Influence of the addition of extruded flours on rice bread quality

Mario M. Martínez, Bonastre Oliete, Laura Román, Manuel Gómez*

Food Technology Area, E.T.S. Ingenierías Agrarias. Valladolid University, Ed. La Yutera, Avd. Madrid 44, 34004 Palencia, Spain.

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

Abstract

The extrusion may improve coeliac bread quality by modifying the functional properties of flour. This study investigates the influence of the substitution of 10% of rice flour by extruded rice flours (three intensities of treatment and two particle sizes) on the characteristics of gluten-free bread (specific volume and texture) at constant consistency. The microstructure and rheology of the doughs obtained and their behaviour during fermentation have also been analysed. The extruded flours increase dough consistency, and the effect is more noticeable with increasing intensities of treatment. The use of extruded flours requires the addition of a larger volume of water to obtain a constant consistency. The addition of extruded flour decreases dough development, producing a lower specific volume and greater bread hardness. This effect is minimized by increasing the particle size. The staling of bread from 24 to 72 hours is less noticeable with a larger particle size.

PRACTICAL APPLICATIONS

This study evidences that the use of extruded flours in rice bread making allows increasing dough hydration and therefore the bread yield while decreasing bread staling. However, the correct selection of extrusion treatment and flour particle size is essential to achieve appropriate results, being preferable the use of coarse flours with more intense extrusion treatment.

Keywords: extrusion, gluten-free bread, particle size, microstructure

1. Introduction

Gluten-free breads are characterized by their deficient quality and high price compared with traditional breads. This has led to increased interest in developing high quality gluten-free products in recent years (Cureton & Fasano, 2009), with the consequent increase in the volume of research and the number of scientific publications on this subject.

Most research studies into the development of gluten-free products have focussed on the substitution of wheat flours by mixtures of gluten-free cereals, starches, proteins and hydrocolloids (Schober, 2009), and on the enzymatic improvement of these formulations (Rosell, 2009). However, less information is available on the use of physical treatments to modify the functional properties of flours used in gluten-free products, and these methods have been less widely employed. Hydrothermal treatments stand out as being among the most effective physical treatments.

If starch, the major component of flour, is subjected to a high-temperature treatment with enough moisture it can be gelatinized, increasing the swelling capacity of the granule, decreasing crystallinity and sometimes causing break-up of the granules (Atwell et al., 1988). Hoover & Vasanthan (1994) also demonstrated that starch undergoing thermal treatment at 100ºC presents a high gelatinization temperature and high resistance to acid hydrolysis due to realignment of the starch chains, although these changes varied depending on the kind of starch used.

Pregelatinized rice flour has been widely used as the principal ingredient in many kinds of foods (rice cakes, infant foods, instant rice pudding) due to its thickener properties. It is known that uses of pregelatinized rice flour are determined by its physicochemical and functional properties, which differ depending on the variety of rice and the processing method employed (Hsieh &

Luh, 1991; Lu, et al., 1994). These hydrothermal treatments may be performed in various ways, such as drying a paste by atomization or heated drums; but one of the most versatile alternatives is extrusion. Extrusion is a treatment which applies heat and mechanical strain to a flour-water mixture. The main interest of the extrusion of flours and starches is to modify their functional properties, which will vary according to the extrusion conditions applied (Curic, et al., 2009).

When flours are extruded, changes take place in starch which modify the rheological behaviour of dough, similar to the changes that occur when dough is subjected to cooling-heating cycles (Hagenimana et al., 2006). However, extrusion causes more intense changes to the starch than traditional cooking methods, as it damages a larger number of starch granules and modifies the cold thickening capacity (Wolf, 2010). This treatment may even rupture amylopectin molecules (Mercier & Feillet, 1975). Colonna et al. (1984) demonstrated that extruded wheat starches contain amylose and amylopectin chains with a lower molecular weight than those obtained by treatment in heated drums. This effect, due to the shear force applied to the starch, is translated into an increase in the solubility and a decrease in the cold thickening capacity (Doublier, et al., 1986).

These functional modifications of flour after extrusion could also lead to changes in the baking properties. However, this has not been extensively researched in gluten-free breads.

Defloor et al. (1991) found that a mixture of extruded starches and emulsifying agents improved the quality of breads prepared with a mixture of tapioca and soya and a high level of hydration (145%).

Sanchez, et al. (2008) observed that the addition of extruded rice flour improved bread volume and crumb structure, but this effect was more noticeable when the waxy varieties of rice were used. However those authors used high percentages of extruded flour (15% and 30%) and modified the quantity of water in the formula according to the penetrometer dough consistency values; those variations led to an increase in dough hydration by more than 30% in the majority of cases. It is also important to note that those authors used over 80% starch in the formula.

The effect of the substitution of 10% of the rice flour by extruded non-acidified and acidified rice flour has also been tested (Clerici & El-Dash, 2006) (Clerici, et al., 2009). However, those authors did not use hydrocolloids in their bread-making process and the specific volume of their breads was excessively low in all cases.

In summary, some studies do exist on the use of extruded flours in gluten-free breads, but research needs to be extended to include formulae with the addition of hydrocolloids, with hydration percentages below 90%, and with rice flour as the main ingredient.

The particle size of the rice flour is also known to have an effect on gluten-free bread-making (Araki, et al., 2009; Nishita & Bean, 1982; Ylimaki, et al., 1988), but there have been no studies to determine the effect of the particle size of extruded rice flour on the functional characteristics of gluten-free breads.

In this study of constant consistency gluten-free bread making we have determined the effect of substituting 10% of non-extruded rice flour by extruded rice flour produced using three different extrusion intensities and with two different particle sizes. We analysed the viscous behaviour of flours in a heating-cooling cycle, dough rheology, dough development and gas production during fermentation, the differences in the microstructure of the flours and doughs, and the texture properties and specific volume of the breads.

2. Materials and methods

2.1 Materials

The rice flour used in this study was provided by Harinera Los Pisones (Zamora, Spain). Rice flour was extruded using an industrial Buhler Basf single-screw extruder (Buhler S.A., Uzwil, Switzerland). Three kinds of flour were used. Flour 1 was extruded with the addition of 2% moisture with a maximum temperature at the end of the extruder of 110ºC. Flour 2 was extruded with the addition of 15% moisture and a maximum temperature of 110ºC. For flour 3, 10% moisture was added and the maximum temperature in the extruder was 140ºC. The resulting products were ground by compression rollers and sieved to obtain flours with two different particle sizes, fine and coarse. Fine flours (f) were obtained by sieving through a 132 micron screen, and coarse flours (c) were retained between a 132 micron sieve and a 200 micron sieve. Depending on the thermal treatment and the particle size, extruded rice flours were referred to by a number (1, 2, 3) and a letter (f, c). Non-extruded rice flour was use as the control. Due to the fact that the chemical composition of coarse and fine flour could be changed by shieving the flour into fractions, chemical composition is attached (table 1).

