Effect of the addition of extruded wheat flours on dough rheology and bread quality

Mario Martínez, Bonastre Oliete, Manuel Gómez*

Área de Tecnología de los Alimentos.

E.T.S. Ingenierías Agrarias. Universidad de Valladolid, 34004 Palencia, Spain.

Tel: +34 979-108359 fax +34 979-108302

*Corresponding author. E-mail: pallares@iaf.uva.es

Abstract

Extruded wheat flours, due to their increased water absorption capacity, constitute an opportunity to increase bread output in bakery production. However extrusion may modify dough and bread characteristics. The aim of this study was to investigate the effect of the substitution of 5% of the wheat flour by extruded wheat flour (produced with different time-temperature extrusion treatments) on dough mixing, handling and fermentation behaviour and bread volume, shape, texture and colour. The RVA curves indicate that extrusion intensity increases with increasing temperature or water content. Water absorption capacity rises with increasing treatment intensity, but dough stability tends to decrease. Adding extruded flours decreases dough extensibility but increases tenacity and gas production. Differences in dough structure were observed on photomicrography, though there were no clear differences in bread quality. These results indicate that it is possible to obtain adequate dough and bread characteristics using dough with 5% extruded wheat flour.

Keywords: hydrothermal treatment, wheat flour, rheology, bread yield.

1. Introduction

One of the main interests of the bakery industry is to improve bread output during the bread making process (obtaining a greater quantity of bread from the same quantity of flour). Such an increase in production would enable manufacturers to maximize benefits or to reduce the retail price and be more competitive. One way to achieve this objective is to increase the amount of water included into the formula, but avoiding any modification of bread quality and preventing water loss during baking. Doughs with excess water are difficult to handle; it thus becomes necessary to modify the recipe or processing conditions. Increasing the water absorption capacity of doughs is the easiest way to obtain high-water content and high-yield breads (Puhr and D'Appolonia, 1992).

The water absorption capacity of dough depends mainly on the flour composition, and increases with increasing protein, pentosan and damaged starch content. The association between the quantity of damaged starch and the water absorption capacity of flour has been established (Dexter et al., 1994). Studies have been also performed with pregelatinized starches, which show a similar behaviour to damaged starch because the starch granules break down during this process. Based on these findings, Miller et al. (2008) investigated the possibility of increasing bread output through the addition of certain pregelatinized (hydroxypropylated and cross-linked) wheat starches, with good results. The addition of heat-moisture treated maize starch has been also studied, although in this case the breads obtained were of low quality (Miyazaki and Morita, 2005). Another possible way to increase output during bread-making consists of the addition of hydrocolloids, due to their high water absorption capacity; however, hydrocolloids produce major alterations in other characteristics of breads and doughs (Rosell et al., 2001).

It is known that the changes that take place in flours during hydrothermal treatment depend on the initial water content of the product, the temperature reached and the time and type of treatment: heated rolls, atomization or extrusion (Chiu and Solarek, 2009). Extrusion produces gelatinization of starch and increased damaged starch content, together with a reduction in lipid oxidation due to enzyme inactivation, an increase in soluble fibre and a reduction in thermolabile vitamins, antinutritional factors and microbial load (Camire et al., 1990). Extrusion also causes higher levels of mechanical damage in starch than traditional cooking methods (Wolf, 2010). Extruded wheat flours may therefore be an interesting alternative to pregelatinized starch and hydrocolloids to increase bread output in the bakery manufacturing process. Furthermore, it is not necessary to label these kinds of flour as additives but as wheat flours, which will facilitate clear labelling, a tendency currently favoured in the food industry (Sloan, 2011).

Few studies have investigated the use of extruded flours in bread-making and they are limited to the addition of these flours into non-wheat doughs or into doughs with a high content of non-wheat flours such as maize (Curic et al., 2009), barley (Gill et al., 2002) or rice (Sanchez et al., 2008) flours in order to make up for gluten deficiency. So that the aim of this work was to evaluate the effect of substituting 5% wheat flour by extruded wheat flours with different time-temperature extrusion treatments. In each case we determined the effect of this addition on dough mixing, handling and fermentation evolution and on the final quality of the bread (volume, weight, height/width ratio, texture and colour).

2. Materials and Methods

2.1 Materials

Wheat flour (14.48% moisture, 0.58% ash, 11.78% protein) was supplied by Harinera Castellana. Extrusion was performed by Harinera Los Pisones (Zamora, Spain). An industrial Buhler Basf single-screw extruder (Buhler S.A., Uzwil, Switzerland) was used for the extrusion process. Five kinds of extrusion treatments were studied: In treatment 1, flour was extruded with 4% water added in the system and the maximum temperature of the extruder was 60ºC; in treatments 2, 3 and 4, flour was extruded at a maximum extruder temperature of 110ºC and with 4%, 10% and 16% water added in the system, respectively; and in treatment 5 flour was extruded with 9% water added in the system and a maximum extruder temperature of 140ºC. The extrusion conditions were fixed to ensure correct flow behaviour of the dough into the extruder. The extruded product was milled with compression drums and sieved through a 200-μm sieve. The product obtained from the sieve was used. Wheat flour composition was determined using AACC Methods (AACC, 2000): moisture, method 44-15A; ash, method 08-01; and protein, method 46-08.

