Developing gluten free bakery improvers by hydrothermal treatment of rice and corn flours

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Abbreviations

RFBS Rice /Faba Bean Semolina

CFBS Corn /Faba Bean Semolina

H/W ratio Height/Width ratio

Abstract

The impact of hydrothermal treatment of rice and corn flours on their potential as gluten free bakery improvers was tested. Hydrothermal treatment of flours was carried out by suspending flours in water on the basis of 5/1 (w/w) and heated until 65°C. Corn or rice semolina supplemented by faba bean semolina in ratio of 2/1 (w/w) were used for obtaining protein enriched gluten free breads, where improvers functionality was tested. Two central composite designs involving water hydration levels (X_1, X'_1) and the level of hydrothermally treated rice or corn flours (X_2, X'_2) were used. Instrumental analyses of breads (specific volume, moisture content, crumb texture and height/width ratio) were carried out to assess the impact of experimental factors. Results showed that hydrothermal treatment of rice or corn flours affected in different extent the bread properties, increasing the specific volume of breads and H/W ratio, and decreasing the hardness and chewiness of both types of breads.

The optimum formulation for rice/faba bean bread contained 7.59 g/100 g treated rice flour and 96.66 g/100 g water, and for corn/faba bean bread the optimum included 4.73 g/100 g treated corn and 78.81g/100 g water. Optimized breads were found acceptable according to color and texture structure.

Key Words: breadmaking, gluten free, hydrothermal treatment, rice, corn.

1. Introduction

Gluten is the main structure-forming protein in flour, because resulting dough presents high elastic characteristics and it contributes to the appearance and crumb structure of many baked products (Gallagher et al., 2004). Nevertheless, when pathologies require the removal of gluten from the diet, the replacement of gluten presents a major technological challenge. In recent years there has been extensive research for the development of gluten free bread, involving diverse approaches, like the use of different starches (maize, potato, cassava or rice), dairy products, gums and hydrocolloids, emulsifiers, other non-gluten proteins and prebiotics, as alternatives to gluten, to improve the structure, mouth feel, acceptability and shelf-life of gluten free bakery products (Matos & Rosell, 2012). Other gluten free ingredients such as leguminous seeds, buckwheat, potato and sorghum flours (Arendt & Dal Bello, 2008; Matos & Rosell, 2015) have been also investigated.

Nevertheless, some autochthonous products offer great opportunities to develop high quality gluten free products, like breads. Studies on celiac disease in Algeria report that adherence to gluten free diet is poor and not easy for concerned population, with the subsequent negative effects on nutritional and health status of patients (Boukezzoula & Zidoune, 2014). One way to improve that status is to find or to develop gluten free products resembling the traditional products on the Algerian market, like *Khobz eddar*. This is the traditional bread made from durum wheat semolina and characterized by a crispy crust and a soft crumb.

Pre-gelatinized starches obtained by heating in the presence of water, are used widely for their technological properties such as solubility in hot or cold water, high viscosity and smooth texture and can be used in food processing whenever thickening is required (Lai, 2001). For instance, in cereal porridge, gelatinized flour was used as ingredient to improve texture (Chiang & Johnson, 1976). Despite the extended use in soups and creams, scarce information has been reported on bakery products. Tsai et al. (2012) confirmed that the addition of rice porridge improved the quality of baked bread promoting soft crumb texture. Even later on, Hesso et al. (2014) proposed the use of pregelatinized starches for delaying the staling of cakes. Despite the previous use of those starches as antistaling, there is limited information about the use of those starches as structuring agents, which are required to obtain gluten free bread.

The aim of this study was to evaluate the potential of hydrothermal treatment of rice and corn flour to obtain pregelatinized slurries for manufacturing gluten free bread based on rice or corn semolina supplemented with faba bean semolina. The study was carried out following a RSM (Response surface methodology) to define the levels of water and pregelatinized slurries (rice or corn), based on a traditional Algerian breadmaking process.