Saf-Instant yeast (Lesaffre, Lille, France), dry refined salt (Esco European Salt Company, Niedersachsen, Germany), local tap water, white sugar (Acor, Valladolid, Spain), refined sunflower oil (Coosur, Vilches, Spain) and hydroxypropylmethylcellulose (HPMC) Methocel K4M Food grade (Dow Wolf Celullosics, Bitterfeld, Germany) were also used in the bread-making.

2.2 Methods

2.2.1. Flour characterisation

The viscous behaviour of flours during the heating-cooling cycle was measured with the Rapid Visco Analizer (RVA) (Newport Scientific, Warriewood, Australia), following AACC method 61.02.01 (AACC, 2012). The microstructure of the flours was analysed with an environmental scanning electron microscope (ESEM) (FEI, Quanta 200FEG, Oregon, USA) with integrated x-ray microanalysis using an EDAX Genesis XM2i, which enables wet samples to be analysed at ambient pressure without superficial metallization.

2.2.2. Dough rheology, gas production and dough microstructure.

The rheological behaviour of dough at constant moisture was studied using a Thermo Scientific Haake RheoStress1 controlled strain rheometer (Thermo Fisher Scientific, Schwerte, Germany) and a Phoenix II P1-C25P water bath which controlled the analysis temperature (set at 25ºC). The rheometer was equipped with parallel-plate geometry (60 mm diameter titanium serrated plate-PP60 Ti) with 3 mm gap. After adjustment of the 3 mm gap, the excess batter was removed and vaseline oil (Panreac, Panreac Química SA, Castellar del Vallés, Spain) was applied to cover the exposed sample surfaces. Dough was rested for 300 seconds before measuring. Samples were analysed in duplicate and without yeast. First, a strain sweep test was performed at 25ºC with a strain range of 0.1 - 100 Pa and a constant frequency of 1Hz to identify the linear viscoelastic region. On the basis of the results obtained, a strain value included into the linear viscoelastic region was used in a frequency sweep test at 25ºC with a frequency range of 100-0.1Hz. Values of the complex modulus (G*[Pa]), elastic modulus (G'[Pa]), viscous modulus (G''[Pa]) and tangent δ (G''/G') were obtained for different frequency values (ω [Hz]) (Dobraszczyk & Morgenstern, 2003).

A rheofermentometer (Chopin, Tripette and Renaud, France) was used to analyse dough height, gas production and gas liberation related to the fermentation time following the method described by Czuchajowska & Pomeranz, (1993). However, the authors adapted the method for gluten-free dough. Only 200g of dough were placed into the rheofermentometer container, the 2 kg weight indicated by the method was removed, 3% yeast was added to the formula, and fermentation in the rheofermentometer was performed at 30ºC.

Dough microstructure was studied with an ESEM microscope (FEI, Quanta 200FEG, Oregon, USA). The doughs did not contain yeast to avoid alterations in image visualization.

2.2.3. Bread making

The following ingredients (g/100g flour) were used in the bread making: Saf-Instant yeast (3g/100g), salt (1.8g/100g), refined sunflower oil (6g/100g), HPMC (2g/100g) and white sugar (5g/100g). The quantity of water in the doughs made with extruded flour was regulated in each sample to obtain a G* value equal to the G* value of the control dough.

The water temperature in all the tests was between 20ºC and 22ºC. Rice flour was substituted by extruded rice flour at a rate of 10g/100g. Control breads containing no extruded rice flour were also prepared. After mixing all the ingredients for 8 minutes in a Kitchen Aid 5KPM50 mixer (Kitchen Aid, Michigan, USA), 250 g of the bread dough were placed in model 151090 aluminium pans measuring 108 mm by 232 mm (ALU-Schale, Wiklarn, Germany). Fermentation was performed at 30ºC and 75% RH for 90 minutes in an FC-K proofer (Salva, Lezo, Spain). After fermentation, doughs were baked in an electric modular oven (Salva, Lezo, Spain) for 40 minutes at 190ºC. The loaves were removed from the moulds after a 60-minute cooling period and were weighted. The measurements on the breads were performed 24 hours after baking, except for the texture parameters which were measured at 1, 24 and 72 hours after baking. The loaves were introduced into polyethylene plastic bags and stored at 20ºC until analysis. All the elaborations were performed twice.

2.2.4. Bread characteristics

Bread volume was determined using a laser sensor with the BVM-L 370 volume analyser (Perten Instruments, Hägersten, Sweden). The volume measurements were performed in duplicate on two loaves from each elaboration. The specific volume was calculated as the ratio of bread volume to its mass.

Crumb texture was measured with a TA-XT2 texture analyzer (Stable Microsystems, Surrey, UK) fitted with the *"Texture Expert"* software. A 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. Hardness (N), cohesiveness and springiness were calculated from the TPA graph (Gómez et al., 2007). Texture analyses were performed on 30 mm thick slices at 1, 24 and 72 hours after baking. Analyses were performed on two slices from two loaves (2x2) from each type of elaboration, taking the average of the 4 measurements made.

2.2.5. Statistical analysis

All data were presented as mean values and analysed using an analysis of unidirectional parametric variance (ANOVA) using Fisher's least significant difference (LSD) ($p<0.05$). The analyses were performed using the Statgraphics Centurion XVI statistical package (StatPoint Technologies Inc, Warrenton, USA). Additionally, in order to plot the hardness values over time, an analysis of variance was also performed taking into account time as a factor for repeated measures using Fisher's least significant difference ($p<0.05$). The Statistica 6 software (Statsoft Inc, Tulsa, USA) was used for this analysis.

3. Results and Discussion

3.1. Electron microscopy of flours

Figure 1 shows the microstructure of the flours used in this study. It may be observed that the particles of non-extruded rice flour (a) was formed by compound starch granules connected by a compact protein structure. In contrast, in the extruded rice flour with the most intense treatment (d), the starch granules lose their integrity and a paste is formed in which the different components cannot be distinguished in the resultant particles. In the extruded flours with low-intensity hydrothermal treatment, intermediate structures are observed. Whilst swollen starch granules, which represent a phase prior to gelatinization, are observed in flour 1 (b), fusion of the different components is observed in flour 2 (c).

Our observations coincide with those reported by Yeh et al. (1999) and by Chao-Chi Chuang & Yeh (2003), who studied the morphological changes of rice starch during heating extrusion. Yeh et al. (1999) showed that non-extruded rice flour had a powder-like appearance and that starch granules swelled as they advanced through the cold zone of the extruder but without losing the powder-like appearance. When the rice flour reached the heating zone of the extruder, the starch granules started to melt and formed a continuous matrix. However, those authors obtained their samples from intermediate zones of the extruder and without milling. Our samples were obtained at the end of the extrusion treatment after drying, milling and sieving. Chao-Chi Chuang & Yeh (2003) showed that starch gelatinization increased with increases in the temperature and duration of treatment.