Saf-Instant yeast (Lesaffre, Lille, France) was used as the leavening agent. Salt from the local supermarket and tap water were used in the bread-making analysis. Analytical quality ascorbic acid (Panreac Quimica S.A.U., Barcelona, Spain) was used.

2.2 Methods

2.2.1 Dough rheology and gas production.

Extruded flours were added at 5g per 95g flour (5% extruded flour) obtaining flours A, B, C, D and E when extruded flour added was from treatments 1, 2, 3, 4 and 5 respectively. Control dough without the addition of extruded flour was also analysed.

The pasting properties of flours were analyzed using the standard method with a Rapid Visco® Analyser (RVA-4) (Perten Instruments Australia, Macquarie Park, Australia) (method 61-02.01, AACC, 2010), controlled by Thermocline for Windows software (Perten Instruments Australia, Macquarie Park, Australia). Analyses were performed in duplicate.

Water absorption and the mixing behaviour of flours were studied using the doughLAB equipment (Perten Instruments Australia, Macquarie Park, Australia). Dough was developed in the mixing bowl at 30ºC, by the rotary action of two sigma-arm mixing blades at 63rpm and its resistance to kneading was obtained as a torque value. Data obtained from the doughLAB were analyzed using doughMAP software (Perten Instruments Australia, Macquarie Park, Australia). The following mixing-profile values were measured: 1) absorption, defined as the amount of water required to reach a flour consistency of 500FU with 14% moisture; 2) development time, defined as the time to reach peak resistance; and 3) stability, defined as the difference between the time required to reach peak resistance and the time required to fall below peak resistance. The analyses were performed in duplicate.

Alveograph measurements were made with an Alveograph MA 82 (Chopin, Tripette et Renaud, Villeneuve La Garenne, France) using the standard AACC Approved Method 54-30 (AACC, 2000). The alveogram characteristics were automatically recorded by the Alveolink-NG computer software program developed by Chopin S. A. (Chopin, Tripette et Renaud, Villeneuve La Garenne, France). The characteristics recorded were maximum over-pressure (P) needed to blow the dough bubble (an indicator of dough tenacity or resistance to extension), the average abscissa (L) at bubble rupture (an indicator of dough extensibility), the deformation energy (W) (an indicator of dough strength), and the curve configuration ratio or balance (P/L).

A second alveogram was performed by adding a quantity of water equal to the absorption capacity obtained on DoughLab analysis. The two alveograms were performed in duplicate.

The rheofermentometer test (Chopin, Tripette and Renaud, Villeneuve La Garenne, France) was used to study dough height according to fermentation time and gas release following the method described by Czuchajowska and Pomeranz (1993).

2.2.2 Bread making.

A straight dough method was used for bread preparation. The following ingredients (g/100g flour basis) were used: water (calculated to obtain a doughLab absorption value of 500FU), instant dry yeast (1g/100g), ascorbic acid (0.01g/100g) and salt (1.8g/100g). Water temperature was calculated to achieve a dough temperature of 23ºC. Wheat flour was replaced with extruded wheat flours to a proportion of 5g per 100g flour. Control bread with no extruded flour was also prepared. After mixing all the ingredients for 15 minutes using a double-arm kneader AB-20 (Salva, Lezo, Spain), the bread dough was divided into 300g portions, hand-rounded, mechanically moulded, and proofed for 90 min at 30ºC and 75% RH. The breads were baked in an electric oven for 30 min at 200ºC. After baking, the loaves were left to cool for 20 minutes, and then weighed. They were then placed in polyethylene bags and stored at 20ºC until analysis. All the elaborations were made twice.

2.2.3. Bread quality.

Weight loss was calculated by weighing the breads one hour after baking. Bread volume was determined using a laser sensor with the BVM-L 370 volume analyser (Perten Instruments, Hägersten, Sweden). A digital calliper was used to measure height/weight ratio. Measurements were run in triplicate.

Crumb texture was determined with a TA-XT2 texture analyzer (Stable Microsystems, Surrey, UK) fitted with the *"Texture Expert"* software. An 25-mm diameter cylindrical aluminium probe was used in a *"Texture Profile Analysis"* (TPA) double compression test to penetrate to 50% of the sample depth at test speed of 2 mm/s and with a 30 second delay between first and second compressions. Firmness (N), cohesiveness, springiness, resilience and chewiness were calculated from the TPA graph (Gómez et al., 2007). Texture analyses were performed 18 hours after baking on slices with a thickness of 30 mm. Analyses were performed on two slices from two breads (2x2) from each type of elaboration, taking the average of the 4 measurements made.