2. Materials and methods

2.1. Materials

Rice (*Oryza sativa*) (Basmati, Thaïland) was grinded using a stone mill grinder until obtaining semolina (200-500 µm particle size) or flour (lower than 200 µm particle size). Rice semolina and flour had 10.30% moisture, 0.04% ash, 0.21% lipid and 10.73% protein content. Corn (*Zea mays*) semolina (>300 µm particle size) or flour (<300 µm particle size) were provided by DACSA (Valencia, Spain), containing 13.69% moisture, 0.33% ash and 7.50% protein. Faba bean semolina (*Vicia faba)* (10% moisture, 0.08 % ash, 1.08% lipid, 30.01% protein) was obtained after grinding the hulled bean seeds purchased from Alamir Company (Albehera, Egypt).

Instant dry yeast (Saf-instant) was donated by Lessafre Iberica (Valladolid, Spain). Egg powder was purchased from EPSA company (Valencia, Spain). Salt and sunflower oil were acquired in local market.

2.2. Hydrothermal treatment

2.2.1. Preparation of treated rice and treated corn

Hydrothermally treated rice or corn was prepared according to TangZhong method (Yvonne, 2007): the treatment was done by suspending flours (rice or corn) in cold distilled water (21± 1°C) at the ratio of 1/5 (w/w). Slurries kept thoroughly stirred were heated until the inner temperature reaches 65°C; it took about 6-7 min for corn and 8-9 min for rice to reach that temperature. After cooling down at room temperature for 1 h, slurries were kept for 24 h at 4°C and used as bread ingredients to improve the breadmaking.

2.2.2. Pasting properties

Pasting properties of hydrothermally treated slurries were determined after 1 hour of cooling at room temperature and after 24 hours storage at 4 ºC. Previously prepared slurries (30 g) were weighed into the aluminum canisters and analyzed using a rapid visco analyser (RVA) (RVA 4500, Perten Instruments SA, Stockholm, Sweden) by following ICC standard method No 162 (ICC, 1996). Peak viscosity, through, breakdown, final viscosity, setback (difference between final viscosity and peak viscosity) and onset temperature were recorded by Thermocline software (Perten Instruments SA, Stockholm, Sweden). Three replicates were carried out per sample.

2.3. Experimental Design

Two central composite designs with 2 factors each were employed to determine the effect of water (X_1 for RFBS, X'_1 for CFBS) and the amount of hydrothermally treated slurries (X_2:

treated rice for RFBS, X'_2: treated corn for CFBS) on rheological and technological properties of breads followed by optimisation of the process using surface response methodology.

Factorial section was a 2^2 test; the star section included four tests. Five replicates center-points were also added, for a total of $2^2+2^2+5=13$ runs for each type of bread (Table 1).

For each response variable, model selection appeared to be quadratic; the significance level was set at 0.05. Responses of each variable were subjected to statistical analysis in order to define the optima points for breadmaking recipe using the desirability function approach (DFA). The desirability function approach is a multi-criteria optimization method useful to find the best compromise between several responses. $D = (d1 \times d2 \times d3 \ldots\ldots xdn)^{1/n}$ where d_i are the desirability indices for each response ($d_i = 0$ least desirable; $d_i = 1$ most desirable) and n is the number of responses in the measure (Simurina et al., 2012).

2.4. Bread making process

Rice /faba bean semolina (RFBS) and corn /faba bean semolina (CFBS), in a ratio of 2/1 (w/w) cereal/faba bean semolina, were the two gluten free recipes studied, aiming to offer a better nutritional balance in amino-acids (Benatallah et al., 2012; Storck et al., 2013). The hydration range applied in the experimental design was determined for each formula by preliminary experiments (55 to 110% for rice breads and 51 to 105% for corn breads). The levels of hydrothermally treated slurries were fixed up to 14.75% or 13.8%, for rice or corn breads, respectively. Hydration and hydrothermally treated slurries percentages are expressed based on the semolinas blend basis.

The basic bread recipe consisted of: 666 g of rice or corn semolina, 333 g of faba bean semolina, 20 g of salt, 20 g of instant dry yeast, 20 g powder egg, 200 ml of sunflower oil and the amount of water defined in the experimental design (Table 1). The making procedure involved manual premixing of dry ingredients, with exception of powder egg and then water was added. When hydrothermally treated slurries were added, the corresponding amount of rice or corn semolina and water were replaced. It must be kept in mind that slurries contained flour/water at the ratio of 1/5 (w/w). The mixture was left to rest for 10 min, then the powder egg and the rest of water were added and manually mixed for 10 min and sunflower oil was added and mixed for additional 5 min. The resulting dough was divided in lumps (100 g) and put into mold and proofed for 45 min at 37 °C in a fermentation cabinet (Salva Industrial S.A., Lezo, Guipuzcoa, Spain).The baking tests were carried out at 165°C for 25 min into an electric oven (Salva Industrial S.A., Lezo, Guipuzcoa, Spain).