3.2. Viscous behaviour of flours during a heating-cooling cycle.

The RVA parameters for non-extruded rice flour and for 10% substituted extruded flours are shown in Table 2. It can be seen that the more intense the extrusion treatment, the lower the values of pasting viscosity (PV), breakdown (BR), trough (TR), setback (ST) and final viscosity (FV). No significant differences were observed in relation to particle size. Dough viscosity decreased throughout the heating-cooling cycle as the treatment intensity increased. However, no significant differences were observed between the milder treatments (1 and 2). It is known that changes in the physicochemical properties of starch during extrusion develop as a result of morphological changes of the starch granules and the degree of gelatinization (Camire et al., 1990; Yeh & Li, 1996). It is also known that dough viscosity depends mainly on the degree of gelatinization of the starch granules and the degree of rupture of the molecular chains (El-Dash et al., 1983). Previous studies related high PV values to a high quantity of non-gelatinized starch, whereas low PV values indicated a proportion of gelatinized starch which is attributable to the variation in the degree of depolymerization and the molecular tangle resulting from the processing conditions (Barres et al., 1990; McPherson et al., 2000). The decrease in PV, BR and TR observed when the intensity of treatment increased, previously observed by Hagenimana et al. (2006), could indicate degradation and gelatinization of the starch. High values of these parameters in the non-extruded rice flour would be related to the presence of non-gelatinized starch. These modifications in the starches and in the flour particles have been studied on the photomicrographs, and the flours undergoing the most intense treatment (flours 3) contained the highest quantity of gelatinized starch.

The fall in FV and ST values in the extruded flours has already been observed by Doublier et al. (1986) and by Mercier & Feillet (1975). These values indicate the degree of retrogradation that occurrs after heating. When the hot gels are cooled, the increase of viscosity depends on the tendency of starch to reassociate. The extruded rice flours that had undergone the milder treatments showed higher FV values than the same flours extruded with more intense treatments. Although it seems that starch gelatinization is the main factor responsible for changes in the RVA curve, other authors have also observed modifications in the amylose/amylopectin ratio during the extrusion treatments of corn flour (Chinnaswamy & Hannah, 1990) and wheat flour (Colonna et al., 1984). Those authors state that fragmentation of amylose and amylopectin chains takes place during extrusion, and that this is more intense in the amylopectin chains; this will therefore modify the behaviour of the flours during the heating-cooling cycle.

3.3. Dough rheology and gas production

3.3.1. Dynamic rheology of dough.

Figures 2 and 3 show the rheological properties of gluten-free doughs at constant moisture. There was a clear tendency to an increase in G’, G’’ and G*, and a decrease in tag δ when extruded rice flours were added to the formula. The most marked effect was observed after the addition of flours 2 and 3; flour 2 was associated with the highest G’ and G* values and the lowest tag δ values. Particle size, on the other hand, produced no clear differences. Thus, when increasing the intensity of the extrusion process, doughs became more consistent and elastic, and this effect was most noticeable with flour 2. G’ values were higher than G’’ values in all cases and over the whole frequency range, which indicated behaviour to be more elastic than viscous.

Chao-Chi-Chuang & Yeh (2002), studying the extrusion process, and Kim et al. (2009), using the steam cooking method, observed that the moisture content in hydrothermal treatments was the key to the variation in G', G'' and tag δ values. In particular, Chao-Chi-Chuang & Yeh (2002) detected higher G' and G'' values in the treatments with lower moisture; our observations did not coincide with their findings, though it should be recognized that those authors subjected the flours to higher moisture contents (45%-55%) than were employed in our study, with lower extrusion temperatures (20ºC-100ºC) and they used waxy varieties of rice. However, those authors did observe that an increase in the mechanical energy applied during extrusion produced an increase in G' and G'' values and a fall in tan δ values. It is already known that an increase in the consumption of mechanical energy usually leads to extruded samples with a higher degree of cooking (González et al., 2000). In our case, the flours with lower viscosity values in the RVA curves, and thus a higher degree of cooking, were those that obtained the highest G',G'' and G* values.

These changes in rheology may be related to changes in the starch during the extrusion treatment, as Shim & Mulvaney (1999) found that the balance between the intact starch granules and gelatinized or damaged ones affected G' values. It has already been shown that extruded flours contain a higher quantity of pregelatinized starch than non-extruded flours and, according to Slade & Levine (1994), this greater degree of gelatinization increases the water absorption capacity of doughs. These rheological changes may also be related to the internal structure of the dough, which may be seen in Figure 4. In the two doughs studied (control dough and dough with flour 3c), the structure is composed of large flour particles covered by small simple starch granules, compacted by a matrix formed of water, hydrocolloids and dissolved substances. However, in the case of dough with flour 3c, there was a smaller quantity of simple starch granules, which is consistent with what was observed in the microstructure of the extruded flours (the starch granules had lost their integrity). The starch granules observed correspond to starch granules from the non-extruded flour. It could therefore be thought that extruded flour is mixed with the network formed by water and hydrocolloids, and this will modify the viscoelastic properties of dough.

Additionally, an increase in the quantity of damaged starch granules was observed in the flour 3c sample compared with the control, as can be seen in Figures 1 and 4 (starch granules with small holes and breaks) and in table 1.

The amount of water needed in bread-making at constant consistency (G*=15500±1550) is shown in Table 3. The addition of extruded flours increased the quantity of water required to obtain doughs with constant consistency, and thus they can increase the bread yield. This increase was greater in doughs prepared with flours 2 and 3 (the more intense extrusion treatments) than doughs prepared with flour 1. This finding may be explained by a higher degree of damage caused to the starch granules and to the greater degree of gelatinization in the extrusion process with more intense processing conditions (temperature and moisture) (Mercier and Feillet, 1975). However no clear difference was observed between the doughs made with flours 2 and 3 or with flours with different particle sizes.

3.3.2. Dough height and gas production.

The curves of dough height during fermentation at constant consistency are shown in Figure 5. Regarding gas production, no significant differences were seen in any case (data not shown). Greater height was observed in doughs made with non-extruded flours than in doughs with extruded flours, but the differences only became evident after a certain duration of fermentation (around minute 90). The poor dough height over the whole fermentation process when using flour 1f, was noticeable. The differences between the other extruded flours were minimal but doughs made with flour 3 were somewhat more stable if over-fermentation occurred. Greatest height was obtained in doughs made with flours 1c and 2c, although over-fermentation had a negative effect in both cases. Doughs with flour 3 showed a higher stability than the other doughs, and higher G' and G* values and lower tan δ values; they are thus more consistent and elastic doughs. This could be related to starch gelatinization and damage during the extrusion treatment (Shim & Mulvaney, 1999), as these changes increase the water absorption capacity of dough, as indicated previously (Slade & Levine, 1994).

