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Textural, rheological and pasting properties of dough enriched with einkorn, cranberry bean and potato flours, using simplex lattice mixture design

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RESEARCH ARTICLE

Abstract

The aim of this study was to analyse the effects of the addition of einkorn, cranberry bean and potato flours on the pasting characteristics of the mixture as well as the rheological properties of the dough formed. An experimental design using a simplex lattice mixture design was employed. The pasting parameters of the samples increased with the addition of cranberry bean and einkorn flours due to their high protein content. The water absorption capacities of the doughs were significantly affected by the polar nature (e.g. potato flour) and protein content (e.g. cranberry bean) of the flours. The creep-recovery properties of the doughs were analysed using the Burger model. Results showed that doughs enriched with potato flour exhibited weak elastic properties and behaved as a highly viscous material. Textural profile analysis of the doughs showed that their structure became firmer with addition of einkorn, cranberry bean and potato flours. The determination coefficient for the samples was higher than 0.70 in the simplex lattice mixture design.

Keywords: dough, einkorn-cranberry bean and potato flours, creep-recovery, pasting properties

1. Introduction

Wheat flour is one the most used flour to produce bakery products. However, consumers affected by celiac and other related diseases are demanding products without gluten and with better functional and nutritional properties. Thus, they are more conscious of what they eat (Menrad, 2003). For this reason, legume flours are being more frequently used in the formulation of novel bakery products as functional supplements and/or for consumers that suffer diseases such as diabetes, obesity and celiac disease (Kayacier *et al.*, 2014; Xu *et al.*, 2007). However, in the formulation of these healthier and nutritious products there are problems concerning the preparation of doughs, which exhibit a poor rheology when compared to doughs prepared with wheat flour (Piasecka *et al.*, 2015). Because of this problem, the result is the production of baked products from dough with poor rheological properties, which difficult processes such as dough division. Therefore, there are pressing needs to develop and optimise the rheology of doughs enriched with legume flours and that have the ability for producing bakery products with better sensory and nutritional qualities.

Einkorn (known as *siyez* in Turkey) wheat (*Triticum monococcum*) has been cultivated during centuries by farmers in some Turkey regions (Kastamonu and Sinop), Balkan countries, Italy, France, Spain and Morocco (Filipovic, 2012; Giuliani *et al.*, 2009; Hidalgo and Brandolinib, 2014). This type of wheat could be used in bread and other bakery products formulations (Borghi *et al.*, 1996) due to its good nutrition properties (Abdel-Aal *et al.*, 2002). Especially, its high protein (Løje *et al.*, 2003), high dietary fibre (Corbelini *et al.*, 1999), high antioxidant (Brandolinia *et al.*, 2008) and high phenol contents (Lachman *et al.*, 2011) compared to other types of wheat. Although the rheology of Einkorn wheat is not optimal to produce bread and bakery products, it is hypothesised that if used in formulations that incorporate legume flours, its rheological properties could be greatly improved. Dough prepared with einkorn (*siyez*) wheat has weaker elastic properties due to its low gluten content and its rheological behaviour resembles that of a very viscous material when compared to doughs produced solely with wheat flour (Piasecka *et al.*, 2015). The variability of the gluten content in einkorn wheat may also negatively affect the production of bakery products at large production scales. Therefore, characterisation of doughs containing einkorn flour enriched with other flours is important to assess the processing performance of these formulation for the development of novel and more nutritious bakery products.

Cranberry bean is important for human nutrition and its flour is now being used by the food industry (Grajales-Garcia *et al.*, 2012). Hence, the potential of using both cranberry bean and their flours for developing nutritious bakery products need to be explored (Dzudie and Hardy, 1996).

Potato is cultivated all around the world and although is mostly consumed as a vegetable, potato starch and flour have found use in the food industry. Potato flour has a high starch content that does not contain gluten, thus products derived from this flour could be used in the production of gluten free products (Niewinski, 2008; Shih *et al.*, 2006).

The objective of this research was to study the pasting, rheological and textural properties of mixtures and doughs prepared with different flours (einkorn, cranberry bean and potato). Proximate analyses, empirical properties of the mixtures, including pasting properties (using a rapid visco analyser; RVA) and mixograph analysis, fundamental rheological properties (creep-recovery test) and textural properties (textural profile analysis; TPA) of the samples were conducted.

2. Materials and methods

Materials

Gold Medal All Purpose flour was obtained from a local market (West Lafayette, IN, USA). Einkorn (*siyez*) flour was obtained from Erciyes University Agriculture Engineering Faculty. Bob's Red Mill Potato Flour (8% total dietary fibre, 1% oil) and Bob's Red Mill Organic Cranberry Bean (Heritage Beans) (56% Dietary fibre, 1% oil) (Milwaukie, OR, USA) were purchased from a local market. Cranberry bean were milled using a rotor beater mill (Glen Mills, NJ, USA) and the milled flour was separated using a 0.0098-inch sieve. Doughs were prepared adding 100 g of flour and the amount of water determined from water adsorption tests. Yeast and other ingredients were not used in the dough formulation. The simplex lattice mixture design used in the research is illustrated in Table 1.

Physico-chemical properties of flours

Moisture, protein, and ash contents of the samples were determined according to the procedures described by AOAC (2000). Moisture content was determined after drying the samples at 105 °C for 4 hours in an oven (Isotemp Vacuum Oven Model 281, Fischer Scientific, Pittsburgh, PA, USA). Ash values of samples were determined by

Table 1. Compositions of flour samples in a simplex lattice mixture design.

