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Dough rheology and bread quality of supplemented flours

Reología de la masa y calidad del pan de harinas suplementadas

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A commercial flour was alternatively supplemented with five enzymatic and two chemical additives. Two levels of addition were considered. The effects of additives on dough behavior and bread quality depended on the type of promoted biochemical reaction and, in some cases, were dose-dependent. Deformation energy (W) proved to be the best single predictor of the specific volume (SV) ($R = 0.847$) whereas the height/width ratio (HW) was better predicted by dough development time (DDT) ($R = -0.619$). The application of response surface regression followed by stepwise regression allowed to write two equations. The SV was greatly and positively affected by W, DDT, E (extensibility) and resistance to extensibility (R). Observed and predicted values were highly correlated ($R = 0.931$). The model did not allow to generalize the positive dependence of the HW ratio of the central slice on W and softening, although predicted and observed values correlated together at middle strong level ($R = 0.704$).

Keywords: bread specific volume; bread-making improvers; dough rheology; flour; height/width ratio; quality prediction

Una harina comercial se suplementó con cinco aditivos enzimáticos y dos químicos. Se consideraron dos niveles de adición. Los efectos de aditivos en el comportamiento de masa y calidad de pan dependieron del tipo de reacción bioquímica estimulada y, en algunos casos, fueron dosis dependientes. La energía de deformación (W) demostró ser el mejor pronosticador de volumen específico ($R = 0{,}847$), mientras el tiempo de desarrollo de masa ($R = -0{,}619$) predijo mejor el índice de altura/anchura. La aplicación de regresión de superficie de respuesta seguida de una regresión progresiva permitió escribir dos ecuaciones. El volumen específico fue mayor y positivamente afectado por W, tiempo de desarrollo de la masa, E (extensibilidad) y Resistencia a extensibilidad (R). Los valores observados y pronosticados resultaron altamente similares ($R = 0{,}931$). El modelo no permitió la generalización de dependencia positiva del índice de altura/anchura de la rebanada central en W y suavidad, aunque los valores observados y pronosticados coincidieron en el nivel medio fuerte ($R = 0{,}704$).

Palabras clave: volumen específico de pan; mejorante para la elaboración pan; reología de la masa; harina; índice de altura/anchura; predicción de calidad

Introduction

Bread is defined as a food made from flour or meal mixed with other dry and liquid ingredients, sometimes combined with a leavening agent, kneaded, shaped into loaves and baked. Soft wheat flour is one of the most largely used flour in breadmaking as it is supplied with proteins such as prolamins and glutelins, respectively responsible for viscosity-extensibility and elasticity of the dough matrix and of its ability to retain gas produced during fermentation (Courtin & Delcour, 2002).

The increasing mechanization of the baking industry and the demand for a wide range of bread types have determined the necessity to modulate structure and viscoelastic properties of doughs. In order to improve bread-making performance, chemical compounds and enzymes are usually included in bread formulas (Dunnewing, van Vliet, & Orsel, 2002). These additions allow to pursue a variety of goals including the obtainment of fermentable sugars, the improvement of workability and loaf volume, the increase of dough strength and the reduction of retrogradation and crumb firmness. Additives for the production of bread of consistent quality with a long shelf life include emulsifiers, enzymes, reductants and antioxidants.

Emulsifiers allow to obtain stable dough before baking and prevent its collapse if subjected to vibrations, other mechanical strain or too long resting time since the gas produced by the yeast during the proofing process is maintained inside the dough. DATEM (diacetyl tartaric esters of mono-glycerides)

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emulsifiers and lecithin can strengthen the wheat gluten due to its specific structure. They improve gas retention and dough stability and provides for the required kneading and proofing tolerance and resistance against mechanical shear. Emulsifiers also include monoglycerides that are used for improving the crumb softness, the tenderness, and the fresh-keeping properties thereby preventing bread staling.

In recent years, the treatments with enzymes has been preferred to the addition of chemical improvers as they do not remain active in the final product and, therefore, do not have to appear on the label (Caballero, Gómez, & Rosell, 2007a).