2.5. Bread quality evaluation

Bread characterization after one hour post-baking consisted of specific volume, crumb texture profile analysis, height/width ratio and bread moisture.

Volume was determined by the rapeseed displacement method according to the AACC Approved Method 10.05. (AACC, 2000); specific volume (cm^3/g) of an individual loaf was calculated by dividing volume by weight. Moisture content was calculated based on ICC 110/1 method (ICC, 1996).

Height/width ratio was measured by capturing the image of the central slice with an HP Scanjet G 3110 scanner in the presence of scale.

Texture profile analysis (TPA) was evaluated on the breadcrumb using a texture analyzer (TA-XT plus, StableMicro Systems Ltd., Godalming, UK), using two bread slices of 1-cm-thickness, which underwent a double compression test up to 50% strain (penetration of its original height) at a cross head speed of 1 mm/s and a 30 s gap between compressions, with a cylindrical stainless steel probe P/25 (25 mm diameter) (Rosell et al., 2009). The parameters recorded were hardness, cohesiveness, springiness and chewiness.

The color of the crumb samples was measured at three different locations by using a Minolta colorimeter (Chroma meter CR-400/410, Konica Minolta, Tokyo, Japan) after standardization with a white calibration plate (L^*=96.9, a^*=−0.04, b^*=1.84). The color was recorded using

CIE-$L^*a^*b^*$ uniform color space, where L^* indicates lightness, a^* indicates hue on a green (−) to red (+) axis, and b^* indicates hue on a blue (−) to yellow (+) axis (Matos & Rosell, 2013). Data from three slices per sample were averaged.

High resolution images (600 ppi) of the bread slices 10 mm thick were captured by HP Scanjet G 3110 scanner. Crumb cell analysis of breads was performed by Image J software according to Gonzales-Barron & Butler (2006) in the optimized breads. Number of cells, average cells area, and average diameter were calculated. Values were the mean of four replicates.

2.6. Statistical analysis

Multiple regression analysis was performed to fit second order model to dependent variables by using Minitab Release 16 (Minitab Inc., State College PA, USA). The models were used to determine responses surfaces in Statistica 10 (Stat soft, France). One way analysis of variance (ANOVA) was applied to compare the effect of water ($X1_{,}$ $X`1_{)}$ and treated flours (X2,X`2) on the dependent variables (Y, Y`). A coefficient of determination (R^2) was computed and the adequacy of models was tested by separating the residual sum of squares into pure error and lack-of-fit. Optimization was performed with Minitab Release 16 (Minitab Inc., State College PA, USA).

3. Results and discussion

3.1. Pasting performance of hydrothermally treated slurries

Rice and corn flours were submitted to hydrothermal treatment to modify their functionality looking for obtaining bakery improvers. After hydrothermally treatment, rice and corn flours were stored for one and 24 hours and the pasting profile of those treated flours were compared with the native ones to check the impact of the thermal treatment on starch gelatinization (Figure 1 and 2). Significant differences were observed among the pasting profiles of the flours before and after treatment. The RVA profile confirmed that hydrothermal treatment partially gelatinized the starch, increasing the initial viscosity of the flours (1800 cP and 2000 cP for rice and corn treated flours, respectively) and decreasing the viscosity during heating. The high initial viscosity for the pre-gelatinized rice and corn was attributed to the disruption of the molecular order within the starch granules during the treatment, resulting in the loss of granule integrity and destruction of starch crystallinity (Marti et al., 2013). Besides the reduction in the maximum viscosity during heating, a shift in the onset pasting temperature was observed due to higher temperature was required to gelatinize the remaining intact starch granules. Nevertheless, differences were observed depending on the flours source, rice (Figure 1) or corn (Figure 2), since botanical origin is responsible of morphological, thermal and rheological properties of starches (reviewed by Sing et al., 2003). Rice flour after treatment showed a significant reduction in the maximum viscosity during heating, but the trend changed during cooling, whose viscosity was higher than in the native flour. During cooling rapid reorganization of the amylose chains is produced increasing the viscosity of the flour (Rosell et al., 2007). It seems that the structure disorder promoted by the thermal treatment favored the amylose released, which was rapidly enabled to reorganize during cooling. It must be stressed that the degree of granule disintegration in rice is greatly dependent on the amount of amylose, particularly low amylose starch granules are weak and fragile whereas high amylose rice starch is strong and rigid (Sandhya & Bhattacharya, 1995), leading to higher viscosities during heating and cooling (Klug Tavares et al., 2010). The storage of the thermally treated rice flour during 24 hours induced a reduction in the viscosity obtained during heating and cooling. In opposition, thermal treatment of corn flour induced a decrease in the viscosity during the heating and cooling stages compared to the native flour. Moreover, the storage of the treated flour resulted in an increase of the viscosity along the temperature gradient likely due to the progress of starch retrogradation during the post-treatment storage. It must be remarked that the staling kinetics is dependent on the starch source, thus differences must be ascribed to the nature of rice or corn starches (Jane et al., 1999).