Colour was measured using a Minolta spectrophotometer CN-508i (Minolta, Co.LTD, Tokio, Japan). Results were expressed in the CIE L*a*b* colour space and were obtained using the D65 standard illuminant, and the 2º standard observer. Colour determinations were made 4x5 times on each piece of bread (two breads from each type of elaboration): crumb and crust colour was checked at four different points on each piece of bread and each point was measured five times.

2.2.4 Electron microscope photomicrographs.

Dough photomicrographs were taken with a Quanta 200FEG (Hillsboro, Oregon, USA) environmental scanning electron microscope (ESEM) fitted with a backscattered electron detector (BSED).

2.2.5 Statistical analysis.

Analysis of variance (ANOVA) was used to analyze the effect of the addition of extruded flour. Fisher's least significant difference (LSD) test was used to describe means with 95% confidence.

3. Results and Discussion

3.1 Dough rheology and gas production

Figure 1 shows the RVA curves from the extruded flours. Observing the differences in behaviour compared to the control, it can be seen that extrusion intensity increases both with temperature and, at a constant temperature, with water content. Increasing the extrusion intensity leads to a decrease in dough viscosity during the heating-cooling cycle. This effect has already been observed by other authors, who attributed the decrease to early starch gelatinization (Doublier et al., 1986; Hagenimana et al., 2006; Mercier and Feillet, 1975); the decrease in viscosity would therefore indicate the proportion of gelatinized starch. It can thus be shown that flours that have undergone the most intense extrusion treatments have the highest quantity of gelatinized starch.

In the analysis of flour behaviour during mixing (Table 1), dough water absorption capacity was found to increase after the addition of extruded flour, and this increase was greater the more intense the extrusion intensity, reaching an increase compared to the control value up to 7% in doughs prepared with flour that had undergone the most intense treatment (flour E). This finding is explained by the greater damage to the starch granules and greater starch gelatinization as the extrusion conditions (temperature and water content) increase (Mercier and Feillet, 1975). There were no significant differences in dough development time in any case;

however, dough stability tended to decrease with increasing extrusion intensity, although significant differences were only observed between the control dough and the doughs prepared with the three flours that had undergone the most intense extrusion treatments. It is known that farinographic stability depends on the characteristics of the protein network, and thus on protein quality (Konopka et al., 2004; Zhu and Khan, 2001). The reduction in stability may therefore be related to the degradation of the gluten matrix occurring during the extrusion process, due to the increase in temperature, as high-temperature treatments will modify the characteristics of the components of the gluten matrix (Li and Lee, 1996; Singh and MacRitchie, 2004).

Gaines et al. (2006) stated that alveographic assay was one of the best methods for measuring dough strength, which has been correlated with bread volume (Janssen et al., 1996). The results of the alveographic assay of doughs made with extruded flours are shown in Table 1. It may be seen that the addition of extruded flours decreases dough extensibility in all cases, and that there was an increase in dough tenacity, though this was only significant after the most intense extrusion treatments. The two effects offset each other on the area of the alveographic curve, meaning that no significant differences were observed in the overall strength values. The P/L ratio or balance did increase when extruded flour was added, although the change was only significant with flours C and D. The variations in the alveogram characteristics were principally related to two factors: gluten matrix degradation and starch modification, both of which are effects of the extrusion treatment. Gluten matrix degradation increases with treatment intensity; this was confirmed by Gómez et al. (2011) when they found significant correlations between the alveogram parameters and the zeleny index, an indicator of protein quality. Starch modification during the extrusion process leads to an increase in dough consistency due to the increase in the quantity of damaged starch and its higher water absorption capacity (Preston et al., 1987), as had already been observed in the DoughLab analysis. In fact, when dough water content was modified on the basis of the DoughLab analysis, unifying dough consistency, a significant effect on dough tenacity was only observed with the dough prepared with flour E, which had the highest extrusion temperature and thus the most extensive modification of the gluten matrix. The decrease in dough extensibility was much lower than that observed with doughs with constant water content, and it was only significant for flours B and D. In this analysis we observed that the decrease in dough strength became more noticeable with increasing intensity of the extrusion treatment, as the decrease in the length of the curve (extensibility) was not compensated by the increase in the height of the curve (tenacity). The increase in the P/L balance therefore also occurs when extruded flours are added, except in the case of flour E as a result of the decrease in tenacity.

Figure 2 shows the curves obtained by the rheofermentometer. It may be seen that the addition of extruded flours increases gas production (Figure 2a) during fermentation. This increase is more noticeable when using flours that have undergone a milder extrusion treatment, and leads to an increase in dough expansion. The doughs did not fall during the assay, except doughs prepared with flour E, which developed a small break at 2 hours (Figure 2b). The increase in gas production may be related to the higher proportion of damaged starch, which is more accessible to enzymatic hydrolysis and to the generation of sugars (Potus et al., 1994). It is noticeable that the flours with the most intense treatments reduced gas production compared to those with the mildest treatments, though it should be taken into account that high-temperature treatments also reduce enzyme activity and hence decrease starch hydrolysis. The lower resistance to excess fermentation observed in flour E may be related to the effect of the treatment on gluten quality due to protein denaturation, as it is known that gluten proteins affect gas retention (Gan et al., 1995). This finding coincides with what was observed on the alveograph curves. Furthermore, photomicrographs of the doughs (Figure 3) showed that whilst the control dough (3a) shows a close structure with large starch granules within a compact mass of small starch granules united by a protein matrix, the doughs prepared with flour E (3b) show an open and less compact structure, with a smaller number of starch granules, as the granules lose their structure during the extrusion process.

3.2 Bread properties

With regard to the bread characteristics, the quantity of extruded wheat flour added did not lead to significant differences in volume, specific volume or height/width ratio (Table 2). A lower weight after baking, indicating greater water loss was only observed in breads made with flour B. The differences observed in dough development during fermentation thus did not lead to noticeable differences in the final product, probably because dough expansion (due to gas expansion and the final phases of gas production by yeasts during baking) led to there being no change in the final volume. This result coincides with the findings reported by Miller et al. (2008) who studied the effect of adding different pregelatinized starch percentages (1-2%) to the formula. The addition of extruded flours may therefore be an alternative to the addition of pregelatinized starch. Nor were there any significant differences in firmness or chewiness. The absence of any difference in bread firmness has also been demonstrated in studies that correlated this parameter with bread volume (Axford et al., 1968; Gómez et al., 2008). The differences in the other textural parameters were minimal (Table 2). The highest cohesiveness and resilience values were observed in breads with flour B, indicating the best resistance to deformation and instantaneous elasticity. Higher springiness values were observed in breads made with flour E compared to control bread.

Finally, bread colour showed no clear trends (Table 3). With regard to crumb colour, only the bread prepared with flour E showed a lower b* value compared to control bread, whereas no significant differences were observed in the other breads or other parameters. In general, crumb colour is related to the flour colour, as the temperatures in the interior of the piece do not reach 100ºC. In contrast, this temperature is greatly exceeded in the crust and crust colour is therefore the result of a Maillard reaction and sugar caramelization due to the presence of reducing sugars and amino acids. Analysis of crust colour revealed that the crust of bread prepared with flour A was paler than the others, and that of bread prepared with flour E was significantly redder or more yellowish, probably due to the higher quantity of sugars and amino acids produced by the intense thermal treatment. Breads made with flours B and C also showed significantly higher b* values than the control bread.

4. Conclusion

The results obtained demonstrate that the addition of 5% extruded wheat flour allows the quantity of water in the formulation to be increased; the more intense the extrusion treatment, the greater the increase in the quantity of water that can be added. This will increase bread output. The doughs obtained show adequate behaviour during mixing, handling and fermentation, with no detriment to bread quality. In the future it would be advisable to establish the limits of bread output with the addition of increasing quantities of extruded flour and to determine if this effect is present in other kinds of bakery products.

5. Acknowledgements

This study was supported financially by Junta de Castilla y león (VA054A12-2), Spain. The authors are also grateful to Harinera Los Pisones for supplying the raw materials.

Bibliographic References

AACC, 2000. Approved Methods of the American Association of Cereal Chemists, Methods 44-15A (moisture), 08-01(ash), 46-08 (protein), 54-30 (alveographic analysis), 61-02.01 (Rapid Visco Analysis) (10th ed.). American Association of Cereal Chemists, St. Paul (MN)

Axford, D.W.E., Colwell, K.H., Cornford, S.J., Elton, G.A.H., 1968. Effect of loaf specific volume on rate and extent of staling in bread. Journal of the Science of Food and Agriculture 19, 95-101.

Camire, M.E., Camire, A., Krumhar, K., 1990. Chemical and nutritional changes in foods during extrusion. Critical Reviews in Food Science and Nutrition 29, 35-57.

Chiu, C., Solarek, D., 2009. Modification of starch. In: BeMiller, J., Whistler, R. (Eds.), Starch. Chemistry and Technology. Academic Press, New York, pp. 629-656.

Curic, D., Novotni, D., Bauman, I., Kricka, T., Dugum, J., 2009. Optimization of extrusion cooking of cornmeal as raw material for bakery products. Journal of Food Process Engineering 32, 294-317

Czuchajowska Z., Pomeranz Y., 1993. Gas formation and gas retention. I. The system and methodology. Cereal Foods World 38, 499-503.

Dexter, J.E., Preston, K.R., Martin, D.G., Gander, E.J., 1994. The effects of protein-content and starch damage on the physical dough properties and bread-making quality of canadian durum-wheat. Journal of Cereal Science 20, 139-151.

Doublier, J., Colonna, P., Mercier, C., 1986. Extrusion cooking and drum drying of wheat-starch. 2. Rheological characterization of starch pastes. Cereal Chemistry 63, 40-246.

Gaines, C.S., Reid, J.F., Vander Kant, C., Morris, C.F., 2006. Comparison of methods for gluten strength assessment. Cereal Chemistry 83, 284-286.

Gan, Z., Ellis, P.R., Schofield, J.D., 1995. Gas cell stabilization and gas retention in wheat bread dough. Journal of Cereal Science 21, 215-230.

Gill, S., Vasanthan, T., Ooraikul, B., Rossnagel, B., 2002. Wheat bread quality as influenced by the substitution of waxy and regular barley flours in their native and extruded forms. Journal of Cereal Science 36, 219-237.

Gómez, M., Oliete, B., Pando, V., Ronda, F., Caballero, P.A., 2008. Effect of fermentation conditions on bread staling kinetics. European Food Research and Technology 226, 1379-1387.

Gómez, M., Ronda, F., Caballero, P.A., Blanco, C.A., Rosell, C.M., 2007. Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. Food Hydrocolloids 21, 167-173.

Gómez, M., Ruiz-Paris, E., Oliete, B., 2011. Influence of Wheat Milling on Low-hydration Bread Quality Developed by Sheeting Rolls. Food Science and Technology International 17, 257-265.

Hagenimana, A., Ding, X., Fang, T., 2006. Evaluation of rice flour modified by extrusion cooking. Journal of Cereal Science 43, 38-46.

Janssen, A.M., vanVliet, T., Vereijken, J.M., 1996. Fundamental and empirical rheological behaviour of wheat flour doughs and comparison with bread making performance. Journal of Cereal Science 23, 43-54.

Konopka, I., Fornal, L., Abramczyk, D., Rothkaehl, J., Rotkiewicz D., 2004. Statistical evaluation of different technological and rheological tests of Polish wheat varieties for bread volume prediction. International Journal of Food Science and Technology 39, 11-20.

Li, M., Lee, T., 1996. Effect of extrusion temperature on solubility and molecular weight distribution of wheat flour proteins. Journal of Agricultural and Food Chemistry 44, 763-768.

Mercier, C., Feillet, P., 1975. Modification of carbohydrate components by extrusion-cooking of cereal products. Cereal Chemistry 63, 283-297.

Miller, R. A., Maningat, C.C., Hoseney, R.C., 2008. Modified Wheat Starches Increase Bread Yield. Cereal Chemistry, 85, 713-715.

Miyazaki, M., Morita, N., 2005. Effect of heat-moisture treated maize starch on the properties of dough and bread. Food Research International 38, 369-376.

Potus, J., Poiffait, A., Drapron, R., 1994. Influence of dough-making conditions on the concentration of individual sugars and their utilization during fermentation. Cereal Chemistry 71, 505-508.

Preston, K.R., Kilborn, R.H., Dexter, J E., 1987. Effects of starch damage and water-absorption on the alveograph properties of canadian hard red spring wheats. Canadian Institute of Food Science and Technology Journal 20, 75-80.

Puhr, D.P., D'Appolonia, B.L., 1992. Effect of baking absorption on bread yield, crumb moisture, and crumb water activity. Cereal Chemistry 69, 582-586.

Rosell, C.M., Rojas, J.A., de Barber, C.B., 2001. Influence of hydrocolloids on dough rheology and bread quality. Food Hydrocolloids 15, 75-81.

Sanchez, H.D., Gonzalez, R.J., Osella, C.A., Torres, R.L., de la Torre, M.A.G., 2008. Elaboration of bread without gluten from extruded rice flours. Ciencia y Tecnología Alimentaria 6, 109-116.

Singh, H., MacRitchie, F., 2004. Changes in proteins induced by heating gluten dispersions at high temperature. Journal of Cereal Science 39, 297-301.

Sloan, E. (2011). Food Expo Highlights Clean Labels & Functional Foods. Food Technology, 65, 48-51.

Wolf, B., 2010. Polysaccharide functionality through extrusion processing. Current Opinion in Colloid & Interface Science 15, 50-54.

Zhu J., Khan K., 2001. Effects of genotype and environment on glutenin polymers and breadmaking quality. Cereal Chemistry 78, 125-130.

361

Table 1. DoughLab and alveographic properties of dough after the addition of extruded flours

Flour	Absorption (%)	Development time (s)	Stability (s)	P (mm H_2O)		L (mm H_2O)		W ($Jx10^4$)		P/L	
				Constant	Adapted	Constant	Adapted	Constant	Adapted	Constant	Adapted
Control	52.7a	98a	414b	43a	104bc	93b	54c	140a	214c	0.46a	1.93a
A	53.5b	97a	400b	51ab	111c	70a	46bc	133a	204c	0.74ab	2.42bc
B	53.7b	92a	348ab	50ab	104bc	62a	40ab	117a	171b	0.83ab	2.6c
C	54.8c	101a	273a	61c	96b	58a	46bc	130a	174b	1.06b	2.13ab
D	55.3c	100a	200a	61c	100bc	58a	38a	133a	159a	1.08b	2.67c
E	56.4d	98a	281a	53bc	79a	69a	48bc	132a	152a	0.78ab	1.65a

Control: wheat flour 14.48% moisture, 0.58% ash, 11.78% protein; Flour A: extruded with 60ºC maximum extruder temperature and 4% water; Flours B, C and D: extruded with 110ºC maximum extruder temperature and 4%, 10% and 16% water respectively.

Extruded flours were added at 5g/100g flour.

Values are means of two replicates

Different letters in the same parameter indicate significant differences ($P<0.05$)

P: tenacity or maximum overpressure in the alveograph; L: extensibility or abscissa at rupture in the alveogram; W: strength or deformation energy of dough; P/L: balance or curve configuration ratio

Table 2: Bread properties and texture after the addition of extruded flours

Flour	Volume (cm^3)	Weight (g)	Specific volume (cm^3/g)	Height/Width	Firmness (N)	Cohesiveness	Springiness	Resilience	Chewiness (N)
Control	386a	128b	3.02a	0.66a	15.86a	0.47a	0.83a	0.19a	6.25a
A	388a	127b	3.06a	0.67a	15.56a	0.48a	0.84a	0.21a	6.25a
B	404a	122a	3.31a	0.72a	14.51a	0.53b	0.86ab	0.28b	6.75a
C	390a	128b	3.06a	0.77a	13.71a	0.50ab	0.88ab	0.23ab	6.01a
D	397a	126b	3.14a	0.67a	14.71a	0.48a	0.86ab	0.22a	6.13a
E	422a	126b	3.36a	0.73a	13.96a	0.49a	0.91b	0.25ab	6.13a

Control: wheat flour 14.48% moisture, 0.58% ash, 11.78% protein; Flour A: extruded with 60ºC maximum extruder temperature and 4% water; Flours B, C and D: extruded with 110ºC maximum extruder temperature and 4%, 10% and 16% water respectively.

Extruded flours were added at 5g/100g flour.

Values of bread properties are means of four replicates (2 breads x 2 elaborations) and values of texture are means of 8 replicates (2 slices x 2 breads x 2 elaborations)

Different letters in the same parameter indicate significant differences ($P<0.05$)

Table 3: Crust and crumb colour characteristics of bread after the addition of extruded flours

	Crust			**Crumb**		
Flour	L*	a*	b*	L*	a*	b*
Control	69.69ab	3.20a	15.05a	76.86a	0.93a	15.90b
A	76.60c	3.29a	23.67ab	73.61a	0.96a	15.61ab
B	72.64bc	7.22ab	26.63b	74.67a	0.59a	15.54ab
C	74.54bc	5.54a	26.91b	74.19a	0.62a	16.25b
D	69.71ab	5.31a	23.59ab	75.41a	0.59a	16.19b
E	65.58a	11.20b	29.49b	73.55a	0.73a	13.58a

Control: wheat flour 14.48% moisture, 0.58% ash, 11.78% protein; Flour A: extruded with 60ºC maximum extruder temperature and 4% water; Flours B, C and D: extruded with 110ºC maximum extruder temperature and 4%, 10% and 16% water respectively.

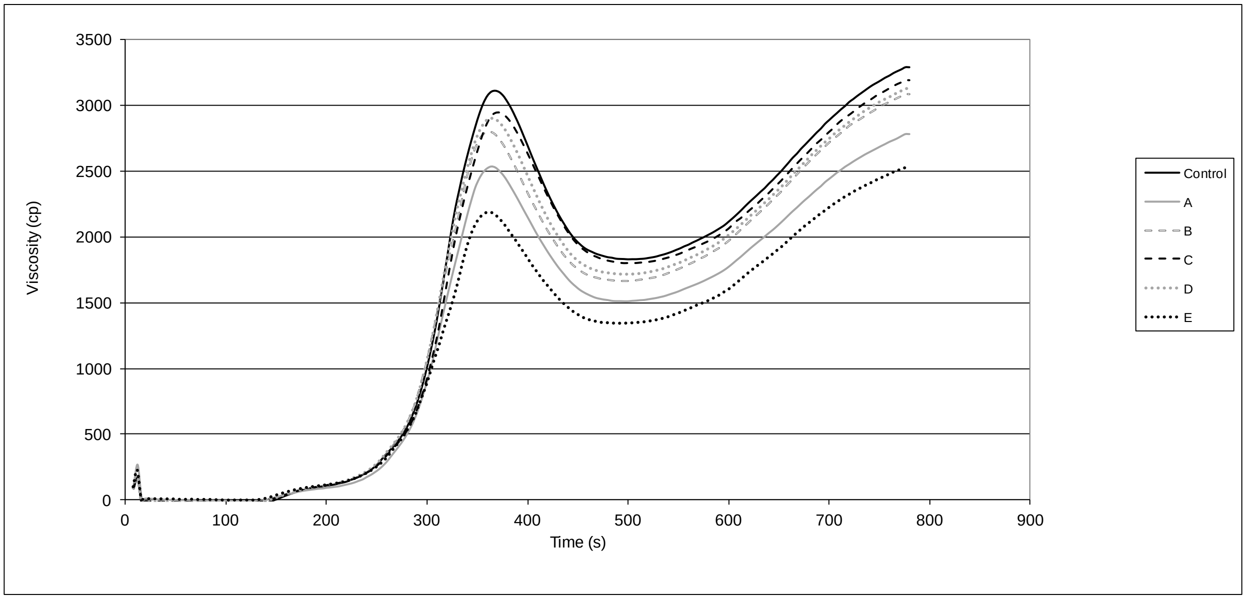
Extruded flours were added at 5g/100g flour.

