normal and water addition level with addition quinoa flour has not changed significantly (Wolter et al., 2013) It is well known that high protein content in flour is correlated with water absorption in the dough system. Hallén et al. (2004) found the same tendency as we observed in the study. Even though they noted that flour

Table 2. Regression analysis of polynomial models of rheological parameters.

	G'	G"	Arrival time	Dough stability	Elasticity	Degree of softening
Intercept	7424.12	5267.23	2.79	10.36	60.19	35.08
A- Particle size	2.71	79.40	-0.12*	-0.75**	-2.58	8.28**
B- Degree of substitution (%)	-2393.64**	-1113.36**	0.37*	-0.44	-5.06*	4.84**
AB	1431.93	585.49	0.50**	-2.49***	-7.97*	13.95***
A^2	476.87**	133.82**	0.16	-0.42	-5.18*	14.10**
B^2	1454.86***	569.19**	-0.09	0.45	-3.19	9.11**
Coefficient of determination - R^2	0.75	0.78	0.90	0.79	0.78	0.89
Coefficient of variance (%)	6.03	4.11	6.56	2.24	5.89	5.08
Lack of fit	0.45	0.25	0.47	0.37	0.14	0.93

***$p \leq 0.001$; **$p \leq 0.01$; *$p \leq 0.05$.

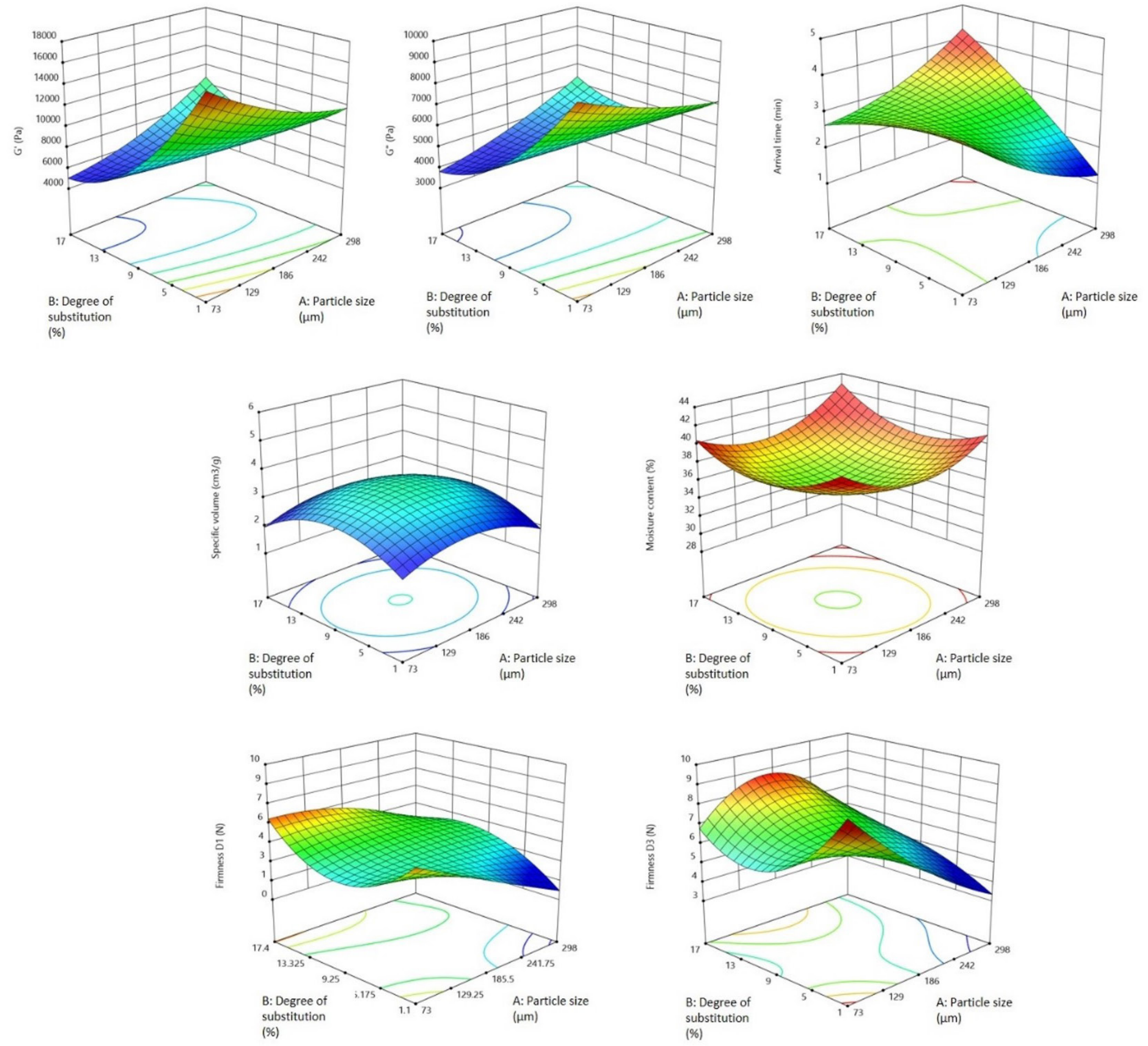

Figure 1. Values of selected measured parameters of dough and bread as function of degree of substitution and particle size of quinoa flour.