The two profiles revealed that the treated rice achieved higher final viscosity (about 9000 cP to 12000 cP) than those of corn (6000-7000 cP) at the end of RVA measurement. Therefore, depending on the extend of the hydrothermal treatment would be possible to obtain different degree of gelatinization and in consequence different level of viscosity, which would be useful for obtaining gluten free bread.

3.2. Improving effect on *khobz eddar* gluten free breads quality

3.2.1. Model fitting

The analysis of variance induced by the hydration level and the amount of treated flours on the quality parameters of rice/faba bean semolina and corn/faba bean semolina breads is shown in Tables 2 and 3. The statistical analysis indicated that the fitting models were adequate because they gave satisfactory values of the R^2 (higher for corn breads) for all the responses and model significance. Results showed that the lack-of-fit test was significant for the specific volume, hardness, chewiness and moisture content for experimental design 1 (Table 2), whereas it was significant for the specific volume, hardness, cohesiveness and chewiness for experimental design 2 (Table 3). This can be attributed to the very large experimental region covered in which all appropriate functions of independent variables were not included. However, when large amounts of data were included in the analysis, a model with a significant lack of fit could still be used (Phatcharee et al., 2014). In the case of gluten free breads this model was really convenient due to their large variability derived from their complex formulations (Matos & Rosell, 2011), and it is always more convenient to extend the range of analysis than to carry out the experimental design within narrow limits to give more robust information.

3.2.2. Gluten free bread quality characteristics

The effect of different concentrations of water and treated rice or corn on the response surface graphs for specific volume and height/width ratio of RFBS bread and CFBS is shown in Figures 3 and 4, respectively. For RFBS breads, the specific volume varied from 1.50 to 2.35 cm^3/g, showing a positive effect of increasing water content and treated rice, although in the later a quadratic effect was observed with a maximum value of 2.35 cm^3/g against 1.70 cm^3/g for the bread without treated flour.

The specific volume of CFBS bread ranged from 1.40 to 2.90 cm^3/g (Figure 4), indicating that a higher specific volume can be obtained with corn in comparison to rice. The response surface (Figure 4) again showed a positive effect of water hydration and treated flour on specific volume, although the water effect was less pronounced than that was observed in rice bread. Many authors confirmed the dependence of gluten free bread volume with water amount and indicated also its dependence on the type of raw material (Marco & Rosell, 2008; Schoenlechner et al., 2010). A quadratic effect of the amount of treated corn rice was observed, with a maximum when 5 g of treated corn were present. Therefore, hydrothermally treated slurries, which have partially gelatinized starch, improved the specific volume of gluten free rice or corn based *khobz eddar*. Presumably, the higher initial viscosity induced by treated flours favor the entrapment of air bubbles in the dough structure, and it is even enough to hold the gas pressure during expansion at the early stage of baking (Shibata et al., 2011). In order to achieve a good bread volume, the dough should have enough strength to develop and maintain the cells gas and gelatinized starch must be able to withstand the rapid expansion of cells during the initial phase of the cooking (Pongjaruvat et al., 2014).