Mixtures	Ingredient proportions[1]			Einkorn (*siyez*) flour (%)	Cranberry bean flour (%)	Potato flour (%)
	X_1	X_2	X_3			
1	0.75	0	0.25	22.5	0	7.5
2	0	1	0	0	30	0
3	0.25	0.25	0.5	7.5	7.5	15
4	0.5	0.25	0.25	15	7.5	7.5
5	0	0.25	0.75	0	7.5	22.5
6	0	0.5	0.5	0	15	15
7	0.5	0	0.5	15	0	15
8	0	0.75	0.25	0	22.5	7.5
9	1	0	0	30	0	0
10	0.5	0.5	0	15	15	0
11	0.25	0	0.75	7.5	0	22.5
12	0.75	0.25	0	22.5	7.5	0
13	0.25	0.5	0.25	7.5	15	7.5
14	0	0	1	0	0	30
15	0.25	0.75	0	7.5	22.5	0

[1] 70:30% (wheat flour+einkorn, cranberry bean and potato flours).

incinerating the samples at 550 °C for 5 hours. Colour analysis of samples was performed using a colorimeter (LabScan XE, Hunter Laboratory, Reston, VA, USA) and recorded as L, a and b values. Protein content of the samples was determined using an automatic nitrogen analyser (TruMac N 4000, Leco, Saint Joseph, MI, USA) based on the Dumas method. Water absorption of the dough samples was determined using a Swanson-Working mixograph (National Mfg. Co., Lincoln, NE, USA).

Pasting properties

Pasting properties of flours were determined according to the method described by Yildiz *et al.* (2017), using an RVA (Newport Scientific Pty. Ltd, Warriewood, NSW, Australia). The standard 2 method was used to determine the pasting properties of the mixtures. Firstly, 3.5 g flour mix (Table 1) was placed into aluminium canisters and then 25 ml distilled water was added. The mixture was heated to 50 °C, and after stirring at that temperature at 960 rpm for 1 min the samples were held at 50 °C for 1 min. Then, samples were heated to 95 °C with a heating rate of 8 °C/min and held at 95 °C for 13 min under agitation. Samples were then cooled down to 50 °C with a cooling rate of 21 °C/min. RVA tests were conducted in triplicate. The pasting parameters peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time and pasting temperature were determined from the pasting curves using the Thermocline Software (V. 3.11, Perten Instruments, North Ryde BC, NSW, Australia).

Creep-recovery analysis

Creep and recovery analysis of doughs including einkorn, cranberry bean and potato flours were determined according to the method described by Yilmaz *et al.* (2012). Creep-recovery analysis was done using a mechanical spectrometer (ARG-2 Model, TA Instruments, New Castle, DE, USA). The tests were performed using a parallel plate geometry with a 40 mm diameter plate. A piece of the fresh dough (15 g) was placed between the parallel plates and the upper plate was lowered until a gap of 1 mm was reached; excess on the sample was trimmed. Creep-recovery tests were performed at 25 °C, where the strain and compliance of the sample were determined using a constant shear stress test of 50 Pa for 120 s. Afterwards, the stress on the dough was suddenly removed and creep recovery data was collected for another 120 s. Measurements were conducted by triplicate. Creep compliance *J(t)* was determined by Equation 1:

$$J(t) = \gamma(t) / \sigma \tag{1}$$

where $\gamma(t)$ and σ are the measured shear strain and constant shear stress applied, respectively; *J(t)* is the resulting compliance at time *t*.

For data analysis the Burger model (Figure 1) was used to describe the creep-recovery test. The Burger model consists of Maxwell and Kelvin-Voigt models connected in series and can describe the experimental data from a creep-recovery test by the Equation 2 (Barnes, 2000; Steffe, 1996):

$$J(t) = \underbrace{\frac{1}{G_0}}_{\text{Elastic}} + \underbrace{\frac{1}{G_1}\left[1-\exp\left(\frac{-tG_1}{\eta_1}\right)\right]}_{\text{Viscoelastic behavior}} + \underbrace{\frac{t}{\eta_0}}_{\text{Viscous flow}} \tag{2}$$

G_0 is the instantaneous shear modulus of the Maxwell element, η_0 the viscosity of the dashpot in the Maxwell element, which gives an indication of the residual strain after recovery. G_1 is the shear modulus of the Kelvin-Voigt element representing the contributions of the retarded elastic region to the total compliance, and η_1 is the viscosity of the dashpot included in the Kelvin-Voigt element, which represents the internal viscosity of the material resisting the deformation of the sample (Barry, 1983).

The final percentage elasticity/recovery and viscosity of the entire system were calculated by Equation 3 and 4:

$$\%E = [(J_{MAX} - J_\infty) / J_{MAX}] \times 100 \tag{3}$$

$$\%V = (J_\infty - J_{MAX}) \times 100 \tag{4}$$

where J_{MAX} is a maximum deformation of the sample after 120 s of the applied stress, and J_∞ is the infinite or residual compliance of the system at the completion of the test. All measurements of curves were replicated 3 times.