Changes in the dough height during fermentation can be also related to the internal structure of the dough (Figure 4). The dough prepared with flour 3c, which was the dough with the highest stability in the case of excess fermentation, had the lowest quantity of simple starch granules. This is consistent with the results observed in the microstructure of extruded flours, which showed a loss of integrity of the starch granules. It can therefore be assumed that extruded flours form a mixture with the network produced by the water and hydrocolloid, modifying dough height during fermentation.

3.4. Bread properties

3.4.1. Specific volume and weight lost

Table 3 shows the specific volume of breads made at constant consistency. A decrease in the specific volume was observed when extruded flours were added to the formula, except after the addition of flour 1c, which produced a specific volume equal to that of the control. Only the breads prepared with flours 1c and 2c stood out, showing higher specific volumes than the other extruded flours.

No differences in weight loss were observed in the doughs during baking (data not shown).

In previous studies it has been found that both acidified (Clerici et al., 2009) and non-acidified (Clerici and El-Dash, 2006) extruded rice flours could improve the specific volume of gluten-free breads, depending on the extrusion conditions. However, those authors did not use hydrocolloids in the formula, and the specific volume values obtained were much lower than in our case. This result could indicate some kind of interaction between the hydrocolloids and the extruded flours or their components. Sanchez et al. (2008) made bread with extruded waxy rice flours and also observed an increase in the specific volume of breads when using the extruded flours with the highest intensity extrusion treatments. It is important to note the difference in the moisture values between the bread obtained by those authors as they prepared bread at constant consistency using a penetrometer. In contrast to our study, those authors used a high percentage of starch in the formula and considered that the increase in volume was related to the increase in the quantity of soluble solids, as those components increased the consistency of the aqueous phase, improving the viscoelastic characteristics of doughs.

Defloor et al. (1991) also found that the addition of extruded starch improved the volume of breads prepared with a mixture of tapioca and soya flour. It is important to note that these authors used high levels of hydration (145%), and their doughs were therefore less consistent than ours. In their case, extruded starches increased the consistency of very soft doughs (in contrast to our study, in which we used more consistent doughs with lower hydration) and made it possible to increase bread volume.

Gallagher et al. (2003), on the other hand, observed that an increase in dough hydration increased bread volume. In our study we also found that the level of hydration could alter the effect of including certain components that increase dough consistency, such as extruded flours, and particularly extruded coarser flours, which have a high amount of damaged starch that could contribute greatly to increase dough hydration, as can be seen in table 1 and in figure 1 and 4.In excessively soft doughs, a certain increase in consistency could therefore be useful, though this can have a negative effect in more consistent doughs with lower hydration. Nevertheless, this factor alone cannot explain the changes observed, as breads with a constant consistency were also found to have a different specific volume.

3.4.2. Texture analysis

The texture parameters of bread at constant consistency are presented in Table 3.

A tendency to increased hardness was observed as the extrusion intensity of the flours increased. Higher hardness values were also found when using fine flours compared to coarse ones, although significant differences were only detected with loaves elaborated using flours 2.

No significant differences were found in the springiness or cohesiveness of loaves made with extruded flours compared to control loaves. As in our study, Clerici & El-Dash (2006) reported higher hardness values in breads made with extruded flours. Maleki et al. (1980) and Morad & Wakeil (1976) found that starch retrogradation was strongly influenced by the moisture content of the product. The reduction of starch retrogradation through increased moisture content would therefore produce softer breads. It is also known that bread hardness correlates with bread volume (Gómez et al., 2011), and thus the explanation of the differences in hardness could be related to differences in the specific volume.

The changes in hardness over time are shown in Figure 6. Loaves made with the control flour and with flours 1f and 2f showed the fastest rates of hardening. Loaves made with flours 1c and 2c showed the lowest hardness values and their hardening curves had a low gradient. Loaves made with flours 3 had the highest hardness values up to 24 hours, but the values subsequently remained almost constant or even fell, indicating a decrease in the rate of staling.

Changes in crumb properties associated with staling include an increase in starch crystallinity and crumb hardness and a decrease in aroma, soluble starch and crumb hydration capacity (D'Appolonia & Morad, 1981). Rogers et al. (1988) stated that the main cause of bread staling is starch retrogradation, which increases with increased moisture content of breads. As gluten-free breads have a high moisture content, starch retrogradation may progress faster during storage than in gluten breads. Extruded flours have a higher water-retention capacity than non-extruded flours and they could thus delay water migration from the crumb to the crust, decreasing the rate of staling. Furthermore, the extrusion process may even break the amylopectin chains (Mercier and Feillet, 1975) and Colonna et al. (1984) demonstrated that extruded wheat starches contain amylose and amylopectin chains with lower molecular weights than drum-dryer starches; this could be another factor that decreases retrogradation and the rate of staling of bread.

4. Conclusion

The use of extruded flours in the elaboration of gluten-free bread offers an interesting alternative approach to improve gluten-free breads. We found that the addition of extruded flours subjected to high intensity extrusion treatments produced doughs with a higher elastic modulus and consistency, and that it was necessary to add larger volumes of water to achieve constant consistency. The bakery yield is therefore increased. However, the development of doughs prepared with extruded flours was lower, but these doughs showed higher stability to over-fermentation. In general, the addition of extruded flours reduced the specific volume of breads and increased hardness, but these effects were minimized by using the coarse flour fractions, which also reduced the rate of staling. Future studies should look in detail at the effect of these extruded flours on the acceptability of breads and their influence in breads with higher levels of hydration.

Acknowledgements

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

References

AACC. 2012. Approved methods of the American Association of Cereal Chemists, method 61-02.01 (RVA) (11th ed.). St. Paul, Minnesota: American Association of Cereal Chemists.

ARAKI, E., IKEDA, T., ASHIDA, K., TAKATA, K., YAMAKA, M., and IIDA, S. 2009. Effects of rice flour properties on specific loaf volume of one-loaf bread made from rice flour with wheat vital gluten. Food Sci Technol, 15, 439-448.

ATWELL, W., HOOD, L., LINEBACK, D., VARRIANOMARSTON, E., and ZOBEL, H. 1988. The terminology and methodology associated and basic starch phenomena. Cereal Foods World, 33, 306-308, 310-311.

BARRES, C., VERGES, B., TAYEB, J., and DELLA VALLE, G. 1990. Transformation of wheat flour by extrusion cooking. Influence of screw configuration and operating conditions. Cereal Chem, 67, 427-433.

CAMIRE, M., CAMIRE, A., and KRUMHAR, K. 1990. Chemical and nutritional changes in foods during extrusion. Crit Rev Food Sci Nutr, 29, 35-57.