Values are means of 80 replicates (4 places x 5 times x 2 breads x 2 elaborations)

Different letters in the same parameter indicate significant differences ($P<0.05$)

L*: luminosity. a*: red index. b*: yellow index.

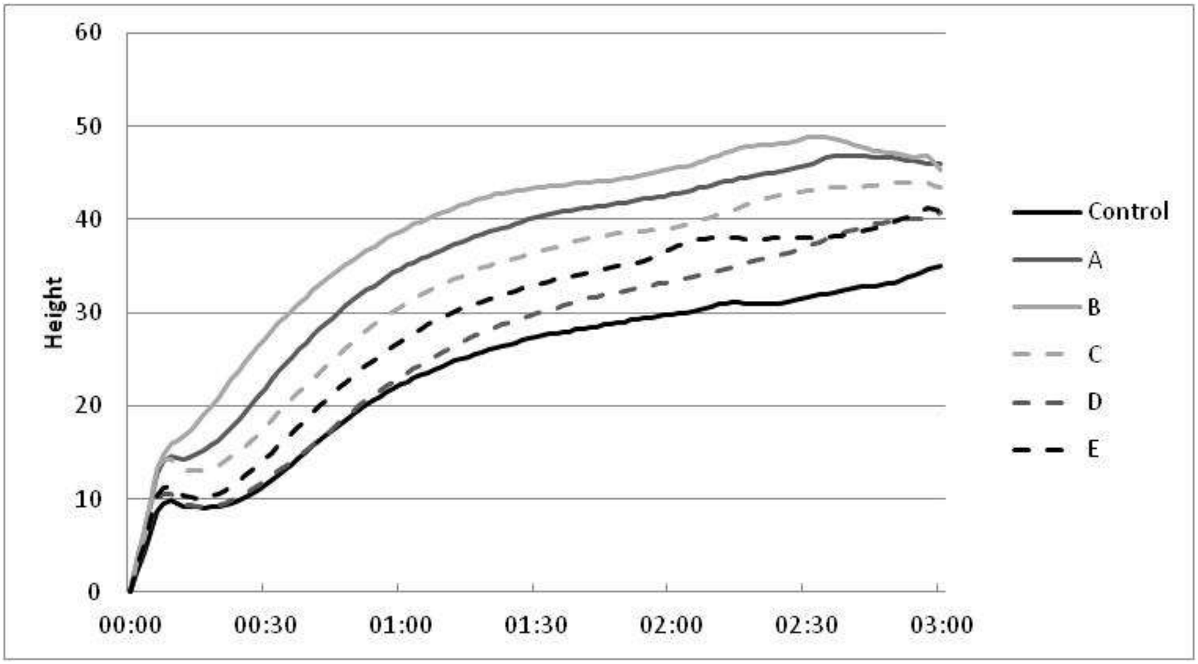
Figure 1: Pasting properties curves of wheat flour, after the addition of extruded flours, measured using a Rapid Visco Analyzer.



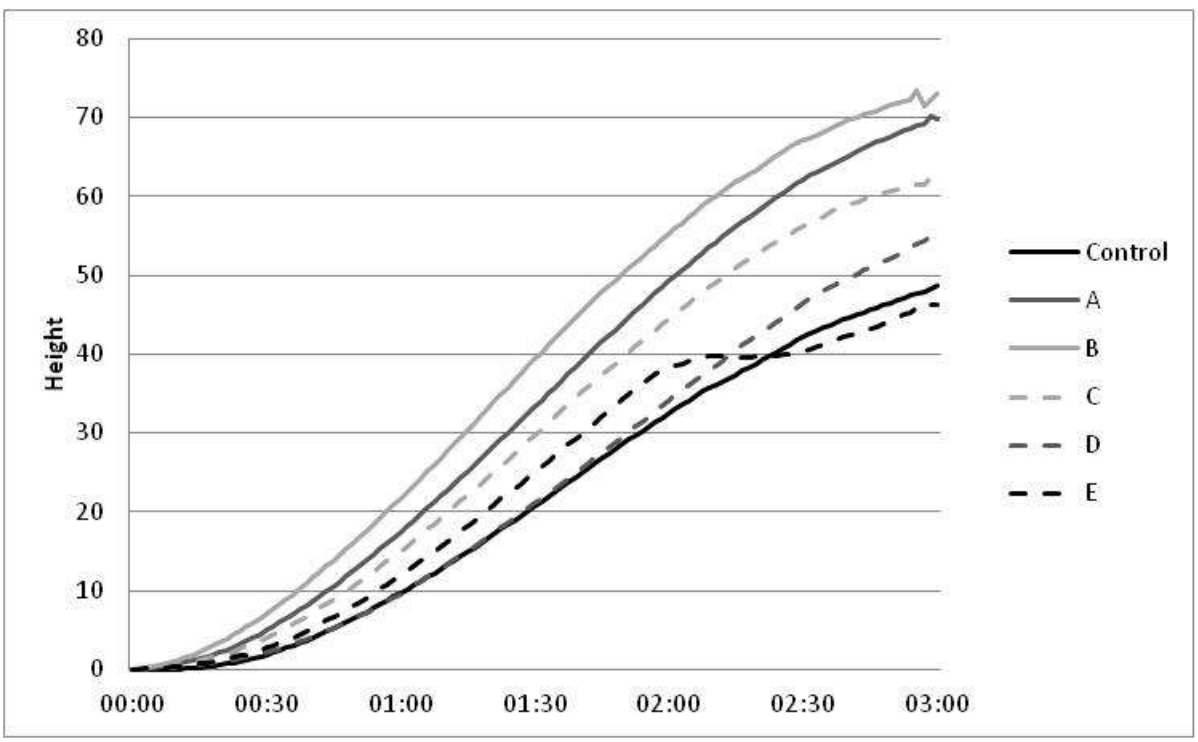
Control: wheat flour 14.48% moisture, 0.58% ash, 11.78% protein; Flour A: extruded with 60ºC maximum extruder temperature and 4% water; Flours B, C and D: extruded with 110ºC maximum extruder temperature and 4%, 10% and 16% water respectively. Extruded flours were added at 5g/100g flour.

Figure 2: Rheofermentograph properties of dough after the addition of extruded flours

a) Gas production



b) Dough development

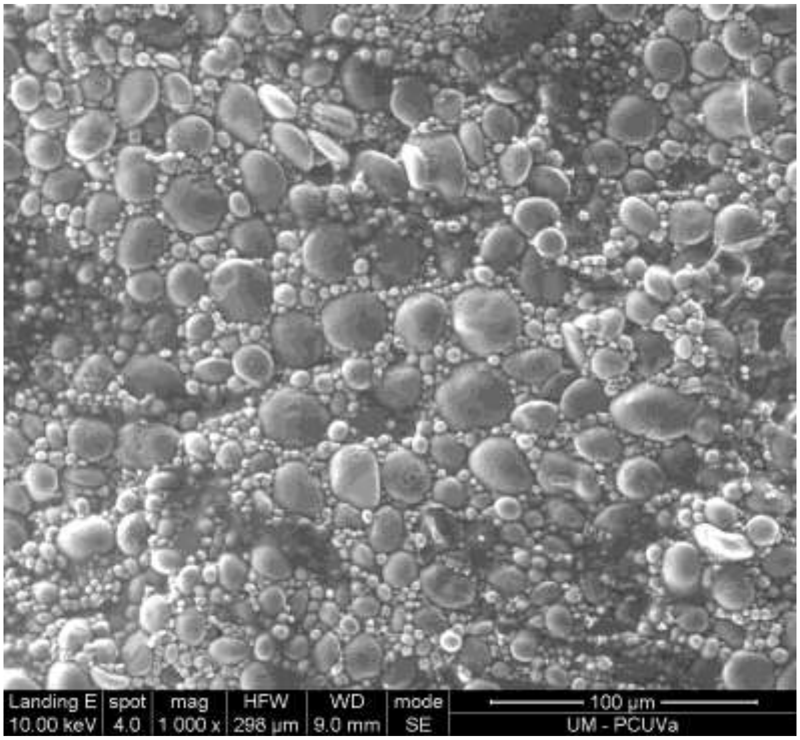


Control: wheat flour 14.48% moisture, 0.58% ash, 11.78% protein; Flour A: extruded with 60ºC maximum extruder temperature and 4% water; Flours B, C and D: extruded with 110ºC maximum extruder temperature and 4%, 10% and 16% water respectively. Extruded flours were added at 5g/100g flour.

The mean results from two replicates of each type of dough were used to define the graph.

Figure 3: Photomicrographs of doughs.

a) Control



b) 5g/100g of extruded flour E (110ºC maximum extruder temperature and 16%water) dough.