Response surface of height/width ratio for RFBS indicated that it varied from 0.61 to 0.82 with the most significant effect observed with the amount of water. A significant different response was observed for CFBS breads, in which a quadratic effect was observed for the water hydration and the amount of treated corn flour. For CFBS the H/W ratio ranged from 0.63 to 0.81 obtaining the optimum at 75-105 ml of water and 3.0-13.8 g of treated corn flour. Taking into account that breads were baked in molds, the H/W ratio gave information about the oven rise and thus the holding ability of the dough structure during baking.

Hardness is one of the most important quality characteristic of bread texture, with consumers desiring soft and flexible crumbs and low hardness (Hager & Arendt, 2013). The response surface for RFBS breads showed a quadratic effect of both factor, with a minimum hardness located in the interval 7 g-10 g of treated rice and 85 ml-98 ml of water per 100 g semolina blends (Figure 3). The same response, although less pronounced, was obtained with the CFBS breads (Figure 4) and lower hardness was obtained within the range 1.8 g-13.8 g of treated corn and 76 ml-110 ml of water. Shibata et al. (2011) also reported higher dough expansion and softer texture when added gelatinized rice flour or rice porridge to wheat bread.

Regarding chewiness (Figures 3 and 4), different effect was observed in the rice and corn breads. Water content and treated rice amount promoted quadratic negative effects on the chewiness of rice breads, with minimum values when containing 5 g-12 g of treated rice and 80 ml-100 ml of water per 100 g semolina blends, indicating easy chewing of the breads. For CFBS bread chewiness, a deep decrease was observed when increasing water, and a smoother decrease was induced by the addition of treated corn. Therefore, the use of rice or corn semolina as ingredients obligated to adapt recipes and even the addition of pregelatinized flours confers different characteristics.

The opposite effect was induced by water hydration and treated flour amount on springiness in rice and corn based breads, being in both cases a quadratic effect. It must be remarked that springiness is associated to fresh, aerated and elastic product, thus high springiness values are recommended (Matos & Rosell, 2012). Values obtained in rice and corn breads fall within the springiness values (0.76 to 1.00) found for gluten free breads (Matos & Rosell, 2012).

Cohesiveness reflects the ability of a material to be deformed before breaking down; in breads high cohesiveness is desirable indicating the bolus formation during mastication without crumbling. Water content and the amount of treated flour induced a quadratic negative effect on the rice and corn bread cohesiveness; with the exception of the positive effect promoted by treated corn flour on CFBS bread (Figures 3 and 4).

Generally, the hydrothermally treated cereal flours improved the quality of gluten free bread, because the partial gelatinization of starch increased the dough consistency and likely the entrapment of gas during mixing and baking. Similarly, Tsai et al. (2012) reported that the addition of rice porridge improved the texture of wheat bread, which was ascribed to the gelatinization of rice starch granules. In addition, results showed the fundamental role of water hydration in the quality of the resulting gluten free breads, and in particular these gluten free *khobz eddar* breads, based on rice or corn semolina. The moisture content of the breads varied from 30 to 45 %, which agree with previous results in commercial gluten free breads (Matos & Rosell, 2012). Gluten free breads usually show high moisture content due to the importance of hydrating the dough. In fact, the response surface obtained with RFBS and CFBS breads showed the increase moisture content of breads when increasing water hydration. For CFBS bread the moisture content ranged from 30 to 45 % and presented a linear rise with increasing water and it was independent on the quantity of treated corn.

3.2.3. Optima gluten free breads

From the results obtained in the experimental design, optimized recipes for rice and corn based gluten free breads were developed with the aim to maximize specific volume, H/W ratio and minimize hardness, chewiness and moisture content. Figure 5 showed the cross-section of the bread slices compared to the references ones without treated flours.

The selection of improver content and water concentration was fundamental for obtaining the two gluten free breads with the best quality characteristics and they were obtained by applying the desirability function. The optima concentrations were 7.59 g/100 g (semolina blends basis) of rice improver and 96.66 g water/100 g semolina blends for the rice formula, with a desirability value of 0.747. At these concentrations of improver and water, maximum specific volume and best textural parameters were obtained compared to the bread without improver. For corn based bread, 4.73 g of corn improver and 78.81 g of water (based on semolina blend) were obtained with a desirability value of 0.627. These concentrations of corn improver and water allowed obtaining a bread with maximum specific volume and minimum hardness and chewiness comparing bread without improver.

The specific volume of the two gluten-free breads, textural properties (hardness, chewiness, springiness and cohesiveness), H/W ratio and moisture content, besides the color and crumb image analysis of the selected gluten free breads are described in table 4. Optimization of gluten free breads based on rice or corn gave different quality characteristics. Specific volume of corn bread was higher than that of rice bread, which also led to softer crumbs when using corn semolina. The estimated values of specific volume in optimally formulated bread were 2.24 cm^3/g for RFBS bread and 2.60 cm^3/g for CFBS bread. H/W ratio for RFBS is 0.79 and for CFBS is 0.85. Bread containing treated corn presented higher specific volume and H/W ratio than bread containing treated rice, which might be related to the pasting properties of the improvers derived from rice or corn flour. Both breads presented the best textural parameters. For RFBS bread, it was obtained lower hardness and chewiness (566 g, 217) than its counterpart without treated rice (2604 g, 1314). For CFBS optimized bread, (435 g, 298) hardness and chewiness improved compared to the reference bread (495 g hardness and 330 chewiness).

The color of the breads was related to the color of the corresponding semolina, being in the case of CFBS higher $b*$ due to the yellowish color derived from corn semolina. No differences were observed in lightness ($L*$). Lightness of ingredients plays an important role in bakery products due to consumer preferences. In fact, numerous efforts have been devoted to lighten the color of the grains and grains products (Metzger, 2003). The hue green (-*a**) varied from 0.55 for RFBS to 1.74 for CFBS.

Image crumb analysis revealed that CFBS breads contained higher number of small holes, whereas rice based bread contained bigger holes. In both cases, breads exhibited an aerated crumb structure.

4. Conclusion

Gluten-free breads based on rice or corn semolina were successfully developed following the Algerian (*khobz eddar)* traditional breadmaking, but applying needed changes for making gluten free products. A recipe based on rice and faba bean semolina or corn and faba bean semolina was used adding hydrothermally treated rice or corn flours as bakery improvers. A experimental design, used to optimize the level of water hydration and the amount of improver, revealed the importance of those factors in the quality characteristics of gluten free breads and allowed determining the optima levels for improving specific volume, H/W ratio and textural parameters. The optimum gluten free rice/faba bean bread was produced by incorporating 7.59 g of treated rice and 96.66 g of water (based on 100 g semolina blends), whereas the optimum gluten free corn/faba bean bread was produced by incorporating 4.73 g of treated corn and 78.81 g of water (based on 100 g semolina blends). According to the results of specific volume, texture parameters, color and crumb structure, it can be concluded that optimized rice or corn breads were obtained using hydrothermally treated slurries as bakery improvers, leading to gluten free *khobz eddar* breads for celiac patients.

Acknowledgements

Authors acknowledge the financial support of Spanish Scientific Research Council (CSIC), the Spanish Ministry of Economy and Sustainability (Project AGL2014-52928-C2-1-R), the European Regional Development Fund (FEDER) and the Generalitat Valenciana (Project

Prometeo 2012/064). H. Bourekoua acknowledges the financial support of Institute of Nutrition, Food and Agrofood Technology (I.N.A.T.A.A.).

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FIGURE CAPTIONS

Figure 1. RVA profiles of rice flour, hydrothermally treated rice flour after 1 h and after 24 h storage. Legend: (——): temperature profile; (— —) rice flour; (– –) treated rice 1 h; (…) treated rice 24 h.

Figure 2. RVA profiles of corn flour, treated corn after 1h and pre-gelatinized corn after 24 h. Legend: (——): temperature profile; (— —) rice flour; (– –) treated rice 1 h; (…) treated rice 24 h.

Figure 3. Responses surfaces of experimental design for rice/faba bean semolina (RFBS) bread.

Figure 4. Responses surfaces of experimental design for corn/faba bean semolina (CFBS) bread.

Figure 5. Cross section of central bread slice obtained with the optima recipes for rice and corn breads. **A**.Control rice based bread; **B.** Optimum rice based bread; **C**. Control corn based bread; **D**. Optimum corn based bread.

Table 1. Factors, levels and code values used in the two Central Composite Designs (CCD1, CCD2) for rice bread and corn breads, respectively.

	Code values		Real values			
			CCD 1		CCD2	
Run	Hydration (ml) X1	Treated flour (g) X2	Hydration X1 (ml)	Treated rice X2 (g)	Hydration X\`1 (ml)	Treated corn X\`2 (g)
1	1.41421	0	110	7.375	105	6.9
2	-1.41421	0	55	7.375	51	6.9
3	0	1.41421	82.5	14.75	78	13.8
4	-1	1	63.055	12.589	58.908	11.779
5	1	-1	101.945	2.160	97.092	2.021
6	1	1	101.945	12.589	97.092	11.779
7	-1	-1	63.055	2.160	58.908	2.021
8	0	-1.41421	82.5	0	78	0
9	0	0	82.5	7.375	78	6.9
10	0	0	82.5	7.375	78	6.9
11	0	0	82.5	7.375	78	6.9
12	0	0	82.5	7.375	78	6.9
13	0	0	82.5	7.375	78	6.9

Table 2. Analysis of variance (ANOVA) test tracing parameters for the response surfaces formula of rice/faba bean breads.

	Sequential sum of squares						
Source	Specific volume (cm^3/g)	Texture parameters				H/W ratio	Moisture content (%)
		Hardness (g)	Springiness	Cohesiveness	Chewiness (g)		
Lack of fit	0.040*	0.019*	0.072	0.804	0.000*	0.597	0.020*
Pure error	0.017954	400591	0.013233	0.028575	529	0.001887	3.032
F	7.52^{*NS}	11.69^{*NS}	5.21^{*NS}	0.33^{*NS}	3078.51^{*NS}	0.70^{*NS}	11.35^{*NS}
R-Sq (%)	71.67	67.67	67.05	81.33	71.39	86.20	78.50

H/W: Height/Width ration; F: variance Ficher—Snedecor; *NS: not significant (P>0.05); *: Significant at $P \leq 0.05$.

Table 3. Analysis of variance test tracing parameters response surfaces formula corn/faba bean.

	Sequential sum of squares						
Source	Specific volume (cm^3/g)	Texture parameters				H/W ratio	Moisture content (%)
		Hardness (g)	Springiness	Cohesiveness	Chewiness (g)		
Lack of fit	0.008*	0.000*	0.061	0.449*	0.010*	0.173	0.182
Pure error	0.02507	98.78	0.000106	0.001803	308.8	0.001073	1.251
F	19.26^{*NS}	23.2^{*NS}	5.81^{*NS}	1.09^{*NS}	16.94^{*NS}	2.79^{*NS}	2.69^{*NS}
R-Sq (%)	74.90	96.38	71.82	91.78	89.37	75.47	97.41

H/W: Height/Width ration; F: Ficher—Snedecor variance; *NS: not significant (P>0.05); *: Significant at $P \leq 0.05$.

Table 4. Characterisics of optima gluten free rice or corn bread.

Parameters	Rice/faba bean Bread	Corn/faba bean Bread
Specific volume (cm^3/g)	2.24 ±0.56	2.60 ±0.32
Hardness (g)	566 ±5	435 ±5
Springiness	0.977 ±0.011	0.918 ±0.010
Cohesiveness	0.766 ±0.010	0.752 ±0.040
Chewiness	217 ±6	298 ±4
Height/Width ratio	0.79 ±0.13	0.85 ±0.01
Moisture content (%)	37.80 ±0.69	36.78 ±0.30
$L*$	61 ±1	61 ±1
$a*$	-0.55 ±0.38	-1.74 ±0.04
$b*$	17.6 ±1.5	27.8 ±0.1
Image crumb analysis		
Number of holes	286 ±2	382 ±0.1
Total area (cm^2)	1.20 ±0.1	1.44 ±0.02
Diameter (cm)	0.03 ±0.02	0.02 ±0.01

Values are means±standard deviation.

Figure 1.