CHAO-CHI CHUANG, G., and YEH, A. 2003. Effect of screw profile on residence time distribution and starch gelatinization of rice flour during single screw extrusion cooking. J Food Eng, 63, 21-31.

CHAO-CHI-CHUANG, G., and YEH, A. 2002. Effects of product temperature and moisture content on viscoelastic properties of glutinous rice extrudate. Cereal Chem, 79, 36-40.

CHINNASWAMY, R., and HANNAH, M. 1990. Macromolecular and functional properties of native and extruded corn starch. Cereal Chem, 67, 490-499.

CLERICI, M., and EL-DASH, A. 2006. Extruder rice flour as a gluten substitute in the production of rice bread. Arch Latinoam Nutr, 56, 288-294.

CLERICI, M., ARIOLDI, C., and EL-DASH, A. 2009. Production of acidic extruder rice flour and its influence on the qualities of gluten free bread. Food Sci Technol, 42, 618-623.

COLONNA, P., DOUBLIER, J., MELCION, J., MONREDON, F., and MERCIER, C. 1984. Extrusion cooking and drum drying of wheat starch. I. Physical and macromolecular modifications. Cereal Chem, 61, 538-543.

CURETON, P., and FASANO, A. 2009. The increasing incidence of celiac disease and the range of gluten-free products in the marketplace . In Gluten-Free Food Science and Technology (E. Gallagher ed.) pp. 1-15. Dublin, Ireland: Wiley-Blackwell.

CURIC, D., NOVOTNI, D., BAUMAN, I., KRICKA, T., and DUGUM, J. 2009. Optimization of extrusion cooking of cornmeal as raw material for bakery products. J Food Process Eng, 32, 294-317.

CZUCHAJOWSKA, Z., and POMERANZ, Y. 1993. Gas-formation and gas retention 1. The system and methodology. Cereal Foods World, 38, 499-503.

D'APPOLONIA, L., and MORAD, M. 1981. Bread staling. Cereal Chem, 58, 186-190.

DEFLOOR, I., DE GEEST, C., SCHELLEKENS, M., MARTENS, A., and DELCOUR, J. 1991. Emulsifiers and/or extruded starch in the productions of breads from cassava. Cereal Chem, 68, 323-327.

DOBRASZCZYK, B., and MORGENSTERN, M. 2003. Rheology and the breadmaking process. J Cereal Sci, 38, 229-245.

DOUBLIER, J., COLONNA, P., and MERCIER, C. 1986. Extrusion cooking and drum drying of wheat-starch 2. Rheological characterization of starch pastes. Cereal Chem, 63, 240-246.

EL-DASH, A., GONZALES, R., and CIOL, M. 1983. Response surface methodology in the control of thermoplastic extrusion of starch. J Food Eng, 2, 129-152.

CURETON, P., and FASANO, A. 2009. The increasing incidence of celiac disease and the range of gluten-free products in the marketplace . In Gluten-Free Food Science and Technology (E. Gallagher ed.) pp. 1-15. Dublin, Ireland: Wiley-Blackwell.

GALLAGHER, E., GORMLEY, T., and ARENDT, E. 2003. Crust and crumb characteristics of gluten free breads. J Food Eng, 56, 153-161.

GÓMEZ, M., JIMÉNEZ, S., RUIZ, E., and OLIETE, B. 2011. Effect of extruded wheat bran on dough rheology and bread quality. Food Sci Technol, 44, 2231-2237.

GONZÁLEZ, R. J., TORRES, R. L., and AÑÓN, M. C. 2000. Comparison of rice and corn cooking characteristics. Polish J Food, 50, 29-54.

HAGENIMANA, A., DING, X., and FANG, T. 2006. Evaluation of rice flour modified by extrusion cooking. J Cereal Sci, 43, 38-46.

HOOVER, R., and VASANTHAN, T. 1994. Effect of heat-moisture treatment on the structure and physicochemical properties of cereal, legume and tuber starches. Carbohydr Res, 252, 33-53.

HSIEH, F., and LUH, B. 1991. Rice snack foods. In Rice volume II: Utilization (B. Luh ed.) pp. 225-249. Nueva York. EEUU: Van Nostrand Reinhold.

KIM, D., BAE, I., INGLETT, G., and LEE, S. 2009. Effect of hydrothermal treatment on the physicochemical, rheological and oil-resistant properties of rice flour. J Texture Stud, 40, 192-207.

LU, S., CHEN, C., and LII, C. 1994. Gel-chromatography fractionation and thermal characterization of rice starch affected by hydrothermal treatment. Cereal Chem, 73, 5-11.

MALEKI, M., HOSENEY, R., and MATTERN, P. 1980. Effects of loaf volume, moisture content, and protein quality on the softness and staling of bread. Cereal Chem, 57, 138-140.

MCPHERSON, A., BAILEY, T., and JANE, J. 2000. Extrusion of cross-linked hydroxypropylated corn starches I. Pasting properties. Cereal Chem, 77, 320-325.

MERCIER, C., and FEILLET, P. 1975. Modification of carbohydrate components by extrusion-cooking of cereal products. Cereal Chem, 63, 283-297.

MORAD, M., and WAKEIL, F. 1976. Effect of wheat starch, protein and moisture content on staling of bread. Getreide, Mehl und Brot, 30, 106-107.

NISHITA, K., and BEAN, M. 1982. Grinding methods: Their impact in rice flour properties. Cereal Chem, 59, 46-49.

ROGERS, D., ZELEZNAK, K., and LAI, C. H. 1988. Effect of native lipids, shortening and bread moisture on bread firming. Cereal Chem, 65, 398-401.

ROSELL, C. 2009. Enzymatic Manipulation of Gluten-Free Breads. In Gluten-Free Food Science and Technology (E. Gallagher ed.) pp. 83-98. Dublin, Ireland: Wiley-Blackwell.

SANCHEZ, H., GONZALEZ, R., OSELLA, C., TORRES, R., and DE LA TORRE, M. 2008. Elaboration of bread without gluten from extruded rice flour. Cienc Tecnol Aliment, 6, 109-116.

SCHOBER, T. 2009. Manufacture of gluten-free specialty breads and confectionery products. In Gluten-Free Food Science and Technology (E. Gallagher ed.) pp. 130-180. Dublin, Irlanda: Wiley-Blackwell.

SHIM, J., and MULVANEY, S. 1999. Effect of cooking temperature and stirring speed on rheological properties end microstructure of corn starch and oat flour gels. Cereal Foods World, 44, 349-356.

SLADE, L., and LEVINE, H. 1994. Structure-function relationships of cookie and cracker ingredients. In The Science of Cookie and Cracker Production (H. Faridi, ed.) pp. 23-241. Nueva York: Chapman and Hall.