water absorption increases with a higher flour protein content, the absorption of flour depends not only on the amount and form of protein, but also on the condition and size of the starches. We can reach an excellent breadmaking property by mixing wheat flour with quinoa flour. The results in Table 2 show that intercept point has arrival time 2.79 min, high dough stability – 10.36 min, good elasticity – 60.19 BU and a low degree of softening – 35.08 BU. The long dough stability characterizes the possibility of dough to save necessary rheological characteristics during the proofing and baking. There is a correlation between dough stability and baking properties of flour. At the same time control sample had lower dough performance than the quinoa samples. For example, dough stability of the control sample was 8.5 min, elasticity – 45 BU, degree of softening – 100 BU. Moreover, the changes in dough starches could be caused by the higher content of phenolic compounds and therefore changes occurring in reduction of high-molecular-weight proteins and increase of SDS extractable protein level (Świeca et al., 2014).

3.2 Technological parameters

The technological parameters coefficients are presented in Table 3. Particle size and substitution decreased the cooking loss in quadratic terms, so they caused a higher yield of production. The degree of substitution negatively influenced the specific volume parameters in linear and quadratic terms. Moisture content was mainly affected by the particle size of quinoa flour

Table 3. Regression analysis of polynomial models of technological parameters.

	Cooking loss	Specific volume	Moisture content
Intercept	10.62	3.51	35.88
A- Particle size	-0.12	-0.05	0.32**
B- % of QN	0.15	-0.03**	0.12
AB	-0.15	0.01	0.36
A^2	-0.89***	-0.32	1.46***
B^2	-0.68**	-0.45*	1.32
Coefficient of determination - R^2	0.79	0.69	0.82
Coefficient of variance (%)	13.28	10.89	9.87
Lack of fit	0.95	1.00	0.99

***$p \leq 0.001$; **$p \leq 0.01$; * $p \leq 0.05$.

and increased the values of this parameter (Figure 1). These parameters can be correlated with water absorption because when flour and water are mixed together, the water molecules hydrate the gluten-forming proteins gliadin and glutenin, as well as damage starch and the other ingredients. The hydration process is achieved when protein and starch molecules create hydrogen bonds and hydrophilic interactions with the water molecules. If we compare the starch of wheat flour and quinoa flour, they have big differences. First of all, starch in wheat is bimodal, it is found in two sizes of starch granules (B-type, 2-10 mm and A-type, 20-35 mm). Despite the fact that the specific surface area of quinoa starch is larger than wheat starches, it makes them more sensitive to hydrolysis by α-amylase than wheat starch (Tester et al., 2004). Quinoa has a slight amylase activity, which may lead to an increase in the production of gas and thus the volume of bread.

The replacement of wheat flour by the quinoa flour with different particle size had a variable effect on loaf volume (Figure 1) The loaf volume slightly deceased with the increasing addition of quinoa flour which could be mainly affected by the higher dietary fiber. A higher addition of water (70-90%) to pseudocereal flour resulted in a higher loaf volume and a much softer crumb texture (Gallagher et al., 2003). Baking loss differs from the control sample but it was slightly different with pseudocereal-containing flour loaves of bread.

3.3 Color parameters

The color parameters of crumb and crust in regression coefficients are presented in Table 4. Quinoa particle size and degree of substitution increased the L* and b*parameters while decreasing the a* parameter. However, these observations were only visible in quadratic terms. Comparison of L* of crumb and crust is presented in Figure 1. More impact of quinoa flour particle size and substitution was observed in crust color changes. Only in L* parameter, the significant impact of the interaction between PS and QS was observed. Increasing PS slightly decreased the a* parameter and more visibly the b* parameter.

In relation to the crust color of the baked breads, the high-level quinoa-containing breads were darker (lower L* values) compared with the control. The color of the crumb has also been an essential parameter for characterizing quinoa-wheat flour bread. In general, the tristimulus color values in both crumb and crust were affected (Iglesias-Puig et al., 2015). Carotenoids, chlorophyll, and lignin give the quinoa seeds their color, these pigments influence the color of flour, crumb and crust of the products (Ruffino et al., 2010).

3.4 Porosity and texture

Porosity and texture regression coefficients are presented in Table 4. Increasing quinoa substitution of wheat flour and interaction of PS and QS significantly increased the porosity of the breadcrumb. Firmness was significantly affected by both PS and QS. However, QS caused the increasing of firmness on days 1 and 3, but particle size had an adverse impact. The significance of PS and QS was observed regarding springiness, but the nominal values of regression coefficients were very moderate.

Quinoa flour in different concentrations has significant effects on the bread samples texture profiles (Figure 1). For example, the hardness of the bread increased to a certain level depending on how much quinoa flour was added (Codină et al., 2016).

Addition of quinoa flour in the dough system makes significant changes in texture such as crumb hardness, and an orderly growth of this parameter was noticed (Table 4). It can depend on the gelatinization temperatures of the starches in both flours, wheat flour has 55 °C, which is higher than quinoa flour 52 °C (Wolter et al., 2013). The incorporation of quinoa in the formulation leads to considerable changes in the diapason of gelatinization. Quinoa starch can change the range of thermal parameters along with lipids, both of them influence the gelatinization process (Iglesias-Puig & Haros, 2013). However, according to the results of Morita et al. (2001), the substitution of wheat flour with quinoa flour results in a markedly higher gelatinization temperature and gelatinization enthalpy compared with control samples. Fiber from whole quinoa flour can influence the stabilization of the water balance in the dough system.

3.5 Chemical parameters and overall quality

Phytic acid content increased with the level of QS and the particle size decreased. However, phenolic compounds content was mainly influenced by QS. The contents of phenols in bread were lower than in the control samples. According to works of

Table 4. Regression analysis of polynomial models of color parameters and porosity, texture parameters, chemical analysis and overall quality.

	Crumb			Crust			Porosity	Firmness		Springness		Phytic acid content	Phenolic content	Overall quality
	L*	a*	b*	L*	a*	b*		Day 1	Day 3	Day 1	Day 3			
Intercept	67.14	3.82	13.66	46.68	16.61	28.87	17.68	3.81	6.50	1.08	0.44	260.78	1.85	5.91
A- Particle size	0.28	-0.21	-0.23	-0.06	-0.03***	-0.31**	0.02	-0.24**	-0.54**	-0.01	0.01***	2.25***	0.01***	-0.08***
B- % of QN	-0.76	0.23	0.26	-4.49***	1.51	-1.59	0.73**	0.67**	0.73***	0.06	0.03**	97.72**	0.27	-0.19
AB	-0.32	-0.24	0.30*	-0.04**	0.32	0.22	2.09**	0.28	0.56**	-0.02*	0.04	5.77*	0.01	0.08
A^2	1.81**	-1.78***	0.24**	2.97*	-0.74**	0.66*	0.85	-0.20	-0.54**	-0.20	-0.01	-10.81	-0.05**	0.14**
B^2	1.22**	-1.69**	0.23**	5.16**	-1.45***	1.05**	1.31**	0.26**	0.40***	-0.23***	0.01**	-17.77***	-0.04	0.27**
Coefficient of determination - R^2	0.89	0.91	0.75	0.91	0.81	0.79	0.78	0.85	0.91	0.84	0.83	0.76	0.81	0.74
Coefficient of variance (%)	4.78	5.97	3.57	2.48	4.95	2.79	4.84	5.97	7.71	9.27	10.12	8.24	3.24	4.14
Lack of fit		0.9994	0.165	0.887	0.887	0.37	0.19	0.81	0.12	0.65	0.64	0.27	0.99	0.95

***$p \leq 0.001$; **$p \leq 0.01$; *$p \leq 0.05$.

Table 5. The selected variables of optimized and control bread.

	Optimized bread	Control bread
Specific volume (cm^3/g)	3.24	3.45
Firmness Day 1 (N)	3.21	2.97
Firmness Day 3 (N)	5.59	7.24
Phytic acid content (mg/100 g)	189.58	101.24
Total phenolic content (mg/g)	1.64	0.95
Overall quality	6.13	6.52

Holtekjølen et al. (2008), it is known that the heating process in breadmaking is the main factor of damage active antioxidant compounds that were in raw materials, such as flour, before baking. To overcome this problem some active oxidative enzymes, which are contained in some ingredients for bread formulas or use ambient oxygen for oxidizing are used. Overall quality was assessed in the hedonic scale. Particle size and quinoa substitution effect in quadratic terms caused an increase of the overall quality. It is valuable results because generally application of pseudocereals decrease the quality assessed by consumers.

3.6 Optimized bread

The optimization revealed that the most suitable composition of bread would be the with 219 µm and 5.41% of substitution. There are no significant differences between results of the specific volume of optimized bread and control sample (Table 5). The initial firmness of optimized bread was higher than the control sample. However, the staling occurred at a slower pace than in the control sample. The content of phytic acid and phenolic compound were significantly different from the control sample.

4 Conclusions

The incorporation of quinoa flour with different particle size had a significant impact on the quality of bread. Furthermore, particle size affected the chemical characteristics of bread as well as the quality assessed by consumers. Quinoa significantly increased the porosity of bread due to its higher protein content. The most visible effect was observed as the interaction between particle size and quinoa flour content. Particle size profoundly influenced the firmness parameter. Response Surface Methodology was a sufficient tool to describe the mechanism observed in bread with quinoa addition as well as to optimize the recipe to obtain bread with requested traits.

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