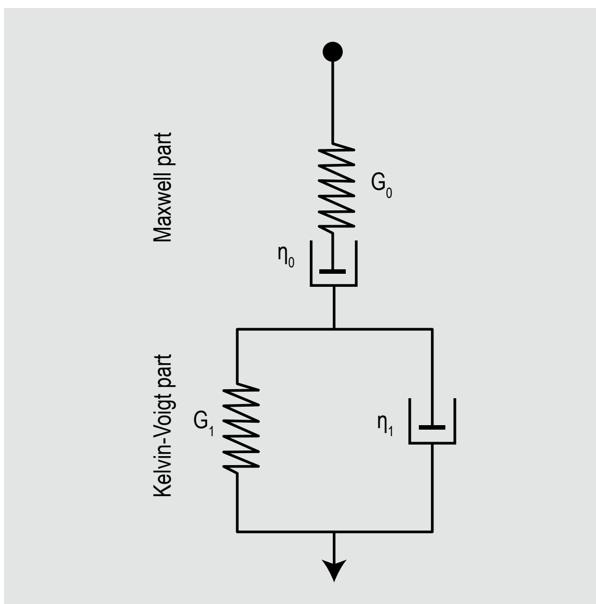

Figure 1. The four element Burger model composed of Maxwell and Kelvin-Voight models in series.

Textural properties

TPA of the doughs was determined according to the method described by Yuksel *et al.* (2015). TPA was carried out by using a Texture Analyzer HD plus (TA Instruments). 15 grams of the freshly prepared dough sample were shaped and placed on the platform of the equipment. A load cell of 50 kg and a cylindrical probe (diameter 25.4 mm) was utilised for the analysis. The trigger force was set at 5 g. Pre-test, test and post-test speeds were selected as 5, 1 and 5 mm/s, respectively. All measurements were replicated 5 times. Hardness (kg), adhesiveness (kg×mm), cohesiveness (%), gumminess (kg), chewiness (kg), springiness (%) and resilience (TPA parameters) of the dough were calculated from the force versus time data using the Texture Exponent software (Stable Micro System, Surrey, UK) and determined as described by Demirkesen *et al.* (2014).

Statistical analysis and modelling of experimental data

The following polynomial was used to assess each factor associated to the experimental results. This polynomial model differs from the full polynomial model because it does not contain a constant term (i.e. it assumes intercept equal to zero):

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \quad (5)$$

Y is the estimated response; β_1, β_2, β_3, β_{12}, β_{13} and β_{23} are coefficients for linear and nonlinear (interactions) terms generated by the prediction model in term of the processing components. The analysis was performed using uncoded units. The JMP statistical package software (Version 5.0.1.a, SAS Institute. Inc. Cary, NC, USA) was used for the analysis. The correlations between the parameters were determined using SAS software package (version 8.2, SAS 2002, SAS Institute Inc.). ANOVA was used, and the Duncan multiple comparison tests were carried out to determine significant differences between the parameters at a significance level of 0.05.

3. Results and discussion

Chemical properties of the flours

Chemical compositions of flours used in the research are given in Table 2. Differences between the dry matter content of the flours was observed to be non-significantly different (P>0.05) whereas differences in the ash content was significantly different (P<0.05). The highest ash content was determined to be 4.1 g/100 g for the cranberry bean flour while the lowest was 0.6 (g/100 g) and found in wheat flour. The protein content of wheat, einkorn, cranberry bean and potato flours were significantly different (P<0.05) with values 11.1, 12.0, 22.4 and 9.4 (g/100 g), respectively. The colour of the flours was determined to be statistically significant (P<0.05). The highest lightness was 91.6 for wheat flour while the lowest was 78.6 for the Einkorn (*siyez*) flour. The redness content of wheat, einkorn, cranberry bean and potato flour was significantly different and with values 0.8, 3.3, 0.4 and -1.3, respectively. The maximum yellowness was determined to be significantly different and with values 15.4 for the Einkorn (*siyez*) flour while the minimum yellowness value was 8.8 and corresponded to cranberry bean flour (Table 2).

The physico-chemical properties of the mixtures are illustrated in Table 3. The moisture content of the mixture samples varied in the range of 5.1-10.8 g/100 g. The highest moisture content was for the wheat/einkorn flour sample (10.8 g/100 g) (9th design). The maximum moisture of the dough sample was 43.0 g/100 g in the 8th design while the minimum was 39.1 g/100 g for the 11th design. The addition of potato flour significantly decreased the dough moisture content (P<0.05). The highest ash content was measured in the formulations having the highest einkorn flour content (Table 3). The ash contents of the flour samples varied between 0.8-1.7 g/100 g. The protein content of the samples was significantly affected (P<0.05 Table 3) by the addition of einkorn, cranberry bean and potato flours to the formulation. Especially given its high protein content, cranberry bean flour was the component having the highest influence on protein content on the samples (Table 3). The

Table 2. Chemical properties of wheat, einkorn (*siyez*), cranberry bean and potato flours.[1]

	Wheat flour	Einkorn (*siyez*) flour	Cranberry bean flour	Potato four
Moisture (g/100 g)	8.6±1.2^a	7.7±2.10^a	6.9±0.51^a	4.0±2.32^a
Ash (g/100 g)	0.6±0.01^d	2.0±0.01^c	4.1±0.02^a	3.8±0.01^b
Protein (g/100 g)	11.1±0.25^c	12.0±0.01^b	22.4±0.02^a	9.4±0.62^d
L	91.6±0.01^a	78.6±0.30^c	89.3±0.01^b	89.0±0.04^b
a	0.8±0.01^b	3.3±0.01^a	0.4±0.01^c	-1.3±0.06^d
b	12.3±0.01^c	15.4±0.01^a	8.8±0.01^d	14.3±0.04^b

[1] In a column, means with no similar superscripts are significantly different at P<0.05 significance levels.

Table 3. Physico-chemical properties of mixture samples.[1]

Mixture number	Flour moisture (g/100 g)	Dough moisture (g/100 g)	Ash (g/100 g)	Protein (g/100 g)	W.A. (ml/100 g)[2]	L	a	b
1	9.4 ± 0.21^{bc}	42.1 ± 0.13^{ab}	1.1 ± 0.01^{bcd}	12.1 ± 0.07^{hi}	57.5 ± 0.06^{gh}	87.6 ± 0.19^{k}	0.8 ± 0.01^{b}	9.4 ± 0.02^{b}
2	6.9 ± 1.29^{bcd}	42.2 ± 0.80^{a}	1.7 ± 0.09^{a}	15.2 ± 0.15^{a}	61.2 ± 0.09^{a}	89.7 ± 0.14^{g}	0.7 ± 0.05^{c}	8.3 ± 0.07^{g}
3	7.3 ± 0.44^{bcd}	41.1 ± 0.28^{ab}	1.3 ± 0.27^{abcd}	12.5 ± 0.07^{fgh}	58.8 ± 0.01^{ef}	90.2 ± 0.02^{f}	0.3 ± 0.02^{g}	9.2 ± 0.01^{d}
4	8.8 ± 0.34^{bc}	42.0 ± 0.21^{ab}	0.8 ± 0.67^{d}	12.6 ± 0.07^{efg}	58.0 ± 0.03^{h}	89.8 ± 0.02^{g}	0.6 ± 0.02^{d}	9.1 ± 0.01^{d}
5	8.8 ± 1.68^{bc}	41.9 ± 1.07^{ab}	1.5 ± 0.03^{ab}	12.3 ± 0.22^{gh}	59.1 ± 0.01^{d}	91.0 ± 0.02^{b}	0.1 ± 0.03^{i}	9.2 ± 0.01^{cd}
6	8.7 ± 1.77^{bc}	42.3 ± 1.12^{a}	1.5 ± 0.15^{ab}	13.2 ± 0.27^{cd}	59.6 ± 0.02^{c}	90.8 ± 0.03^{c}	0.2 ± 0.02^{h}	9.0 ± 0.01^{e}
7	$7.7\pm1.84b^{cd}$	40.9 ± 1.18^{ab}	1.2 ± 0.04^{bcd}	11.7 ± 0.18^{i}	57.7 ± 0.08^{i}	89.1 ± 0.01^{i}	0.8 ± 0.02^{b}	8.8 ± 0.01^{f}
8	9.3 ± 2.87^{bc}	43.1 ± 1.80^{a}	1.6 ± 0.03^{ab}	14.3 ± 0.46^{b}	60.1 ± 0.01^{b}	90.5 ± 0.02^{e}	0.6 ± 0.02^{e}	8.8 ± 0.01^{f}
9	10.8 ± 0.70^{a}	43.0 ± 0.45^{a}	1.0 ± 0.02^{dc}	12.7 ± 0.17^{efg}	56.5 ± 0.01^{g}	88.4 ± 0.03^{j}	1.0 ± 0.01^{a}	9.4 ± 0.01^{b}
10	6.3 ± 0.38^{cd}	41.0 ± 0.35^{ab}	1.2 ± 0.03^{abcd}	13.1 ± 0.02^{cde}	58.7 ± 0.10^{f}	89.4 ± 0.03^{h}	0.7 ± 0.02^{c}	8.9 ± 0.01^{ef}
11	5.1 ± 1.29^{d}	39.1 ± 0.83^{b}	1.3 ± 0.08^{abcd}	11.2 ± 0.17^{j}	58.2 ± 0.02^{g}	90.7 ± 0.08^{cd}	0.0 ± 0.02^{j}	9.8 ± 0.08^{a}
12	9.5 ± 0.15^{bc}	42.5 ± 0.10^{a}	1.2 ± 0.02^{bcd}	12.9 ± 0.05^{def}	57.5 ± 0.04^{j}	89.1 ± 0.02^{i}	0.8 ± 0.02^{b}	9.1 ± 0.01^{d}
13	9.8 ± 1.83^{b}	43.0 ± 1.15^{a}	1.5 ± 0.06^{ab}	13.5 ± 0.34^{c}	59.0 ± 0.08^{e}	90.6 ± 0.02^{d}	0.4 ± 0.02^{f}	8.8 ± 0.01^{f}
14	7.1 ± 1.10^{bcd}	40.3 ± 0.71^{ab}	1.4 ± 0.05^{abc}	11.2 ± 0.01^{j}	58.7 ± 0.17^{f}	91.6 ± 0.16^{a}	-0.1 ± 0.02^{k}	9.3 ± 0.21^{bc}
15	8.2 ± 0.45^{bcd}	42.5 ± 0.28^{a}	1.2 ± 0.07^{abcd}	14.2 ± 0.03^{b}	59.6 ± 0.06^{c}	90.2 ± 0.01^{f}	0.6 ± 0.02^{de}	8.8 ± 0.01^{f}

[1] In a column, means with no similar superscripts are significantly different at $P<0.05$ significance level.
[2] W.A. = water absorption of doughs.

maximum protein content was determined to be 15.2 g/100 g in the wheat/cranberry bean flour sample (2nd design) while the minimum protein content was 11.2 g/100 g for the wheat/einkorn+potato flour sample (11th design).

Water absorption of the samples varied in the range 56.5-61.2 ml/100 g. The highest water absorption was 61.2 ml/100 g for the wheat/cranberry bean (70:30) flour sample (2nd design) while the lowest was 56.5 ml/100 g for the wheat/einkorn (70:30) flour sample (9th design). The main reason for the higher water absorption of the mixture containing cranberry bean flour is related to its high protein content. Similar results were reported by Sathe and Salunkhe (1981) for northern bean proteins, where it was demonstrated that water and oil absorption values were the highest for mixtures having bean flours, i.e. a flour with a high protein content.

The colour parameters were significantly different ($P<0.05$ Table 3) depending on the flour type. For all samples, maximum values of lightness (L), redness (a) and yellowness (b) were 91.6, 1.0 and 9.8, respectively (Table 3), while minimum values of lightness (L), redness (a) and yellowness (b) were 87.6, -0.1 and 8.3, respectively. It could be observed that the addition of potato flour in the formulation decreased redness value (a) to -0,1 due to the negative redness value of potato flour itself.

Creep-recovery analysis of dough samples

The creep parameters G_0, η_0, G_1 and η_1 corresponding to the Burger model along the standard error and the associated determination coefficients are given in Table 4. Figure 2A illustrates a typical creep curve whereas Figure 2B illustrates a typical creep-recovery curve for the different samples including the control (dough prepared only with wheat flour). As it can be seen in Table 4, the highest G_0 value was 3.7×10^4 in the 13th design, which includes 7.5% einkorn, 15% cranberry bean and 7.5% potato flours while the lowest G_0 value was 0.9×10^4 in the 7th design that includes 15% einkorn and 15% potato flours. It must be noted that since the fitting of the experiments was done on the creep compliance versus time data, rheological parameters such as G_0 and others do not have units. The η_0, G_1 and η_1 parameters decreased with the increase of cranberry bean flour and increased with the addition of both einkorn and potato flours. The determination coefficients of all samples were high with values ranging between 0.91 and 0.99.

Parameters determined from creep recovery curves are given in Table 5. The high maximum compliance (J_{MAX}) was 3.1×10^{-4} Pa^{-1} in the 7th design that included 15% einkorn and 15% potato flours whereas the lowest maximum compliance (J_{MAX}) was 0.7×10^{-4} in the 4th design, which contained 15% einkorn flour and 7.5% potato and cranberry bean flours. The maximum compliance (J_{MAX}) parameter decreased with the addition of cranberry bean flour and increased with

Table 4. The creep data model system for dough with using burger model parameters.[1,2,3]

Sample no.	G_0×10^4	η_0×10^4	G_1 (Pa)	η_1×10^4	R^2
1	2.4±15.1	1.3±4.5	2.6±12.4	1.3±5.1	0.99
2	2.8±91.3	1.0±0.2	1.1±0.2	1.0±0.2	0.96
3	2.5±78.3	1.2±5.5	1.1±90.1	1.2±4.7	0.93
4	3.6±54.8	0.8±8.1	0.3±14.7	0.8±8.0	0.99
5	1.8±61.0	0.5±0.1	0.2±0.1	0.5±0.1	0.98
6	3.3±64.4	1.2±0.6	2.0±26.3	1.2±0.5	0.99
7	0.9±61.0	1.2±1.0	2.9±4.5	1.2±1.7	0.91
8	3.3±71.7	1.2±0.6	2.0±29.2	1.2±0.6	0.97
9	1.3±44.3	1.3±10.2	3.0±9.7	1.3±10.4	0.96
10	2.7±88.6	1.2±0.1	2.2±29.6	1.2±0.1	0.95
11	1.9±76.4	1.1±5.8	2.0±5.3	1.2±6.2	0.93
12	3.3±41.7	1.1±6.6	1.6±17.3	1.2±6.9	0.99
13	3.7±74.6	1.1±6.2	1.4±11.8	1.2±6.5	0.98
14	1.1±72.7	1.3±12.1	2.7±24.0	1.3±13.1	0.91
15	3.1±84.8	1.2±0.2	1.8±0.2	1.2±0.2	0.96
Control	2.4+76.9	1.1+0.1	1.7+38.7	1.1+0.1	0.96

[1] The shear moduli of Maxwell and Kelvin-Voight spring is G_0 and G_1.
[2] η_0 and η_1 are the corresponding dashpot viscosities.
[3] R^2 is the determination coefficients and control is the wheat flour dough.

Table 5. Result of recovery phase.[1]

Sample no.	J_{MAX} × 10^{-4} (Pa^{-1})	J_∞× 10^{-4} (Pa^{-1})	Viscosity (%)	Elasticity (%)
1	1.7	0.8	46.4	53.6
2	1.3	0.8	64.6	35.4
3	1.3	0.8	60.6	39.4
4	0.7	0.4	52.9	47.1
5	1.2	0.8	67.9	32.1
6	1.0	0.6	56.6	43.4
7	3.1	1.8	57.7	42.3
8	1.1	0.7	59.5	40.5
9	1.8	1.2	69.0	31.0
10	1.4	1.1	75.0	25.0
11	1.7	1.1	66.8	33.2
12	1.0	0.3	35.9	64.1
13	1.0	0.6	58.8	41.2
14	2.6	1.7	65.6	34.4
15	1.4	0.9	67.7	32.3
Control	1.3	0.8	62.5	37.5

[1] J_∞ is the infinitive compliance and J_{MAX} is the maximum compliance. The control is wheat flour dough.

the addition of einkorn and potato flours. The equilibrium compliance (J_∞) values increased with the addition of both einkorn and potato flours whereas cranberry bean flour did not change its value. Maximum and minimum viscosity and elasticity parameters were obtained in the 10th and 12th designs as 75.0, 35.9, 64.1 and 25.0% respectively. The viscosity parameter decreased with the addition of einkorn flour (1st and 12th designs) while increased with the addition of both cranberry bean and potato flours (2nd and 14th designs). In general, % elasticity increased with the addition of a mixture of flours (Einkorn+cranberry bean+potato flour+wheat flour) used to enrich wheat flour doughs and decreased when the enriching flour mixture included the designs 2nd, 9th, and 14th (Table 5).

As illustrated in Figure 2B, creep and recovery curves of the dough samples corresponding to the designs 2nd, 9th, 14th, which include a ratio 30:70 of einkorn, cranberry bean and potato flours and wheat flour, respectively, increased with the addition of both einkorn and potato flours but did not change with the addition of cranberry bean flour. Similar results have been found by other researchers, who found that the rheological properties of dough were affected by the addition of modified starch (Witczak *et al.*, 2012), potato flour and β-glucan fibre (Mis, 2011). In the present study the viscoelastic properties of the dough samples were significantly affected by the presence of einkorn and potato flours due to the high dietary fibre content and the type of starch of these flours. Einkorn wheat has a higher content of dietary fibres due to the structure of its grain

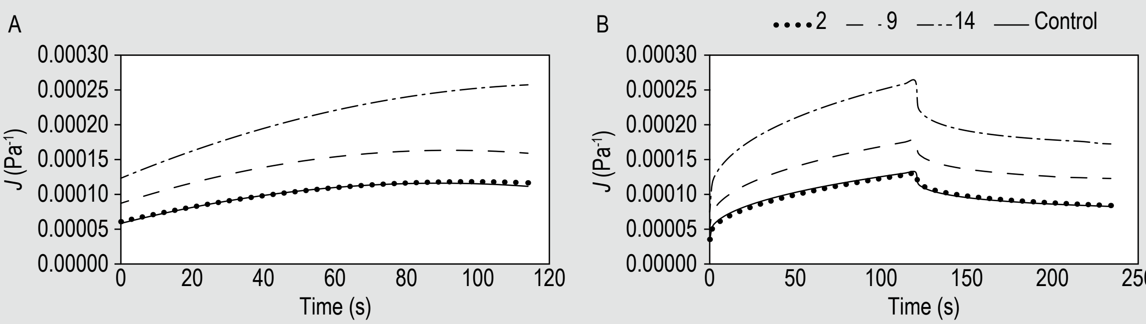

Figure 2. Creep curves of the dough model and Creep-Recovery curves of the 2nd, 9th, 14th design and control samples (wheat flour dough).

(a high proportion of husk) and potato starch has a higher amylopectin content, so doughs prepared with these flours exhibited weaker viscoelastic properties.

Pasting properties of flours

The pasting parameters obtained from the RVA tests are given in Table 6. The pasting parameters of samples with enriched einkorn, cranberry bean and potato flours depended on formulation and concentration level ($P<0.05$). Pasting temperature, trough, breakdown, and final viscosity increased with the addition of einkorn and cranberry bean flours and decreased with the addition of potato flour. Maximum peak was 1,303.5 cP for the 2nd and 10th designs and the minimum peak was 544.5 cP in the 14th design that included 30% potato flour and 70% wheat flour. As illustrated in Table 6, the highest trough, breakdown, final viscosity and setback were 580, 813.5, 1,415.5, 951 for the 2nd, 12th, 10th and 12th design, respectively, whereas the lowest values of peak, trough, breakdown, final viscosity and setback were obtained in the design (14th design) that include only potato flour and the values were 544.5, 228.5, 316, 517.5 and 289 cP respectively. The highest peak times were observed in the 9th and 12th designs while the lowest values were found in the 6th and 14th designs. From the data, it can be deduced that the pasting properties of samples were significantly affected by the type of added flour due to their different physical and chemical properties such as water absorption capacity and protein content. The water absorption capacity and the protein content of the formulation components could affect the structure and the rheology of the final product. Potato flour had low water absorption capacity and protein content so increasing of amount of potato flour in the mixture decreased the pasting parameters ($P<0.05$) associated to these properties. The response of the simplex lattice design model is illustrated in Table 7 and it shows high correlation coefficients. According to the table, the pasting parameters were highly correlated with the measured variables ($P<0.05$). The peak trough, breakdown and final viscosity all have R^2 of 0.99. As illustrated in Figure 3, the viscosity of the samples decreased with the addition of potato flour whereas increased with the addition of both cranberry bean and einkorn flours. Similar results were reported by other researches. For instance, Brandolini *et al.* (2008) who found that the pasting parameters of einkorn flours were high due to the high content of protein of these flours. Witczak *et al.* (2012) reported that in a study of flour enriched with modified starch, the pasting parameters of the mixtures were affected by the starch granule size, the level of amylose and the starch gelatinisation temperature. Similar results were also found in the present study, where it was observed that the pasting properties were significantly affected by the composition of the flours specifically the level of starch and proteins. It is also noted that the amylopectin and amylose levels of the flours were different, so gelatinisation of starch in the dough could be also affected.