WOLF, B. 2010. Polysaccharide functionality through extrusion processing. Curr Opin Colloid Interface Sci, 15, 50-54.

YEH, A., and LI, J. 1996. A continuous measurement of swelling of rice starch during heating. J Cereal Sci, 23, 277-283.

YEH, A., WU, T., and JAW, Y. 1999. Starch transitions and their influence on flow pattern during single-screw extrusion cooking of rice flour. Food Bioprod Process, 77, 47-54.

YLIMAKI, G., HAWARYSH, Z., HARDIN, R., and THOMSON, A. 1988. Application of response surface methodology to the development of rice flour yeast breads: objective measurements. J Food Sci, 53, 1800-1805.

Table 1: Chemical composition of different types of flour of non-extruded flour with 10% substituted extruded flour.

Flours	Damage Starch (%)	Protein (%)	Moisture (%)
Flour 3f	29,81±2.50	7,85±1.24	9,56±0.40
Flour 3c	36,57±0.28	8,42±1.50	10,23±0.65
Flour 2f	19,78±2.60	8,25±1.30	13,96±2.10
Flour 2c	30,29±4.22	8,11±1.11	14,04±1.74
Flour 1f	11,09±2.91	8,74±0.98	10,72±3.65
Flour 1c	10,88±1.64	8,04±1.01	11,2±2.64
Control	5,75±0.97	7,81±0.99	13,45±3.05

Table 2: Viscous behaviour in a heating-cooling cycle of non-extruded flour with 10% substituted extruded flour.

Flours	PV (cp)	BR (cp)	TR (cp)	ST (cp)	FV (cp)
Flour 3f	3793a±94	1296a±2	2496a±93	2510b±6	5006a±98
Flour 3c	3913a±46	1224a±182	2688ab±135	2306a±106	4994a±29
Flour 2f	4596b±64	1759bc±19	2837b±84	2773cd±17	5610b±67
Flour 2c	4571b±16	1690bc±160	2881b±176	2656bc±121	5537b±56
Flour 1f	4444b±77	1663b±35	2781ab±42	2777cd±26	5558b±16
Flour 1c	4682b±244	1706bc±11	2975bc±234	2706c±6	5681b±228
Control	5175c±142	1947c±192	3228c±49	2925d±62	6153c±12

Values with different letters in the same parameter are significantly different ($p<0.05$).

Data shown are the mean of two repetitions for each type of simple

PV = Pasting temperature; BR = Breakdown; TR = Trough; ST = Setback; FV = Final viscosity

Table 3: Specific volume, texture properties and percentage hydration of breads made at constant consistency.

Flour	Specific volume (m^3/kg)	Hardness (N)	Springiness	Cohesiveness	% Hydration
Flour 3f	2.807a±0.121	22.018e±1,155	0.689a±0,030	0.244a±0,001	76.67d±0,01
Flour 3c	2.813a±0.192	21.370e±0,588	0.738a±0,045	0.314a±0,102	74.55c±0,31
Flour 2f	2.987a±0.171	13.675d±0,583	0.706a±0,015	0.271a±0,005	74.86c±0,08
Flour 2c	3.637b±0.259	6.430c±1,649	0.635a±0,070	0.307a±0,061	78.92c±0,23
Flour 1f	3.041a±0.311	4.153b±0,181	0.615a±0,007	0.286a±0,003	72.98b±0,01
Flour 1c	4.597c±0.121	2.431b±0,378	0.590a±0,125	0.297a±0,013	73.36b±0,33
Control	4.802c±0.044	1.723a±0,693	0.656a±0,067	0.348a±0,018	70.00a±1,17

Values with different letters in the same parameter are significantly different ($p<0.05$).

Data shown are the means of two repetitions for each kind of simple

Figure captions:

Figure 1: Photomicrographs from the environmental scanning electron microscope (ESEM) (×2000) study of the control flour and flours extruded with different intensities of treatment (analysis made in triplicate with subsequent selection of the most representative photomicrographs). a) control flour (non-extruded), b) extruded flour 1f, c) extruded flour 2f, d) extruded flour 3f. 1) compound starch granule, 2) swollen starch granule, 3) gelatinized starch granules.

Figure 2: Mechanical spectrum of doughs. G' and G'' values according to oscillation frequency (ω) in fine flours (a) and coarse flours (b). G' values are represented by filled symbols and G'' values are represented by unfilled symbols. Control (diamond), flour 1 (square), flour 2 (triangle), flour 3 (circle).

Figure 3: Mechanical spectrum of dough. $\tan \delta$ (a) and G^* (b) according to oscillation frequency (ω). Extruded fine flours are represented by unfilled symbols and extruded coarse flours by filled symbols. Control (cross), flour 1f (unfilled square), flour 2f (unfilled triangle), 3f (unfilled circle), 1c (filled square), 2c (filled triangle), 3c (filled circle)

Figure 4: Photomicrographs of the scanning electronic microscope (SEM) (×1000) of doughs prepared with non-extruded flour with 10% substitution by extruded flour (analysis performed in triplicate with subsequent selection of the most representative photomicrographs). a) control, b) dough made with flour 3c,. Arrows indicate damaged starch granules.

Figure 5: Dough height during fermentation.

Figure 6: Changes in hardness over time. Extruded fine flours are represented by unfilled symbols and discontinuous lines. Extruded coarse flours are represented by filled symbols and

continuous lines. Control (cross), flour 1f (unfilled square), flour 2f (unfilled triangle), 3f (unfilled circle), 1c (filled square), 2c (filled triangle), 3c (filled circle)

Figure 1:

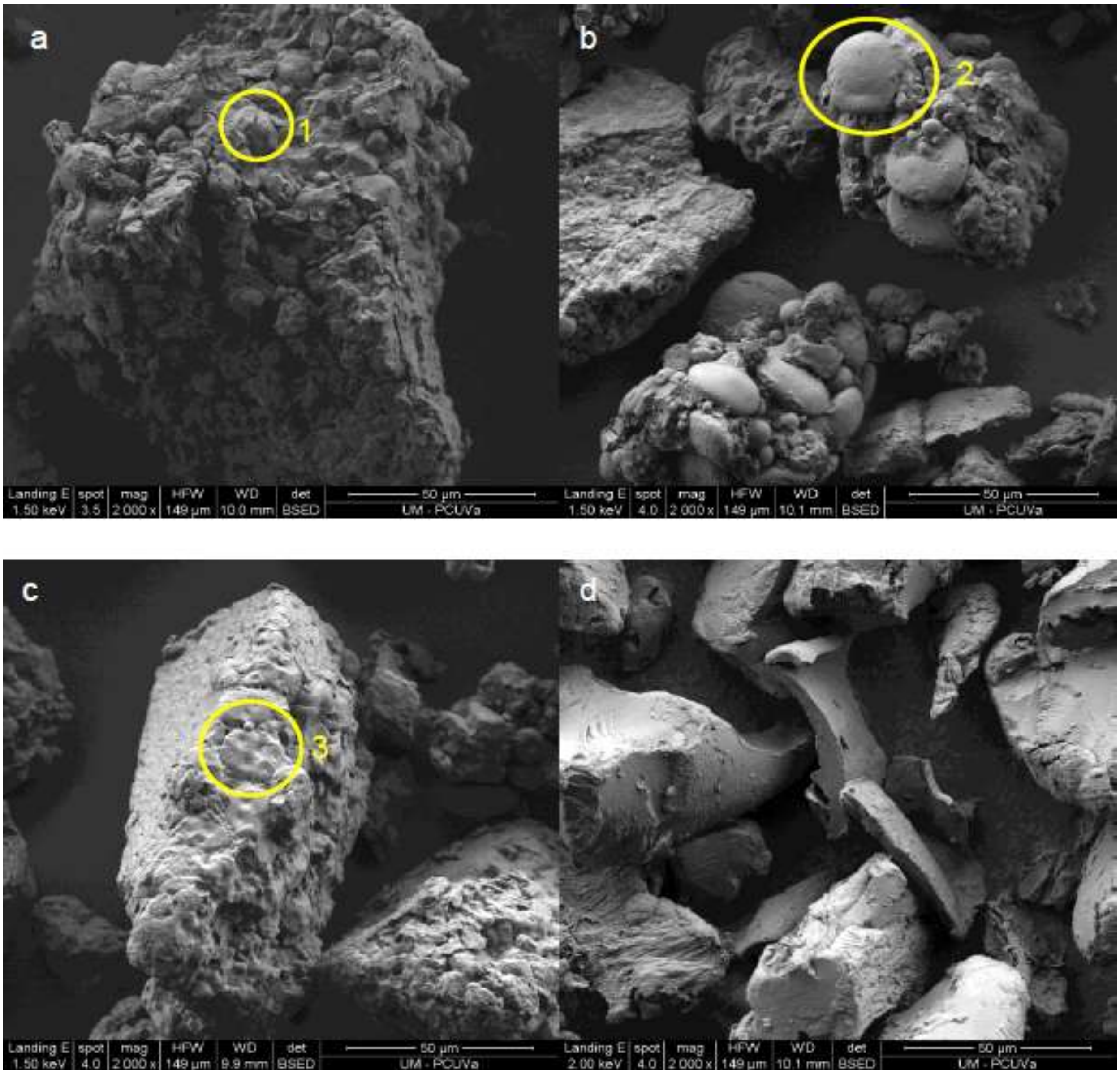

a
1
Landing E | spot | mag | HFW | WD | det
1.50 keV | 3.5 | 2 000 x | 149 µm | 10.0 mm | BSED
50 µm
UM - PCUVa
b
2
Landing E | spot | mag | HFW | WD | det
1.50 keV | 4.0 | 2 000 x | 149 µm | 10.1 mm | BSED
50 µm
UM - PCUVa
c
3
Landing E | spot | mag | HFW | WD | det
1.50 keV | 4.0 | 2 000 x | 149 µm | 9.9 mm | BSED
50 µm
UM - PCUVa
d
Landing E | spot | mag | HFW | WD | det
2.00 keV | 4.0 | 2 000 x | 149 µm | 10.1 mm | BSED
50 µm
UM - PCUVa

Figure 2:

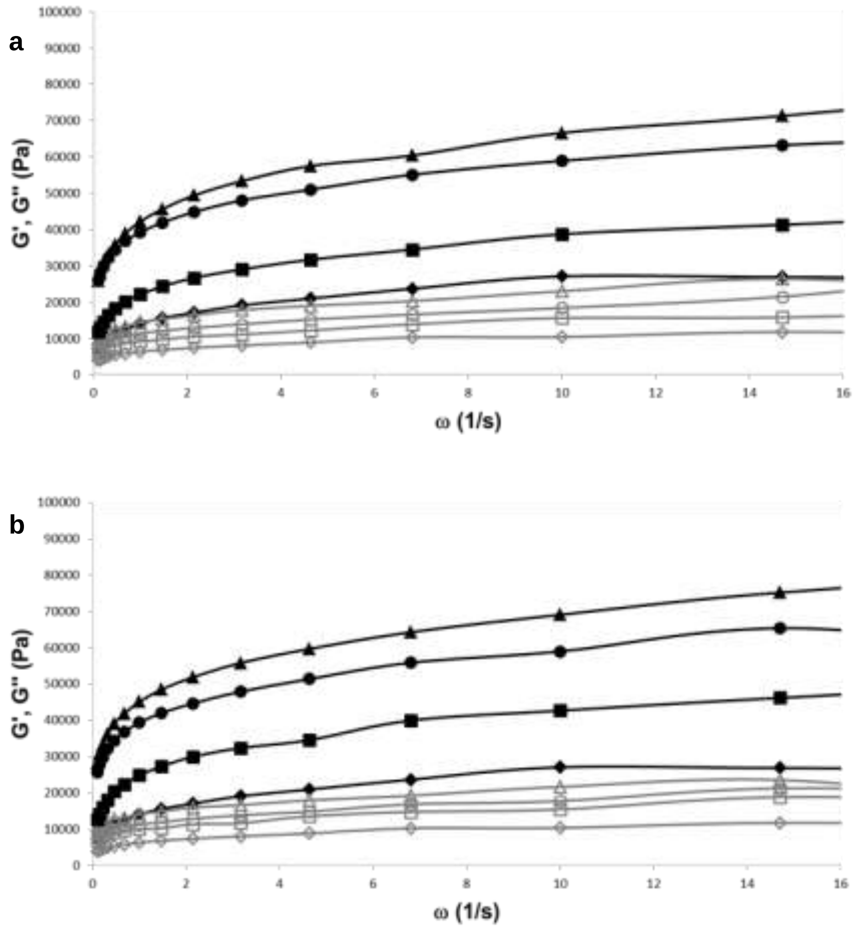


Figure 3:

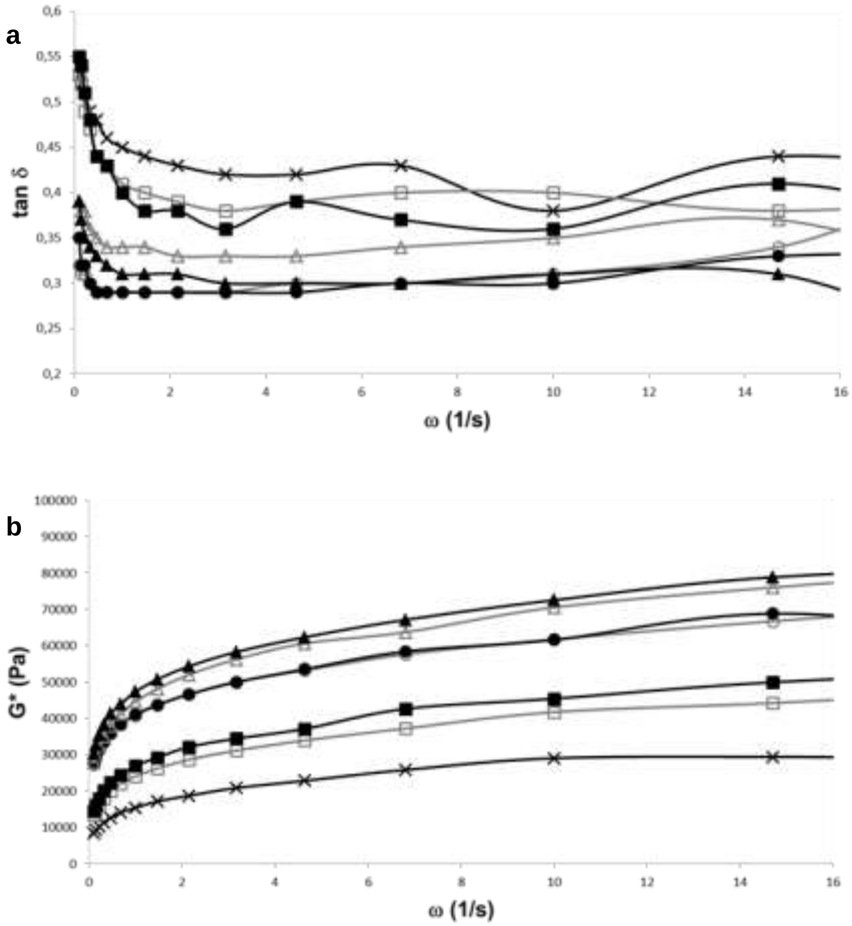
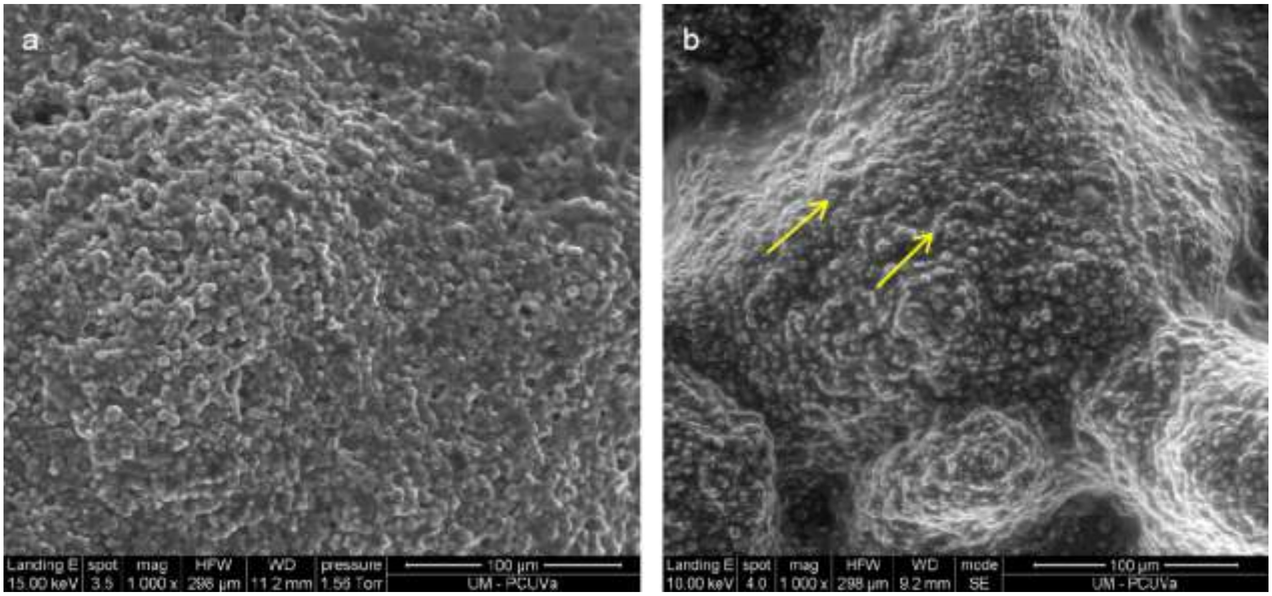
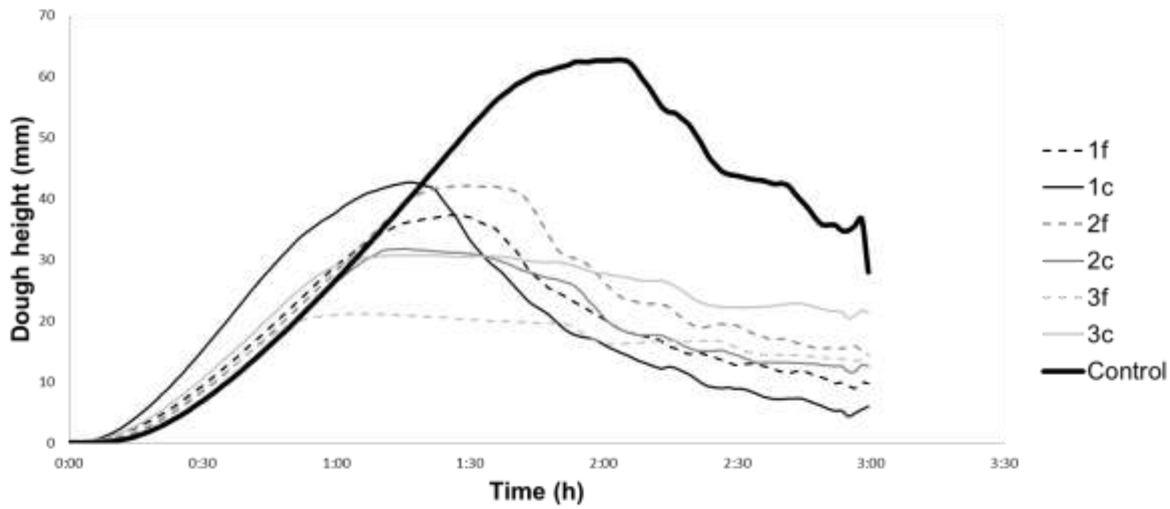


Figure 4:


a
Landing E spot mag HFW WD pressure
15.00 keV 3.5 1 000 x 298 µm 11.2 mm 1.56 Torr
100 µm
UM - PCUVa
b
Landing E spot mag HFW WD mode
10.00 keV 4.0 1 000 x 298 µm 9.2 mm SE
100 µm
UM - PCUVa

566 Figure 5:



567

568

Figure 6: