Brazilian Journal
of Chemical
Engineering

ISSN 0104-6632
Printed in Brazil
www.abeq.org.br/bjche

Vol. 29, No. 03, pp. 503 - 510, July - September, 2012

EFFECT OF QUINOA AND POTATO FLOURS ON THE THERMOMECHANICAL AND BREADMAKING PROPERTIES OF WHEAT FLOUR

E. Rodriguez-Sandoval[1*], G. Sandoval[2] and M. Cortes-Rodríguez[1]

[1]Department of Agricultural and Food Engineering, Faculty of Agricultural Science,
Phone: + 57-4-4309065, Fax: + 57-4-4309014, Universidad Nacional de Colombia,
Cll 59 No. 63-02, B14, Of 303, Núcleo el Volador Sede Medellín, Antioquia, Colombia.
E-mail: edrodriguezs@unal.edu.co
[2]Operative Research Unit on Food Technology, (UOITA), Faculty of Science and Food Engineering,
Universidad Técnica de Ambato, Ambato, Tungurahua, Ecuador.

(Submitted: September 24, 2011 ; Revised: November 20, 2011 ; Accepted: November 29, 2011)

Abstract - The thermomechanical properties of dough and the physical characteristics of bread from quinoa-wheat and potato-wheat composite flours at 10 and 20% substitution level were evaluated. The functional properties of flours were measured by the water absorption index (WAI), water solubility index (WSI) and swelling power (SP). The thermomechanical properties of wheat and composite flours were assessed using a Mixolab and the baking quality characteristics of breads were weight, height, width, and specific volume. The results showed that the higher values of WAI (4.48), WSI (7.45%), and SP (4.84) were for potato flour. The quinoa-wheat composite flour presented lower setback and cooking stability data, which are a good indicator of shelf life of bread. On the other hand, the potato-wheat composite flour showed lower stability, minimum torque and peak torque, and higher water absorption. Weight, height, width, and specific volume of wheat bread were most similar to samples of potato-wheat composite flour at 10% substitution level.
Keywords: Quinoa; Potato; Wheat flour; Composite flour; Thermomechanical properties.

INTRODUCTION

There is a large commercial unbalance in the most Andean countries between wheat production and the needs of wheat flour for the baking industry. The main causes of this problem are the lack of suitable land for cereal crop cultivation, low yield, international prices, agricultural subsidies by developed countries and investment in research and technology. However, a proportion of wheat flour could be replaced by flour from locally grown crops, such as non–wheat cereal or root, tuber and legume flours in bread and other bakery products (Greene and Bovell-Benjamin, 2004). However, the replacement of wheat flour (gluten-containing grain) is a major technological challenge because gluten is an essential structure-building protein in flour, responsible for the elastic and extensible properties needed to produce good quality bread (Gallagher *et al*., 2003).

Quinoa (*Chenopodium quinoa* Willd), one of the pseudocereals, is a traditional food crop in several South American countries and has been attracting attention due to its high protein and mineral content (Park and Morita, 2005). Currently, it is widely cultivated in Peru, Bolivia, Ecuador, Chile and

*To whom correspondence should be addressed

Argentina (Abugoch *et al*., 2009). The proximate composition of quinoa varies with cultivar, but mostly ranges from 10 to 18% for protein, from 4 to 9% for crude fat, from 54 to 64% for carbohydrates, from 2 to 4% for ash, and from 2 to 5% for crude fiber. The amino acid balance of quinoa is better than that of wheat or corn because the first limiting amino acid, lysine, is present in relatively higher amounts in quinoa seeds (Lorenz and Coulter, 1991). Different studies focused on breadmaking with quinoa-wheat composite flour have reported excellent results with substitutions lower than 10% (Lorenz and Coulter, 1991; Chauhan *et al*., 1992; Morita *et al*., 2001; Park *et al*., 2005; Rosell *et al*., 2009)

On the other hand, potatoes (*Solanum tuberosum* L.) are fourth among the food crops in the world after wheat, rice and corn in total production. They contain good quality edible grade protein, dietary fiber, several minerals and trace elements, essential vitamins and little or negligible fat (Misra and Kulshrestha, 2003). Potato flour has become the most viable value-added product due to its versatility as a thickener and color or flavor improver. It is used in sauces, gravy, bakery products, extruded products or fabricated snacks and also in soup mixes (Yadav *et al*., 2006). In breadmaking, potato can be blended with wheat flour in different ways, currently as starch and/or precooked and native flour. In general, the suitable substitution level of wheat flour with potato flour is lower than 10%, because higher levels produced unacceptable bread in terms of the loaf volume, flavor, and texture (Greene and Bovell-Benjamin, 2004).

Rheological tests on dough can predict their behavior in a bakery, although only if the applied stress and the extent of the deformation are in the same range as those encountered during dough processing. The traditional instruments, which provide practical information for the baking industry, measure the power input during dough development caused by a mixing action (Farinograph, mixograph) and determine the extensional deformation of a prepared dough (Extensigraph, alveograph) (Steffe, 1996). The Mixolab instrument has been used to evaluate the behavior of both wheat proteins and starch when subjected to a dual mechanical shear stress and temperature constraint. Therefore, it is possible to record the mechanical changes due to mixing and heating, simulating the mechanical work as well as the heat conditions that might be expected during the baking process (Rosell *et al*., 2007). Thus, the aim of this study is to assess the thermomechanical profiles and fresh bread quality of wheat, quinoa-wheat, and potato-wheat composite flours.

MATERIALS AND METHODS

Materials

Wheat flour fortified with calcium, thiamine, riboflavin, niacin, iron and folic acid was purchased from Molinos del Ecuador C.A. (Guayaquil, Ecuador). The potato (*Solanum tuberosum* L.), cultivar Gabriela, was cultivated in Quero, Tungurahua province, Ecuador (3000 m.a.s.l.). Potatos were cleaned, washed with tap water to remove dirt and soil, and peeled using an abrasive potato peeler (Proingal, Quito, Ecuador). The peeled samples were dipped in sodium chloride (NaCl) solution (4% w/w) at room temperature for 5 min, then cut into slices (3-5 cm, 1 cm in width) and dipped again in a sodium erythorbate solution (0.4% w/w) for 15 min. The slices were steam cooked in an autoclave at 105 °C for 6 min and then air dried at 45 °C to a final moisture content of 10 – 13 g/100g (wb). The dried samples were ground in a disc mill (Proingal, Quito, Ecuador) and sieved through a 180 μm mesh. The potato flour was packed in polyethylene bags, kept in air tight tin containers and stored at 12 °C until further use.

Quinoa (Tuncahuan cultivar) was cultivated in Colta, Chimborazo province, Ecuador (2800 m.a.s.l.). The seeds were washed with cold water to remove possible saponin residues and conditioned to 16% moisture to improve the separation of the botanical tissues of the grain (endosperm from pericarp). The grains were then ground in a double-roll roller mill with specific angle of inclination. Overheating was controlled in the milling step because it affects the seed protein. The whole grain quinoa flour was sieved through a 180 μm mesh (Proingal, Quito, Ecuador).

Functional Properties

The moisture content of wheat, potato and quinoa flours were determined with a moisture analyzer (MLS50-3, Kern & Son GmbH, Balingen, Germany). The water absorption index (WAI), water solubility index (WSI) and swelling power (SP) can be used as indicators of starch modification by thermomechanical treatment. WAI measures the volume occupied by the starch granule after swelling in an excess of water, WSI determines the amount of free molecules leached out from the starch granule in addition to excess water and the SP is the ratio of weight of the wet sediment to the initial weight of dry starch (Collado *et al*., 2001; Ortiz *et al.*, 2010). The WAI, WSI and SP of the flours were determined by slightly modifying the method of Anderson *et al*. (1969). The flours were sieved through a 180 μm mesh to standardize the sample size. Flour samples (0.5 g) were weighed into centrifuge tubes using an analytical balance (BBL31 Boeco, Beockel+Co, Germany), mixed with 6 mL of distilled water at 30 °C and incubated in a stirred water bath (WiseBath, Wisd Laboratory Instruments, USA) for 30 min. Then, the samples were centrifuged at 5000 rpm for 20 min in a centrifuge (EBA 12, Hettich Zentrifugen, Tuttlingen, Germany). The supernatant liquid was poured carefully into a tared evaporating dish. The remaining gel was weighed and the WAI calculated from its weight (Eq. (1)). As an index of water solubility, the amount of dried solids recovered by evaporating the supernatant from the water absorption test was expressed as percentage of dry solids (Eq. (2)). The SP was determined as the change in the weight of the flour (Eq. (3)). All measurements were done in triplicate and the results were then averaged.

$$\text{W.A.I} = \frac{\text{gel weight(g)}}{\text{sample weight(g)}} \tag{1}$$

$$\text{W.S.I(\%)} = \frac{\text{weight of dried supernatant (g)}}{\text{sample weight(g)}} * 100 \tag{2}$$

$$\text{S.P.} = \frac{\text{gel weight(g)}}{\text{sample weight(g)} - \text{weight of dried supernatant (g)}} \tag{3}$$

Thermomechanical Measurements

Quinoa and potato flours replaced wheat flour to produce blends with 10 and 20% (w/w) substitution levels, taking into account preliminary baking tests. Mixing and pasting behavior of composite flour dough was studied using the Mixolab (Chopin Technologies, Villeneuve la Garenne, France), which allows mixing of the dough under controlled temperature and also with a temperature increase to 90 °C, followed by a cooling step. The Mixolab measures, in real time, the torque (Nm) that is produced by the passage of dough between two kneading arms, thus allowing the study of its physicochemical behavior (Rosell *et al*., 2007). The procedure followed for the analysis of the mixing and pasting behavior is shown in Table 1. The process was repeated twice for each blend, as well as for the control (wheat flour).

Table 1: Instrumental settings defined in the Mixolab for running the samples

Settings	Values
Mixing speed	80 rpm
Dough weight	75 g
Tank temperature	30 °C
Temperature first plateau	30 °C
Duration first plateau	8 min
Heating rate	4 °C/min
Temperature second plateau	90 °C
Duration second plateau	7 min
Cooling rate	4 °C/min
Temperature third plateau	50 °C
Duration third plateau	5 min

The parameters obtained from the recorded curves were (Figure 1): water absorption (%) or percentage of water required for the dough to produce a torque of 1.1 Nm, dough development time (min) or time to reach the maximum torque at 30 °C, development (Nm) (C1) or maximum torque reached during mixing at 30 °C, stability (min) or elapsed time at which the torque produced is kept at 1.1 Nm, mechanical weakening (Nm) or the torque difference between the maximum torque at 30 °C and the torque at the end of the holding time at 30 °C, minimum torque (Nm) (C2) or the minimum value of torque produced by dough passage subjected to mechanical and thermal constraints, thermal weakening (Nm) or the difference between the torque at the end of the holding time at 30 °C and the minimum torque, peak torque (Nm) (C3) or the maximum torque produced during the heating stage, cooking stability calculated as a ratio of the torque after the holding time at 90 °C (C4) and the maximum torque during the heating period (C3), and setback (Nm) or the difference between the torque produced after cooling to 50 °C (C5) and the one after the heating period (C4).

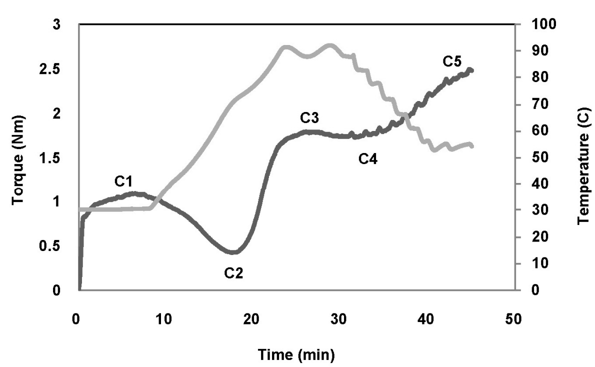

Figure 1: Typical thermomechanical curve recorded by the Mixolab: torque (-) and temperature (-).

Breadmaking Process

The baking tests were carried out according to Ecuadorian Technical Standards (NTE) (1980) INEN 530 that involved mixing 500 g of flour with 100 mL of fresh yeast solution (15 g) and sugar (15 g) at 28 ± 5 ºC. In addition, 100 ml NaCl solution (10% w/w) and water were added according to the Mixolab absorption value. The kneading time was 8.5 min in a horizontal type mixer (Proingal, Quito, Ecuador). Shortening (10 g) was added 2 min after ending the kneading step. The dough was rounded, placed into aluminum pans and allowed to rest in a proofing cabinet (Proingal, Quito, Ecuador) for 100 min at 30 °C and 85% RH. Afterwards, the dough was kneaded manually for 2 min, rounded again and proofed for 25 min. Then, the dough was divided into five pieces with the same weight, which was molded in pans (90 mm × 51 mm base, 83 mm height). The samples were proofed again for 60 min and baked at 210± 5ºC for 25 min in a rotary oven (Equipan, Quito, Ecuador). After baking, the loaves were removed from the pans and cooled for 60 min at room temperature before being characterized for weight, height, width, and specific volume (determined by rapeseed displacement). Baking trials were repeated twice.

Statistical Analysis

A factorial design of two factors (type of flour and percentage of substitution) was used in this study. Experimental data were submitted to ANOVA at a 5% significance level, and the least significant difference (LSD) was used to compare treatments when significant differences were found. Statistical analysis was performed using Statgraphics Plus 5.1. The data are reported as means ± SD.

RESULTS AND DISCUSSION

Flour Characteristics

The moisture content, water absorption index (WAI), water solubility index (WSI), swelling power (SP) of wheat, potato and quinoa flours are reported in Table 2. These parameters were affected significantly by the flour type ($P<0.05$). Wheat flour presented the lowest values of WAI, WSI and SP, whereas potato flour showed the highest values. The moisture content of wheat and quinoa samples were similar, but slightly lower for potato flour. The WAI of quinoa flour was lower than that reported by Abugoch *et al*. (2009), which ranged from 2.3 to 4.5; however, the method used in this study was different.

Table 2: Moisture content, water absorption index (WAI), water solubility index (WSI), swelling power (SP) of wheat, potato and quinoa flours

Flour	Moisture content (%)	WAI	WSI (%)	SP
Wheat	12.57±0.28[b]	1.92±0.06[a]	2.09±0.26[a]	1.96±0.07[a]
Potato	12.03±0.19[a]	4.48±0.11[c]	7.45±0.72[c]	4.84±0.12[c]
Quinoa	12.47±0.12[b]	2.31±0.08[b]	5.10±0.12[b]	2.43±0.08[b]

The gelatinization causes an increase of the WAI, WSI, and SP, parameters that provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains. These interactions are influenced by the amylose/ amylopectin ratio and by the characteristics of amylose and amylopectin in terms of molecular weight/distribution, degree and length of branching, and conformation. The higher WAI, WSI, and SP values of potato starch are probably due to a higher content of phosphate groups on amylopectin, which resulted in repulsion between phosphate groups on adjacent chains, increasing hydration by weakening the extent of bonding within the crystalline domains (Hoover, 2001). The functional properties of flours are affected by their morphology, processing and composition. For instance, the lipids of wheat starch are present at lower levels and significantly affect the swelling and water absorption of starch. Furthermore, the technological quality of proteins is also related to the water absorption of the flour (Singh *et al*., 2003).

Thermomechanical Properties

During 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 gas-retaining properties (Rosell *et al*., 2007; Collar *et al*., 2007; Angioloni and Collar, 2009). Table 3 shows the rheological parameters of wheat flour, quinoa-wheat and potato-wheat composite flours in the mixing stage of the Mixolab. The type of flour and the percentage of substitution did not significantly influence ($P<0.05$) development (C1) and mechanical weakening. The water absorption (%) of potato-wheat composite flour at the 20% substitution level was the highest, whereas that of quinoa-wheat composite flour at 10% substitution was the lowest.

This result is consistent with the WAI and SP data, which suggest that the potato flour significantly affects the water absorption of composite flour due to the amylose to amylopectin ratio and phosphorus content and by the characteristics of the amylose and amylopectin (Kaur *et al*., 2007). The water absorption of wheat flour was similar to data reported elsewhere (Codină, 2008; Sun *et al.*, 2010).

Dough development time was significantly lower for potato-wheat composite flour and higher for quinoa-wheat composite flour at 20% substitution. Quinoa flour increases the time required for complete hydration of the material, which could be related to the composition and characteristics of starch. Quinoa starch has a low solubility and swelling power due to the strong uniform binding forces or the cross-linkages present in the granules. Moreover, the increase of amylase activity during the washing and drying process could affect the behavior of quinoa flour hydration (Ruales and Nair, 1994; Ahamed *et al*., 1996).

The lowest stability was for potato-wheat composite flour at 20% and the highest was for quinoa-wheat composite flour. The low stability time during the dough mixing period is indicative of a weak gluten network structure of the dough (Park and Morita, 2005). The addition of quinoa flour increases the dough stability; even though Morita *et al*. (2001) reported that the farinograph stability decreased as the substitution of quinoa flour increased from 7.5 to 20%. Ruales and Nair (1994) suggested that the behavior of quinoa starch is similar to that of chemically cross-linked starch, which increased the viscosity of the slurry of quinoa flour. The stability of wheat flour was similar to results reported elsewhere (Angioloni and Collar, 2009; Sun *et al.*, 2010). When the mixing is excessive, the dough strength decreases, which is attributed to weakening of the protein network due to the mechanical shear stress. The mechanical weakenings of wheat flour and composite flours were very low compared to the results reported by Rosell *et al*. (2007), with values in the range of 0.28 to 0.33 Nm.

Table 4 presents the rheological parameters of wheat flour, quinoa-wheat and potato-wheat composite flours at the pasting stage of the Mixolab. The minimum torque (C2) and thermal weakening are related and gave similar results. These parameters were affected significantly by the type of substituted flour (quinoa and potato), but not by the percentage of substitution. Potato-wheat composite flour gave the lowest minimum torque, while wheat flour and quinoa-wheat composite flour had higher values, close to 0.45Nm. These data are in agreement with results reported elsewhere, which were in the range of 0.26–0.47 Nm (Rosell *et al*., 2007; Angioloni and Collar, 2009; Sun *et al*., 2010). In the case of thermal weakening, wheat flour had lower values compared to potato-wheat composite flour. The thermal weakening results of this study were higher than those reported by Rosell *et al*. (2007) for wheat flour with different hydrocolloids, which ranged from 0.24 to 0.4 Nm. The combined effect of the mechanical shear stress and the temperature constraint produced a further decrease in the torque that could be related to the beginning of the protein destabilization and unfolding (Rosell *et al*., 2007; Angioloni and Collar, 2009).

Table 3: Rheological parameters of wheat flour, quinoa-wheat and potato-wheat composite flours at the mixing stage of the Mixolab

Flour	Substitution (%)	Water absorption (%)	Development time (min)	Development (C1) (Nm)	Stability (min)	Mechanical weakening (Nm)
Wheat	0	61.93±0.1^{b}	6.21±0.09^{b}	1.12±0.03^{a}	8.58±0.41^{b}	0.08±0.01^{a}
Potato	10	64.5±0.02^{c}	1.24±0.13^{a}	1.09±0.03^{a}	8.95±0.04^{b}	0.05±0.06^{a}
	20	68.7±0.01^{d}	0.98±0.01^{a}	1.08±0.01^{a}	7.3±0.21^{a}	0.03±0.01^{a}
Quinoa	10	60.4±0.42^{a}	6.65±0.14^{bc}	1.11±0.02^{a}	10.26±0.25^{c}	0.02±0.02^{a}
	20	61.0±0.01^{ab}	7.1±0.71^{c}	1.11±0.01^{a}	10.22±0.02^{c}	0.05±0.01^{a}

Table 4: Rheological parameters of wheat flour, quinoa-wheat and potato-wheat composite flours at the pasting stage of the Mixolab

Flour	Substitution (%)	Minimum torque (C2)) (Nm)	Thermal weakening (Nm)	Peak torque (C3) (Nm)	Cooking stability	Setback (Nm)
Wheat	0	0.45±0.02^{b}	0.59±0.01^{a}	1.84±0.04^{d}	0.98±0.01^{c}	0.76±0.05^{d}
Potato	10	0.37±0.01^{a}	0.67±0.03^{c}	1.51±0.01^{b}	0.98±0.01^{c}	0.43±0.02^{b}
	20	0.34±0.01^{a}	0.71±0.02^{c}	1.18±0.01^{a}	0.99±0.02^{c}	0.40±0.02^{b}
Quinoa	10	0.45±0.02^{b}	0.64±0.02^{b}	1.80±0.04^{d}	0.93±0.01^{b}	0.47±0.01^{c}
	20	0.45±0.01^{b}	0.62±0.01^{b}	1.69±0.01^{c}	0.89±0.01^{ab}	0.30±0.01^{a}

The type of flour and the percentage of substitution significantly affect peak torque (C3). Quinoa-wheat composite flour showed higher values compared to potato-wheat composite flour; furthermore, the 10% substitution level gave higher results for C3. The data of this study are in agreement with results reported elsewhere, which ranged from 1.4 to 1.9 Nm (Rosell *et al*., 2007; Rosell *et al*., 2009; Angioloni and Collar, 2009). Quinoa-wheat composite flour at a 10% substitution level also presented values closer to wheat flour, similar to the results reported in previous studies (Park and Morita, 2005; Rosell *et al*., 2009); however, C3 decreased as the percentage of substitution increased, contrary to the behavior shown by Rosell *et al*. (2009). This difference could be due to the cultivar used and/or the process used to make the quinoa flour, in which the seeds were conditioned in water at 50 °C for 4 h.

On the other hand, C3 decreased as the substitution of potato flour increased, in contrast to the behavior found by Zaidul *et al*. (2007), who analyzed the pasting properties of potato starches and wheat flour (individually and in their mixtures). This difference could be explained because the potato flour used in this study underwent a cooking process that affected the functional characteristics of starch. As the temperature increases, the role of the proteins becomes secondary, starch gelatinization being the main element responsible for further torque variations. During this stage, starch granules absorb the water available in the medium and swell; amylose chains leach out into the aqueous intergranular phase, promoting the increase in the viscosity and thus the increase in the torque. This enhancement continued until the mechanical shear stress and the temperature constraint led to the physical breakdown of the granules, which is associated with a reduction in viscosity (Rosell *et al*., 2007).

In the cereal starch pastes, cooking stability was related to the stability of the already broken starch granules under the heating temperature constraint (Rojas *et al*., 1999). The cooking stability of wheat flour and potato-wheat composite flour were similar and higher than that of quinoa-wheat composite flour. High viscosities during pasting and low viscosities after the holding period at 95 °C of wheat dough slurries are considered to be among the valuable predictors of bread firming behavior during storage. These viscosity trends were in agreement with high sensory scores of bread obtained for both crumb and crust eatability (Collar, 2003). Therefore, low cooking stabilities are related to extended shelf-life of bread, which might suggest that bread substituted with quinoa flour could have a longer shelf-life.

The lowest setback was for quinoa-wheat composite flour and the highest was for wheat flour. Quinoa flour gave a low consistency during cooling, particularly at 20% substitution, which indicates very low recrystallization or retrogradation. These results are in agreement with those reported elsewhere (Rosell *et al.*, 2009). In contrast, the setback of potato-wheat composite flour was lower than that of wheat flour; an opposite behavior was observed by Zaidul *et al*. (2007), who found a higher setback for wheat-potato starch mixture; furthermore, this parameter increased as potato starch increased from 10 to 30%. This difference could be due to the precooking process of potato flour used in this study, which affected the pasting characteristics of the starch and decreased the amount of amylose leached out to the medium. Advisable parameters for delaying bread staling and for obtaining high sensory scores concerning crumb and crust chewiness include high pasting temperature, high viscosity during pasting and gelling and low viscosities after the heating period (Collar, 2003).

Bread Quality Parameters

The breadmaking parameters are given in Table 5. There were no significant differences ($P < 0.05$) in bread width among the samples tested. The products made from quinoa-wheat composite flour at 10% substitution level had the highest height, followed by samples from potato-wheat composite flour at 10%. Breads from wheat flour and quinoa-wheat composite flour at 20% resulted in similar height. As the percentage of substitution increased, sample weight significantly increased, especially when wheat flour is replaced by 20% potato flour. Breads from quinoa-wheat composite flour at 10% resulted in lower weight, whereas the highest weight was for samples from potato-wheat composite flour at 20% substitution; the rest presented similar weights. The lowest weight and highest height for samples substituted with 10% of quinoa flour was indicative of large air cells in the crumb, probably because higher α-amylase activity in quinoa increases the amount of fermentable sugars produced from starch (Lorenz and Coulter, 1991).

Table 5: Breadmaking parameters of samples from wheat flour, quinoa-wheat and potato-wheat composite flours

Flour	Substitution (%)	Weight (g)	Width (cm)	Height (cm)	Specific Volume (cm^3/g)
Wheat	0	132.86±0.88[b]	6.02±0.28[a]	8.97±0.63[b]	3.65±0.19[d]
Potato	10	133.86±1.13[b]	6.01±0.17[a]	9.57±0.49[c]	3.76±0.11[d]
	20	140.61±1.97[c]	5.95±0.18[a]	7.84±0.37[a]	3.45±0.17[c]
Quinoa	10	130.80±1.26[a]	6.20±0.32[a]	9.94±0.68[d]	3.25±0.17[b]
	20	133.65±1.73[b]	6.03±0.18[a]	8.89±0.4[b]	2.57±0.14[a]

Loaf volume is regarded as the most important bread characteristic since it provides a quantitative measurement of baking performance. Moreover, this parameter is also extremely important to consumers because they desire breads that appear to be light and not so dense. Consumers associate a certain amount of lightness and high loaf volume with certain breads and low loaf volumes with others (Hathorn *et al*., 2008). In the case of specific volume, samples from quinoa-wheat composite flour resulted in lower values, while higher specific volumes were for the products from wheat flour and potato-wheat composite flour at 10%.