Bread-making improvers can be classified in groups such as cross-linking enzymes and oxidants, polysaccharides and gluten degrading enzymes (Stojceska & Ainsworth, 2008). Gluten cross-linking enzymes improve the ability of dough to entrap gas and the bread crumb texture and volume promoting the formation of covalent bonds between polypeptide chains (Gujral & Rosell, 2004) through mechanisms such as oxidative coupling of thiols, cross-link of tyrosine residues mediated by hydrogen peroxide and acyltransfers between aminoacid residues (Gerrard, 2002). When added to a dough, oxidant enzymes such as hexose oxidases induce the formation of disulphide bridges between proteins and the gelation of pentosans, increasing dough strength and bread volume (Poulsen & Hostrup, 1998). Amylases, pentosanases, xylanases are hydrolytic enzymes able to change physicochemical and structural properties of polysaccharides, making dough softer and viscous and increasing the availability of fermentable sugars. α-amylase prolongs oven rise and results in an increased loaf volume. Polysaccharides degrading enzymes are used also for their contribution to fresh quality enhancement and staling prevention (Caballero, Gómez, & Rosell, 2007b). Gluten degrading enzymes (protease) are sometimes used in bread-making formulation in order to avoid an excessive increase in dough tenacity due to the addition of gluten cross-linking enzymes (Caballero et al., 2007a).

An increase in loaf volume and an improvement of bread crumb structure can be pursued with the addition of ascorbic acid that acts on the redox systems of a wheat dough. In particular, the improver action of the ascorbic acid is due to its oxidation by gaseous oxygen to dehydroascorbic acid which determines the rapid oxidation of glutathione present in flour thus minimizing the SH/SS interchange reactions of reduced glutathione with intermolecular SS bonds of gluten molecules. These interchange reactions would depolymerise gluten proteins and weaken the dough (Grosch & Wieser, 1999).

In the present study, the authors tested several enzymatic and chemical bread-making improvers and evaluated their effects on dough rheology and bread quality of supplemented soft wheat flour.

Materials and methods

Raw materials

A commercial Italian soft wheat flour usually employed in bread-making was used. Its composition on wet basis was: proteins 114.6 g kg^{-1} (nitrogen to protein conversion factors 5.81), water 138.0 g kg^{-1}, ash 5.2 g kg^{-1}.

Enzymatic and chemical bread-making improvers were tested at two different levels of addition chosen on the basis of preliminary tests and included in the ranges usually applied in bakery industry. The five commercial enzymes were: an α-amylase (5 and 15 mg kg^{-1}; 4150 units g^{-1}; BakeZyme P 180 BG, DSM, The Netherlands); a synergistic blend of xylanase and amylase (20 and 100 mg kg^{-1}; 60 units g^{-1}; Fungamyl Super AX, Novozymes, Bagsvaerd, Denmark); a cellulase (80 and 180 mg kg^{-1}; 3500 units g^{-1}; Celluclast, Novozymes, Bagsvaerd, Denmark); an hemicellulase (40 and 80 mg kg^{-1}; Panlyve HCB-5, Panlyven, France); a glucose oxidase (15 and 40 mg kg^{-1}; 7500 units g^{-1}; M 300 B4, Millbo, Trecate, Italy).

The two commercial chemical improvers included ascorbic acid (60 and 120 mg kg^{-1}; E300, DSM, The Netherlands) and a deactivated yeast rich in glutathione (10 and 30 g kg^{-1}; ERV HA41, DSM, The Netherlands).

Dough preparation and bread-making procedure

Fifteen types of dough were produced: a control (C), made of 400 g of flour, 220.8 g of water (29 ± 1°C), 8 g of sodium chloride and 4 g of active dried *Saccharomyces cerevisiae*; 14 formulations, each of them made with the same ingredients of the control (the dough water moisture was adjusted on the basis of the farinographic water absorption) and the further addition of one of the seven bread-making improvers at two different concentrations.

Doughs were produced at least in triplicate. Breads were prepared according to the procedure described in the AACC method 10–10B (2000). Dough was mixed in a spiral mixer (FA.M.A.G. srl, Messina, Italy) for 15 min. At the end of mixing, the dough was placed in a proofing cabinet (JUNIORLEV, Castel MAC SpA, Treviso, Italy) for 60 min at 30°C (80% moisture) for leavening; subsequently dough was flattened, folded and replaced in the proofing cabinet. Then, it was flattened again and shaped in loaves of 600 g and placed in moulds for 45 min. Baking was carried out in a ventilated oven with steam injection at the beginning of baking (CIMAV-Verona, Italy) at 220°C for 30 min. Loaves were removed from the moulds and cooled for 2 h at room temperature before analysis.

Analyses

The α-amylase activity was determined according to the AACC Falling Number Method 56–81 method

(1999) through a Falling Number apparatus (1500 s/n 067182, Roma, Italy). The α-amylase activity is inversely correlated to the falling number thus a low α-amylase activity corresponds to a high value of this parameter.

Farinograph tests (water absorption, %; development time or DDT, min; softening index, Brabender Units or B.U.; stability, min) of doughs were performed through a Farinograph E (Brabender, Duisburg, Germany) according to the AACC method 54–21 (1995).

Alveograph tests were carried out in an Alveograph NG (Villeneuve La Garenne Cedex, France) according to the AACC Method 54–30 (2000). The following parameters were determined: tenacity (P, elasticity or resistance to extension), dough extensibility (L), the deformation energy (W) and the curve configuration ratio (P/L).

Concerning extensograph tests, flour strength (also known as dough energy, expressed as cm^2), maximum resistance to extensibility (R, expressed as Extensographic Units, E.U.), extensibility (E, expressed as mm) and R/E ratio of doughs were tested using a Brabender extensograph E (Duisburg, Germany) according to the AACC Method 54–10 (1995). After mixing in the Farinograph, each dough was divided into three pieces (150 g/piece) and proofed in a humidity chamber at 30°C. After 45, 90 and 135 min of proofing, one piece was stretched until it breaks. The results were recorded on extensograms.

Quality analysis of fresh bread samples was carried out by measuring, for each loaf, volume and the height/width ratio (HW) of the central slice. The loaf volume was obtained by rapeseed displacement according to the AACC Method 10–05 (2000).

Statistical analysis

Analyses were generally repeated at least three times. The averages and the standard deviations were calculated using Excel software version 11.5.1 (Microsoft, Redmond, USA). The Principal Component Analysis (PCA), the analysis of variance (ANOVA) and the Duncan test ($p < 0.05$) were performed using the software Winstat version 5.1 (Statsoft, Tulsa, USA). In order to determine the best single predictors of the specific volume (SV) and the HW ratio, simple correlations analyses were performed between dough rheological parameters and bread quality indices and the relative correlation coefficients (R), significance levels (p) and standard errors (SE) were reported. Statistical methods were also employed to determine if the quality characteristics (SV and HW ratio) of supplemented breads could be predicted by the use of an algorithm incorporating the dough rheological parameters. Models were calculated by means of response surface regression at first to test accuracy of prediction, and by means of stepwise regression to find the best subgroup of tested variables with the highest multiple determination coefficient (R^2 adjusted). Both statistics were calculated on $p < 0.05$ using the software Winstat version 5.1 (Statsoft, Tulsa, USA).

Results and discussion

α-amylase activity and rheological properties of control and supplemented doughs

A certain α-amylase activity is desirable in flour since this enzyme is able to hydrolyze damaged raw starch acting upon interior portions of the starch molecules and, thus, allowing the activity of the β-amylase. These hydrolysis reactions result in the production of maltose molecules and other fermentable sugars that represent a source of energy for yeasts involved in fermentation. Nevertheless, they are also responsible for several changes in dough properties including decrease of the absorption capacity, slackening of dough consistency and development of a stickier dough. The rate at which these changes occur is directly proportional to the amount of starch damage and α-amylase level of the flour. Bread flours with normal diastatic activity have falling number values in the range from 220 to 250 s. Flours deficient in diastatic activity have values higher than 400 s whereas over supplemented flours or flour milled from sprout damaged wheat can show values up to 60 s.

The falling number values of the control and the supplemented flours are reported in Supplementary Table 1. Most of the samples showed a deficient diastatic activity since their falling number values were included within the range 326–355 s. The exceptions were represented by the α-amylase-supplemented flours, which showed mean values included in the range of the normal diastatic activity and significantly lower than those of the other samples (266 and 230 s corresponding to the addition of 5 and 15 mg kg^{-1} of the enzyme, respectively). The addition of the blend xylanase–amylase did not determine reduction of the falling number due to the counterbalancing effect of the first enzyme that is responsible for the hydrolysis of the β-xylan bounds, forming oligomers with diverse molecular mass, and responsible for the liberation of water, which becomes available to gluten (Bordei, 2005). According to literature (Satin, 1998; Defloor, De Geest, Schellekens, Martens, & Delcour, 1991; Khalil, Mansour, & Dawoud, 2000), a high falling number is correlated with a high dough viscosity and, consequently, with a high bread firmness.

Among the farinograph parameters (Supplementary Table 1), the water absorption percentage was positively and significantly affected by the incorporation of glucose oxidase into the flour but without differences between the two levels of addition. Glucose oxidase catalyses the oxidation of β-D-glucose to gluconic acid and hydrogen peroxide. The mechanism by which this enzyme improves bread quality is still not completely

understood. Nevertheless, it has been found that hydrogen peroxide induces the oxidative gelation of water soluble pentosans (Gujral & Rosell, 2004) and a greater water sequestration (Bettge & Morris, 2007) that should explain the increase in water absorption. This hypothesis is coherent with the results obtained by Vemulapalli, Miller, and Hoseney (1998) who observed the drying effect exerted by glucose oxidase on dough, attributing it to the gel formation of water soluble pentosans. Water absorption was negatively affected by the supplementation with the powerful reducing agent glutathione since this tripeptide reduces the molecular weight of glutenin polymers by SH/SS interchange reactions (Joye, Lagrain, & Delcour, 2009) and consequently determines the water release. The addition of α-amylase to flour significantly decreased dough development time (DDT) in accordance with the results reported previously (Hyun Kim, Maeda, & Morita, 2006; Maeda, Hashimoto, Minoda, Tamagawa, & Morita, 2003). This tendency could be attributed to weakening of mixed doughs caused by the presence of a low molecular weight dextrins produced from damaged starches by amylase hydrolysis. The DDT was also decreased by addition of cellulase due to the partial degradation of cellulose to liberate oligosaccharides and glucose. Reduction of DDT was detected on dough supplemented with the highest level of xylanase–amylase blend and ascorbic acid or with the lowest level of glucose oxidase. Glutathione decreased DDT when added at the lowest level. On the contrary, DDT was increased when glutathione was added at the highest concentration. The reason of these opposite behaviors should be found in the different redox potentials established into the dough systems depending on the simultaneous presence and concentration of substances that can possess oxidising or reducing properties. All improvers tested increased the softening index, except for glucose oxidase. This oxidizing agent is not specific but acts on gluten thiols, glutathione or, also, ascorbic acid, resulting in prevention of dough softening through the transformation of thiol groups into disulphide bonds. The highest softening values were detected on dough supplemented with glutathione, cellulase, and xylanase–amylase blend at the highest levels of addition. Glucose oxidase added at the highest concentration was also the only additive able to increase dough stability. The lowest stability times were measured on doughs supplemented with α-amylase, ascorbic acid and xylanase–amylase blend. Concerning ascorbic acid, this could seem an anomalous result since the already explained effects of this acid on SH/SS interchanges. Nevertheless, ascorbic acid functions as an oxidizing agent only in presence of sufficient amounts of oxygen otherwise it cannot be converted in dehydroascorbic acid and, in its reduced form, breaks gluten disulfide bonds (Hrušková & Novotná, 2003). The result obtained through addition of xylanase–amylase blend could be explained with the loss of dough tenacity and the production of a sticky dough.

Concerning alveograph parameters (Supplementary Table 2), supplementation with deactivated yeast cells rich in glutathione caused significant decreases in both deformation energy (W) and tenacity (P) and significant increases in extensibility (L) with respect to the control. The larger W and P changes occurred into samples added with glutathione at the highest concentration. These results were to be expected since glutathione behaves as a reducing agent and is able to cause ruptures of disulfide cross-links by SH/SS interchanges (Grosch & Wieser, 1999), thus reducing the mean molecular weight of glutenins and inducing changes in the gluten structure and in the balance between viscous and elastic properties (G′ decreases more rapidly than G″) (Berland & Launay, 1995). The addition of both an oxidative enzyme, such as glucose oxidase and the ascorbic acid determined the opposite effect. The strengthening action of glucose oxidase (especially at the highest concentration) was related to the hydrogen peroxide produced during reaction that promoted the formation of disulphide linkages in gluten protein (Poulsen & Hostrup, 1998). The mechanism proposed for the improver action of the ascorbic acid (L-threo-ascorbic acid, in particular) is based on the assumption that the dehydroascorbic acid formed inhibits the cleavage of the intermolecular SS bonds of gluten proteins that happens in presence of reduced glutathione (Grosch & Wieser, 1999). The rate of L-threo-ascorbic acid oxidation in dough depends on the amount of oxygen kneaded into dough. The results reported in Supplementary Table 2 highlight that the amount of ascorbic acid added to the flour significantly influenced L and P/L parameters whereas no significant differences were registered for W and P between the two concentrations tested. The effects of polysaccharides degrading enzymes on the alveograph parameters were lower than those of the additives that act on gluten surely due to the greater influence of gluten network on dough rheology. The addition of cellulase, hemicellulase and the xylanase–amylase blend induced significant and consistent decreases in tenacity and P/L ratio. In fact, the presence of polysaccharides deriving from outer layers of grain, pericarp and aleurone layer negatively influences the gluten properties by changing the water distribution in the dough and also by having covalent interactions with gluten. Such enzymes are able to improve the rheological properties of dough by degrading and solubilizing the polysaccharides thus allowing the water redistribution and the reduction of the interference of polysaccharide chains on the cell architecture (Baiano, Romaniello, Lamacchia, & La Notte, 2009).

The extensograph data (Supplementary Table 3) are mainly useful in studying changes of flour strength, an important parameter correlated with bread quality. Maforimbo, Skurray, Uthayakumaran, and Wrigley

(2006) found that a decrease in resistance to extensibility explain the difficulties in breadmaking. Nevertheless, the test still remains very empirical, although several efforts have been made (Bloksma, 1962) to relate the data obtained by this test to more fundamental parameters. Glutathione significantly reduced flour energy and resistance to extensibility. Glucose oxidase and ascorbic acid showed the opposite effect, increasing flour energy and resistance to extensibility and reducing extensibility. Concerning flour strength, cellulase and hemicellulase showed dose-dependent effects. The addition of the lower levels of cellulase and hemicellulase left the flour strength almost unchanged. Cellulase at the higher level determined a significant decrease in strength whereas the higher level of hemicellulase caused its significant increase.

Bread quality of control and supplemented doughs

All additives influenced significantly ($p < 0.05$) the bread SV (Supplementary Figure 1). The addition of deactivated yeast rich in glutathione produced considerable decrease of SV due to the dough weakening and the coalescence of small gas cells in larger cells during proofing. The other additives allowed to obtain loaves having higher SV than the unsupplemented ones. The greatest volume was measured on bread loaves from flour supplemented with 180 mg kg^{-1} of cellulase. As the consequence of the hydrolytic action of this and other polysaccharide degrading enzymes, some free sugars such pentoses and hexoses can be released and fermented by the microorganisms (Martinez-Anaya, Devesa, Andreu, Escriva, & Collar, 1999).

HW ratio is included among parameters necessary for the evaluation of the baking product quality. In fact it is an index of the proofing behavior (the better is proofing, the higher is this ratio) and, consequently, of the loaf shape. The HW ratio (Supplementary Table 4) was increased by addition of cellulase and ascorbic acid independently on concentration. Concerning the other improvers, the effect was dose-dependent. In fact, the addition of the lowest amount of α-amylase and of the highest amounts of xylanase–amylase blend and hemicellulase caused increases of HW ratio. Instead, the HW ratio was decreased by addition of xylanase–amylase blend at the lowest concentration and by the highest amount of deactivated yeast rich in glutathione.

Relationship between rheological properties and bread quality parameters of control and supplemented doughs

The PCA was applied to dough rheological parameters (Supplementary Figure 2) in order to provide knowledge about the existence of relationships among properties and to reach a preliminary definition of groups of parameters that can characterize and discriminate between dough samples. The first two principal components (PC1 and PC2) accounted for 75.55% of the variance (58.44 and 17.06%, respectively). High relationships were shown within each of the following three groups of rheological parameters: alveograph W, P, P/L, farinograph water absorption, and extensograph flour strength, R, R/E; α-amylase activity and farinograph DDT and stability; alveograph L, farinograph softening index, and extensograph E. On the basis of their rheological properties, it was possible to discriminate the following groups of samples: one group including doughs supplemented with ascorbic acid 60 and 120 mg kg^{-1} (clearly characterized by the highest values of P, P/L, R and R/E); one group including doughs supplemented with α-amylase 5 and 15 mg kg^{-1}; another group made of control and doughs supplemented with hemicellulase 40 mg kg^{-1}, xylanase–amylase blend 20 mg kg^{-1}, hemicellulase 80 mg kg^{-1}. The other supplemented doughs were clearly separated on the plane of the principal components 1 and 2. Doughs supplemented with cellulase 180 mg kg^{-1} were characterized by the highest values of softening, L and E. On the basis of these results, the effects of the addition of α-amylase or ascorbic acid on the whole set of the rheological parameters were independent on their concentration whereas the other improvers showed dose-dependent effects.

Because the dough characteristics are known to influence the quality of bakery products, it was reasonable to expect that these rheological parameters would be correlated with measurable characteristics of the final product.

First of all, simple correlations between dough rheological parameters and quality characteristics of supplemented breads were tested and the results are presented in Supplementary Table 5. According to these data, various alveograph, farinograph and extensograph parameters influenced the SV of supplemented breads. The alveograph parameters W, P and P/L were found to be positively and significantly correlated to the SV whereas no significant correlations were found between L and the SV. According to previous works (Shogren, Finney, Bolte, & Hoseney, 1963; Shogren, Finney, Hoseney, & Bolte, 1963), L is an important predictor of loaf volume in bread from USA wheat flours since additional extensibility is required to moderate their high elasticity (P) and prevent the crumb chewiness. Instead, W is the best single predictor in bread from European flours (Faridi & Rasper, 1987) since the latter have lower P values and, thus, a better balance between elasticity and extensibility. According to Junqueira, Rocha, Moreira, and Castro (2007), wheat flour strength has a great effect also on volume of French breads and increases in volume are often positively correlated to flour strength and tenacity (Gómez, Oliete, Caballero, Ronda, & Blanco, 2008; Jai Pal Singh Sidhu & Bawa, 2002). In fact, flour strength is a measure of the gluten quality whereas tenacity is a predictor of the ability of the dough to retain gas. Among farinograph indices, the water

absorption was positively correlated to the SVs since evaporation of water absorbed in dough at kneading stage supports bread volume increase (Švec & Hrušková, 2009) whereas a negative correlation was found between the DDT and the SV. Both the extensograph flour strength and R were positively correlated to the SV, accordance with the finding of Nash et al. (2007). Among the rheological properties studied, W was positive correlated to the HW ratio of loaves whereas the DDT showed a good but negative correlation to it. Concerning the DDT, these results were opposite to those obtained by Uhlen et al. (2004) that found a high but positive correlation of this index to both the volume ($R = 0.89$) and HW ratio of the loaf ($R = 0.90$) of hearth bread. Nevertheless, Uhlen et al. (2004) used a baking system different from that applied in the present research and this thing could explain the different results obtained by the two groups of researchers. On the basis of correlation coefficient, probability level and standard error, the best single predictor of the SV was represented by the alveograph parameter W whereas the HW ratio was better predicted by the DDT. DDT was negatively correlated to the HW ratio. It could be supposed that the longer was the DDT (the time necessary to reach the optimal consistency of 500 B.U.), the lower was the elasticity and cohesiveness of dough, thus giving rise to less leavened loaves. The farinograph softening index and stability were not suitable to predict neither the SVs nor the HW ratio since those indices are greatly affected by the presence of large molecules able to bind water.

For prediction of bread SV and HW ratio, the application of response surface regression followed by stepwise regression allowed to write the following two final equations:

(1) $\mathrm{SV} = 21.26945 + 0.81647 \times W + 0.00343 \times E^2 + 0.06898 \times R \times \mathrm{DDT}$, with a rate of explained variability $R^2_{\mathrm{adjusted}} = 0.830$.
(2) $\mathrm{HW} = 0.520903 + 0.000009 \times W \times \mathrm{softening}$, with a rate of explained variability $R^2_{\mathrm{adjusted}} = 0.457$.

According to the high R^2_{adjusted} value, the SV of supplemented breads was greatly affected by alveograph W, farinograph DDT and extensograph E and R parameters. Observed and predicted values were highly correlated ($R = 0.931$) regardless the high standard error (14.209). On the basis of the low R^2_{adjusted} value, the model did not allow to generalize the dependence of HW ratio on the selected rheological properties, although predicted and observed values correlated together at middle strong level and with a low standard error ($R = 0.704$, SE 0.034).

Conclusions

The addition of bread-making improvers can be used in order to modify dough rheological behavior and bread quality characteristics. Parameters correlated to dough strength and elasticity were increased by glucose oxidase and ascorbic acid. With the exception of glucose oxidase, all the additives increased softening index and decrease stability. The negative effect of ascorbic acid on farinograph softening index and stability was not observed neither on alveogram nor on extensograph parameters. This absence of correlation between farinograph softening and alveograph or extensograph strength indices could be explained by the statement that the first describe the dough behavior during kneading whereas the latter are a measure of the behavior of a dough submitted to a stress like the proofing is.

Bread SV and HW ratio was significantly affected by individual enzyme addition. The addition of deactivated yeast rich in glutathione decreased SV of 16–22% whereas the other additives allowed to obtained loaves with higher SV than control. The best performances were obtained through addition of 180 mg kg^{-1} of cellulase that allowed to increase the bread SV of about 21% and the HW ratio of 16% with respect to the unsupplemented formulation. On the contrary, the addition of deactivated yeast rich in glutathione gave the worst results.

Some dough rheological properties can be used as predictors of bread quality characteristics and this ability could be used to modify dough formulations depending on the characteristics desired in bread final products. In particular, the alveograph parameter W and the farinograph DDT were proved to be the best single predictor of SV and HW ratio, respectively, whereas the application of response surface regression followed by stepwise regression allowed to establish that the SV of supplemented breads was positively affected by W, DDT, E and R whereas the HW ratio positively depended on W and softening.

Supplementary material

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References

American Association of Cereal Chemists. (1995). *Methods 54–10 – Extensograph method and 54–21 – Farinograph method*. St Paul, MN: AACC.

American Association of Cereal Chemists. (1999). *Approved methods. Method 56–81 – Determination of Falling Number*. St Paul, MN: AACC.

American Association of Cereal Chemists. (2000). *Approved methods. Methods 10–10B – Bread-making and 54–30 – Alveograph method*. St Paul, MN: AACC.

Baiano, A., Romaniello, R., Lamacchia, C., & La Notte, E. (2009). Physical and mechanical properties of bread loaves produced by incorporation of two types of toasted durum wheat flour. *Journal of Food Engineering*, *95*, 199–207.

Berland, S., & Launay, B. (1995). Rheological properties of wheat flour doughs in steady and dynamic shear: Effect of water content and some additives. *Cereal Chemistry*, *72*, 48–52.

Bettge, A.D., & Morris, C.F. (2007). Oxidative gelation measurement and influence on soft wheat batter viscosity and end-use quality. *Cereal Chemistry*, *84*, 237–242.

Bloksma, A.H. (1962). Slow creep of wheat flour doughs. *Rheologica Acta*, *2*, 217–230.

Bordei, D. (2005). Tehnologia moderna a panificatiei'. *AGIR Editure*, Bucharest.

Caballero, P.A., Gómez, M., & Rosell, C.M. (2007a). Bread quality and dough rheology of enzyme-supplemented wheat flour. *European Food Research and Technology*, *224*, 525–534.

Caballero, P.A., Gómez, M., & Rosell, C.M. (2007b). Improvement of dough rheology, bread quality and bread shelf-life by enzymes combination. *Journal of Food Engineering*, *81*, 42–53.

Courtin, C.M., & Delcour, J.A. (2002). Arabinoxylans and endoxylanases in wheat flour bread-making. *Journal of Cereal Science*, *35*, 225–243.

Defloor, I., De Geest, C., Schellekens, M., Martens, A., & Delcour, J.A. (1991). Emulsifiers and/or extruded starch in the production of breads from cassava. *Cereal Chemistry*, *68*, 323–327.

Dunnewing, B., van Vliet, T., & Orsel, R. (2002). Effect of oxidative enzymes on bulk rheological properties of wheat flour doughs. *Journal of Cereal Science*, *36*, 357–366.

Faridi, H.A., & Rasper, V.F. (1987). *The Alveograph handbook*. St. Paul, MN: American Association of Cereal Chemists.

Gerrard, J.A. (2002). Protein–protein crosslinking in food: Methods, consequences, applications. *Trends in Food Science and Technology*, *13*, 389–397.

Gómez, M., Oliete, B., Caballero, P.A., Ronda, F., & Blanco, C.A. (2008). Effect of nut paste enrichment on wheat dough rheology and bread volume. *Food Science and Technology International*, *14*, 57–65.

Grosch, W., & Wieser, H. (1999). Redox reactions in wheat dough as affected by ascorbic acid. *Journal of Cereal Science*, *29*, 1–16.

Gujral, H.S., & Rosell, C.M. (2004). Improvement of the breadmaking quality of rice flour by glucose oxidase. *Food Research International*, *37*, 75–81.

Hrušková, M., & Novotná, D. (2003). Effect of ascorbic acid on the rheological properties of wheat fermented dough. *Czech Journal of Food Sciences*, *21*, 137–144.

Hyun Kim, J., Maeda, T., & Morita, N. (2006). Effect of fungal α-amylase on the dough properties and bread quality of wheat flour substituted with polished flours. *Food Research International*, *39*, 117–126.

Jai Pal Singh Sidhu, & Bawa, A.S. (2002). Dough characteristics and baking studies of wheat flour fortified with xanthan gum. *International Journal of Food Properties*, *5*, 1–11.

Joye, I.J., Lagrain, B., & Delcour, J.A. (2009). Use of chemical redox agents and exogenous enzymes to modify the protein network during breadmaking – A review. *Journal of Cereal Science*, *50*, 11–21.

Junqueira, R.M., Rocha, F., Moreira, M.A., & Castro, I.A. (2007). Effect of proofing times and wheat flour strength on bleaching, sensory characteristics, and volume of French breads with added soybean lipoxygenase. *Cereal Chemistry*, *84*, 443–449.

Khalil, A.H., Mansour, E.H., & Dawoud, F.M. (2000). Influence of malt on rheological and baking properties of wheat-cassava composite flours. *Lebensmittel-Wissenschaft und-Technologie*, *33*, 159–164.

Maeda, T., Hashimoto, T., Minoda, M., Tamagawa, S., & Morita, N. (2003). Effects of mutant thermostable α-amylase on rheological properties of wheat dough and bread. *Cereal Chemistry*, *80*, 722–727.

Maforimbo, E., Skurray, G., Uthayakumaran, S., & Wrigley, C.W. (2006). Improved functional properties for soy–wheat doughs due to modification of the size distribution of polymeric proteins. *Journal of Cereal Science*, *43*, 223–229.

Martinez-Anaya, M.A., Devesa, A., Andreu, P., Escriva, C., & Collar, C. (1999). Effects of the combination of starters and enzymes in regulating bread quality and shelf life. *Food Science and Technology International*, *5*, 263–273.

Nash, D., Lanning, S.P., Fox, P., Martin, J.M., Blake, N.K., . . ., & Graybosch, R.A. (2007). Relationship of dough extensibility to dough strength in a spring wheat cross. *Cereal Chemistry*, *83*, 255–258.

Poulsen, C.H., & Hostrup, P.B. (1998). Purification and characterization of a hexose oxidase with excellent strengthening effects in bread. *Cereal Chemistry*, *75*, 51–57.

Satin, M. (1988). Bread without wheat. *New Scientist*, *28*, 1–5.

Shogren, M.D., Finney, K.F., Bolte, L.C., & Hoseney, R.C. (1963). A modified alveograph technique for hard winter wheat flour. *Agronomy Journal*, *55*, 19–21.

Shogren, M.D., Finney, K.F., Hoseney, R.C., & Bolte, L.C. (1963). Correlations of certain properties of the alveogram with important hard winter wheat quality characteristics. *Agronomy Journal*, *55*, 21–24.

Stojceska, V., & Ainsworth, P. (2008). The effect of different enzymes on the quality of high-fibre enriched brewer's spent grain breads. *Food Chemistry*, *110*, 865–872.

Švec, I., & Hrušková, M. (2009). Modelling of wheat, flor and bread quality parameters. *Scientia Agriculturae Bohemica*, *40*, 58–66.

Uhlen, A.-K., Sahlstrøm, S., Magnus, E.M., Færgestad, E.M., Dieseth, J.A., & Ringlund, K. (2004). Influence of genotype and protein content on the baking quality of hearth bread. *Journal of the Science of Food and Agriculture*, *84*, 887–894.

Vemulapalli, V., Miller, K.A., & Hoseney, R.C. (1998). Glucose oxidase in breadmaking systems. *Cereal Chemistry*, *75*, 439–442.