Table 6. Mean values for pasting properties (rapid visco analyser; RVA) of mixture flours samples.[1]

Sample no.	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp. (°C)
1	1,040.5±17.7^{c}	369.5±2.1^{e}	671±15.6^{d}	1,055.5±5.0^{e}	686±2.8^{e}	8.5±0.1^{abcd}	80.2±2.2^{a}
2	1,303.5±26.1^{a}	580±4.2^{a}	723.5±21.9^{c}	1,366±15.6^{bc}	786±11.3^{d}	8.3±0.0^{de}	77.1±1.6^{a}
3	825.5±10.6^{e}	330.5±9.2^{f}	495±1.4^{g}	856±7.1^{g}	525.5±16.3^{h}	8.3±0.0^{cde}	82.5±0.3^{a}
4	1,047±5.7^{c}	420.5±7.8^{d}	626.5±13.4^{e}	1,127±18.4^{d}	706.5±10.6^{e}	8.5±0.0^{abcd}	81.9±1.2^{a}
5	670±8.5^{g}	270±24.0^{g}	400±15.6^{i}	654±52.3^{i}	384±28.3^{j}	8.3±0.1^{cde}	68.9±10.4^{b}
6	788±18.4^{ef}	326.5±2.1^{f}	461.5±20.5^{h}	735±2.8^{h}	408.5±0.7^{ij}	8.2±0.1^{e}	82.1±1.9^{a}
7	769±14.1^{f}	303±12.7^{f}	466±1.4^{h}	861.5±44.5^{g}	558.5±31.8^{g}	8.4±0.1^{bcde}	83.9±0.6^{a}
8	987±19.8^{d}	419.5±3.5^{d}	567.5±16.3^{f}	995±5.7^{f}	575.5±9.2^{fg}	8.3±0.0^{de}	78.6±0.5^{a}
9	1,239±14.1^{b}	441.5±3.5^{d}	797.5±10.6^{ab}	1,344±9.9^{c}	910±4.2^{b}	8.6±0.1^{ab}	82.1±1.4^{a}
10	1,303.5±38.9^{a}	523±33.9^{b}	780.5±4.9^{b}	1,415.5±40.3^{ab}	892.5±6.4^{b}	8.5±0.0^{abc}	80.4±3.1^{a}
11	657±14.1^{g}	261±4.2^{g}	396±9.9^{i}	679.5±6.4^{i}	418.5±2.1^{i}	8.3±0.1^{cde}	79.9±2.3^{a}
12	1,308.5±0.7^{a}	495±8.5^{c}	813.5±7.8^{a}	1,446±5.7^{a}	951±2.8^{a}	8.6±0.1^{a}	82.7±0.5^{a}
13	1,027.5±12.0^{c}	414.5±9.2^{d}	613±2.8^{e}	1,013.5±7.8^{ef}	599±1.4^{f}	8.4±0.1^{bcde}	80.7±1.1^{a}
14	544.5±19.1^{h}	228.5±12.0^{h}	316±7.1^{j}	517.5±14.8^{j}	289±2.8^{k}	8.2±0.1^{e}	84.7±0.0^{a}
15	1,280±21.2^{a}	547±4.2^{b}	746±1.4^{c}	1,380.5±4.9^{bc}	833.5±0.7^{c}	8.5±0.1^{abcd}	78.1±1.4^{a}
Control[2]	1,218±19.8^{bc}	289.5±9.2^{d}	928.5±10.6^{b}	885.5±34.5^{cd}	596±25.5^{cd}	8.365±0.05^{c}	80.325±0.6^{a}

[1] In a column, means with no similar superscripts are significantly different at $P<0.05$ significance levels.

[2] The control is wheat flour.

Table 7. Evaluation of constructed regression models for the experimental data from mixture samples (flours) and dough.

Parameters		Model performance[1]		
		R^2	RMSE	F
Physico-chemical properties (flours)	Moisture	0.79	1.1	6.6**
	Dough moisture	0.78	0.6	6.4**
	Ash	0.77	0.1	6.1**
	Water absorption	0.99	0.2	148.4**
	Protein	0.99	0.1	164.8**
Colour properties (flours)	L	0.89	0.4	15.3**
	a	0.90	0.1	16.4**
	b	0.70	0.2	4.1*
Pasting properties (flours)	Peak	0.99	25.9	290.3**
	Trough	0.99	10.2	320.8**
	Breakdown	0.99	18.8	207.1**
	Final viscosity	0.99	36.5	198.9**
	Setback	0.98	30.0	135.2**
	Peak time	0.94	0.0	30.2**
	Pasting temperature	0.22	4.1	0.5
Textural properties (dough)	Hardness	0.85	121.1	10.1*
	Springiness	0.70	0.0	4.1**
	Cohesiveness	0.71	0.0	4.4**
	Resilience	0.86	0.1	10.8*

[1] RMSE = root mean square error; ** = P<0.01; * = P<0.05.

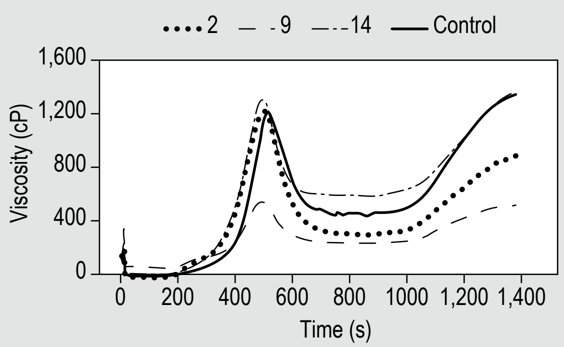

Figure 3. Rapid visco analysis curves of the 2nd, 9th, 14th design and control samples (wheat flour dough).

Textural/mechanical properties of doughs

TPA results performed on all samples are illustrated in Table 8. As shown, TPA parameters increase significantly with the addition of the different flours used in the formulations when compared to the control sample (P<0.05). Maximum hardness value was 1.2 kg in the 14th design while minimum hardness was 0.4 kg in the 12th design. The texture of the dough samples changed with increases in the content of potato flour in the formulation, which as indicated increased the hardness of the doughs. The increase in the hardness value was associated to the increase in potato flour in the formulation, likely due to the high water absorption capacity, the low gluten level of potato flour and its polar nature. Al-Muhtaseb *et al.* (2004) reported that potato starch showed high water binding capacity due to its high polar sites located on the surface. The statistical model performance of the dough samples is shown in Table 7. Results show that TPA parameters are significantly determined (P<0.05, P<0.01). The Hardness determination coefficient was 0.85.

The statistical model performance can be tested by examining the coefficients of determination, which are reported in Table 7. The coefficients of determination were high and able to explain the results with a high degree of significance, which is assumed to have a threshold value of 0.7 (Henika, 1982).

4. Conclusions

Suitable and doughs that can be easily handled can be prepared using einkorn, cranberry bean and potato flours, which could contribute to develop food products with enhanced nutritional properties and improved textural properties.

Table 8. Mean values for textural profile analysis (TPA) of dough samples.[1]

Sample no.	Hardness (kg)	Springiness (%)	Cohesiveness (%)	Resilience
1	0.6±3.91^{c}	0.2±0.0^{b}	0.4±0.0^{bc}	0.1±0.0^{b}
2	0.5±8.60^{de}	0.2±0.1^{b}	0.3±0.1^{c}	0.1±0.0^{e}
3	0.4±32.14^{ef}	0.3±0.1^{ab}	0.4±0.1^{bc}	0.1±0.0^{bc}
4	0.4±27.49^{fg}	0.2±0.0^{b}	0.4±0.1^{bc}	0.1±0.0^{bcd}
5	0.4±20.91^{ef}	0.3±0.1^{ab}	0.5±0.1^{ab}	0.1±0.0^{b}
6	0.5±15.78^{de}	0.4±0.0^{a}	0.5±0.0^{a}	0.1±0.0^{b}
7	0.4±8.94^{ef}	0.2±0.0^{b}	0.4±0.1^{bc}	0.1±0.0^{bc}
8	0.4±11.38^{gh}	0.3±0.0^{ab}	0.4±0.0^{bc}	0.1±0.0^{de}
9	0.5±18.31^{d}	0.2±0.0^{b}	0.4±0.0^{bc}	0.1±0.0^{bcd}
10	0.3±14.45^{h}	0.2±0.1^{b}	0.4±0.1^{bc}	0.1±0.0^{de}
11	1.0±58.76^{b}	0.3±0.0^{a}	0.5±0.0^{a}	0.1±0.0^{a}
12	0.4±13.34^{gh}	0.2±0.0^{b}	0.4±0.0^{bc}	0.1±0.0^{cde}
13	0.4±17.27^{fg}	0.3±0.0^{ab}	0.4±0.1^{bc}	0.1±0.0^{cde}
14	1.2±72.39^{a}	0.3±0.0^{a}	0.5±0.0^{ab}	0.1±0.0^{a}
15	0.4±29.12^{fgh}	0.3±0.1^{ab}	0.4±0.1^{bc}	0.1±0.0^{de}
Control[2]	0.2±0.02^{d}	0.3±0.27^{a}	0.6±0.58^{a}	0.1±0.03^{a}

[1] In a column, means with no similar superscripts are significantly different at P<0.05 significance levels.
[2] The control is wheat flour dough.

The viscoelastic properties of the doughs produced with the designed formulations were negatively affected by the content of potato flour while no significant changes were observed with the addition of einkorn and cranberry bean flours. Therefore, doughs with similar characteristics to typical wheat flour doughs could be prepared using either 30% einkorn or cranberry bean flours. Because cranberry bean flour has high protein and dietary fibre contents, doughs prepared with cranberry bean flour absorb more water resulting in viscoelastic properties that resemble than those of wheat dough.

Concerning modelling the viscoelastic data, the burger model was suitable to describe the viscoelastic behaviour of doughs enriched with einkorn, cranberry bean and potato flours. The model parameters showed that the potato flour could remarkably change the mechanical properties of doughs and the hardness of doughs were significantly increased (P<0.05).

The simplex lattice model design used in the research showed high coefficient of determination among physico-chemical properties, colour, pasting parameters and textural properties of the formulated doughs, so optimal formulations could be achieved by using these ingredients. Thus, results are revealing that einkorn and cranberry bean flours could be successfully used in the formulation of bakery products providing doughs with suitable rheological properties resembling the properties of wheat flour doughs. Results also showed that products enriched with potato flour could be utilised in the production of bakery products such as bread and snack foods.

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