The results for bread with quinoa flour agree with previous reports (Lorenz and Coulter, 1991; Chauhan *et al*., 1992; Morita *et al*., 2001; Park *et al*., 2005; Rosell *et al*., 2009). Loaf volume of breads decreased with quinoa replacement levels up to 10%. Quinoa flour does not have a gluten-forming protein like wheat flour does and the reduction in loaf volume is due to a gluten dilution effect and/or the increase of alkaline-insoluble protein, which is strongly correlated with poor dough mixing quality (Lorenz and Coulter, 1991; Park *et al*., 2005). Morita *et al*. (2001) found that dough containing 20% quinoa flour showed a more irregular structure with most gluten layers without a continuous distribution and surrounded by large starch granules. Breads from potato-wheat composite flour at 10% resulted in higher specific volume. This result could indicate that amylolytic enzymes were responsible for potato-starch breakdown, producing simple sugars and more fermentable substrate for the yeast and thus increasing the fermentation rate (Greene and Bovell-Benjamin, 2004). However, as the level of potato flour in the composite flour went above 10%, the loaf volume of samples decreased due to a gluten dilution effect.

CONCLUSIONS

The substitution of wheat flour (10% and 20%) with quinoa and potato flours resulted in dough with different thermomechanical profiles and products with different bread quality characteristics, depending on the amount and the type of starch used. The composite flour at the 10% substitution level showed physical properties similar to wheat bread samples, especially for products from potato-wheat composite flour. The quinoa-wheat composite flour had the lowest setback and cooking stability, which indicated low staling or aging of bread substituted with quinoa flour. Further studies on the range of substitution, sensory quality and textural properties of composite breads could be helpful to find the suitable substitution level for quinoa and potato flours. Moreover, it is suggested that changes in texture should be measured during storage and correlated with the results of the Mixolab.

ACKNOWLEDGEMENTS

This work was financially supported by Universidad Técnica de Ambato, Ecuador (PHPPF-PIC-08-0000162). Italo-Latin American Institute (IILA) is kindly acknowledged for providing a research grant to E. Rodriguez-Sandoval. The authors are grateful to Alexandra Lascano for her technical assistance.

REFERENCES

Abugoch, L., Castro, E., Tapia, C., Añon, M. C., Gajardo, P., Villaroel, A., Stability of quinoa flour proteins (*Chenopodium quinoa* Willd.) during storage. International Journal of Food Science and Technology, 44, 2013-2020 (2009).

Ahamed, N. T., Singhal, R. S., Kulkami, P. R., Palb, M., Physicochemical and functional properties of *Chenopodium quinoa* starch. Carbohydrate Polymers, 31, 99-103 (1996).

Anderson, R. A., Conway, V. F., Pfeifer, V. F., Griffin, E. L., Gelatinization of corn grits by roll – and extrusion – cooking. Cereal Science Today, 14, 4-12 (1969).

Angioloni, A., Collar, C., Significance of structuring/ prebiotic blends on bread dough thermo-mechanical profile. European Food Research and Technology, 229, 603-610 (2009).

Chauhan, G. S., Zillman, R. R., Eskin, N. A. M., Dough mixing and breadmaking properties of quinoa-wheat flour blends. International Journal of Food Science and Technology, 27, 701-705 (1992).

Codină, G. G., Influence of flour quality with different extraction ratio on the rheological properties of uniaxial extension induced by the mixolab. Journal of Agroalimentary Processes and Technologie, 14, 119-122 (2008).

Collado, L. S., Mabesa, L. B., Oates, C. G., Corke, H. Bihon-type noodles from heat-moisture-treated sweet potato starch. Journal of Food Science, 66, (4), 604-609 (2001)

Collar, C., Bollaín, C., Rosell, C. M., Rheological behaviour of formulated bread doughs during mixing and heating. Food Science and Technology International, 13, (2), 99-107 (2007).

Collar, C., Significance of viscosity profile of pasted and gelled formulated wheat doughs on bread staling. European Food Research and Technology, 216, 505-513 (2003).

Ecuadorian Technical Standards (NTE) INEN 530, Harina de trigo. Ensayo de panificación, 2da. Revisión. 1ra Ed., Instituto Ecuatoriano de Normalización, Quito, Ecuador, p. 10 (1980).

Gallagher, E., Gormley, T. R., Arendt, E. K., Crust and crumb characteristics of gluten free breads. Journal of Food Engineering, 56, 153-161 (2003).

Greene, J. L., Bovell-Benjamin, A. C., Macroscopic and sensory evaluation of bread supplemented with sweet-potato flour. Journal of Food Science, 69, (4), SNQ167-SNQ17 (2004).

Hathorn, C. S., Biswas, M. A., Gichuhi, P. N., Bovell-Benjamina, A. C., Comparison of chemical, physical, micro-structural, and microbial properties of breads supplemented with sweetpotato flour and high-gluten dough enhancers. LWT-Food Science and Technology, 41, 803-815 (2008).

Hoover, R., Composition, molecular structure, and physicochemical properties of tuber and root starches: A review. Carbohydrate Polymers, 45, 253-567 (2001).

Kaur, L., Singh, J., McCarthy, O. J., Singh, H., Physico-chemical, rheological and structural properties of fractionated potato starches. Journal of Food Engineering, 82, 383-394 (2007).

Lorenz, K., Coulter, L., Quinoa flour in baked products. Plant Foods for Human Nutrition, 41, 213-223 (1991).

Misra, A., Kulshrestha, K., Potato flour incorporation in biscuit manufacture. Plant Foods for Human Nutrition, 58, 1-9 (2003).

Morita, N., Hirata, C., Park, S. H, Mitsunaga, T., Quinoa flour as a new foodstuff for improving dough and bread. Journal of Applied Glycoscience, 48, (3), 263-270 (2001).

Ortiz, J. A. R., Carvalho, C. W. P., Ascheri, D. P. R., Ascheri, J. L. R., Andrade, C. T., Effect of sugar and water contents on non-expanded cassava flour extrudates. Ciência e Tecnologia de Alimentos, 30, (1), 205-212 (2010).

Park, S., H., Maeda, T., Morita, N., Effect of whole quinoa flours and lipase on the chemical, rheological and breadmaking characteristics of wheat flour. Journal of Applied Glycoscience, 52, (4), 337-343 (2005).

Park, S. H., Morita N., Dough and breadmaking properties of wheat flour substituted by 10% with germinated quinoa flour. Food Science and Technology International, 11, (6), 471-476 (2005).

Rojas, J. A., Rosell, C. M., Benedito de Barder, C., Pasting properties of different wheat flour-hydrocolloid systems. Food Hydrocolloids, 13, 27-33 (1999).

Rosell, C. M., Collar, C., Haros, M., Assessment of hydrocolloid effects on the thermo-mechanical properties of wheat using the Mixolab. Food Hydrocolloids, 21, 452-462 (2007).

Rosell, C. M., Cortez, G., Repo-Carrasco, R., Breadmaking use of andean crops quinoa, kañiwa, kiwicha, and tarwi. Cereal Chemistry, 84, (4), 386-392 (2009).

Ruales, J., Nair, B. M., Properties of starch and dietary fibre in raw and processed quinoa (*Chenopodium quinoa,* Willd) seeds. Plant Foods for Human Nutrition, 45, 223-246 (1994).

Singh, N., Singh, J., Kaur, L., Sodhi, N. S., Gill, B. S., Morphological, thermal and rheological properties of starches from different botanical sources. Food Chemistry, 81, 219-231 (2003).

Steffe, J., Rheological Methods in Food Process Engineering. Freeman Press, Michigan, 63-66 (1996).

Sun, H., Yan, S., Jiang, W., Li, G., MacRitchie, F., Contribution of lipid to physicochemical properties and Mantou-making quality of wheat flour. Food Chemistry, 121, 332-337 (2010).

Yadav, A. R., Guha, M., Tharanathan, R. N., Ramteke, R. S., Influence of drying conditions on functional properties of potato flour. European Food Research and Technology, 223, 553-560 (2006).

Zaidul, I. S. M., Norulaini, N. A. N., Omar, A. K. M., Yamauchi, H., Noda, T., RVA analysis of mixtures of wheat flour and potato, sweet potato, yam, and cassava starches. Carbohydrate Polymers, 69, 784-791 (2007).