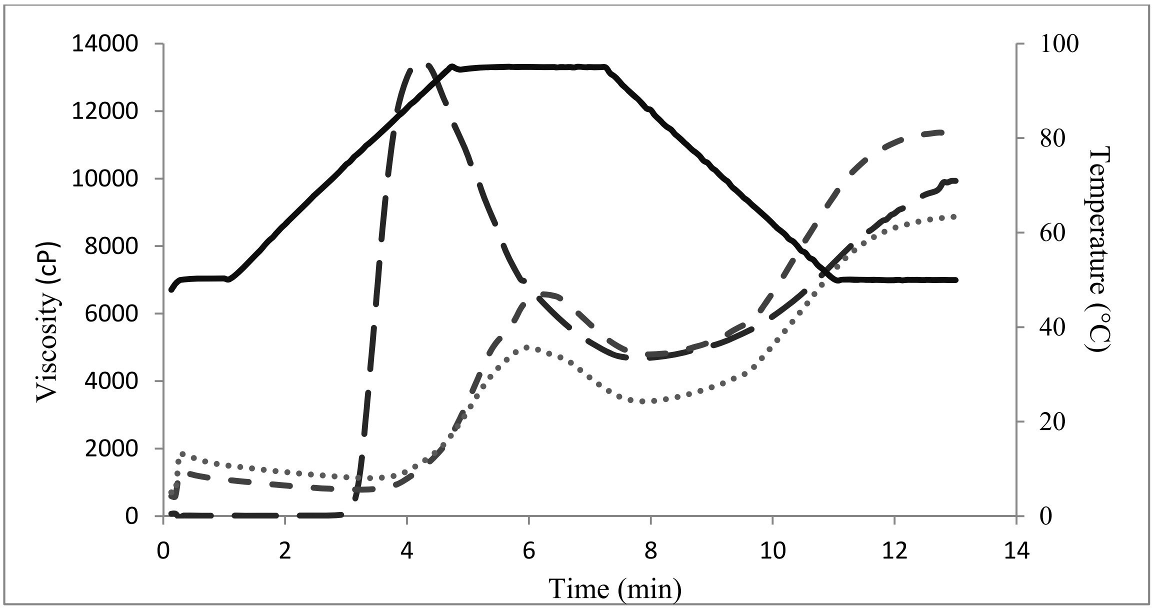


Figure 2.

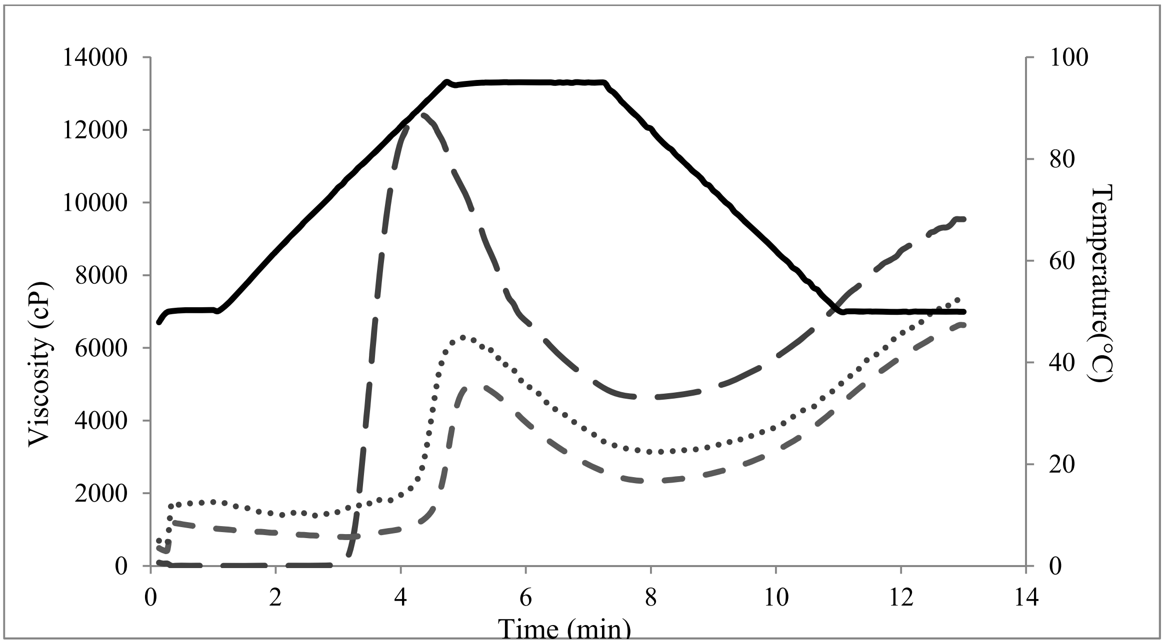
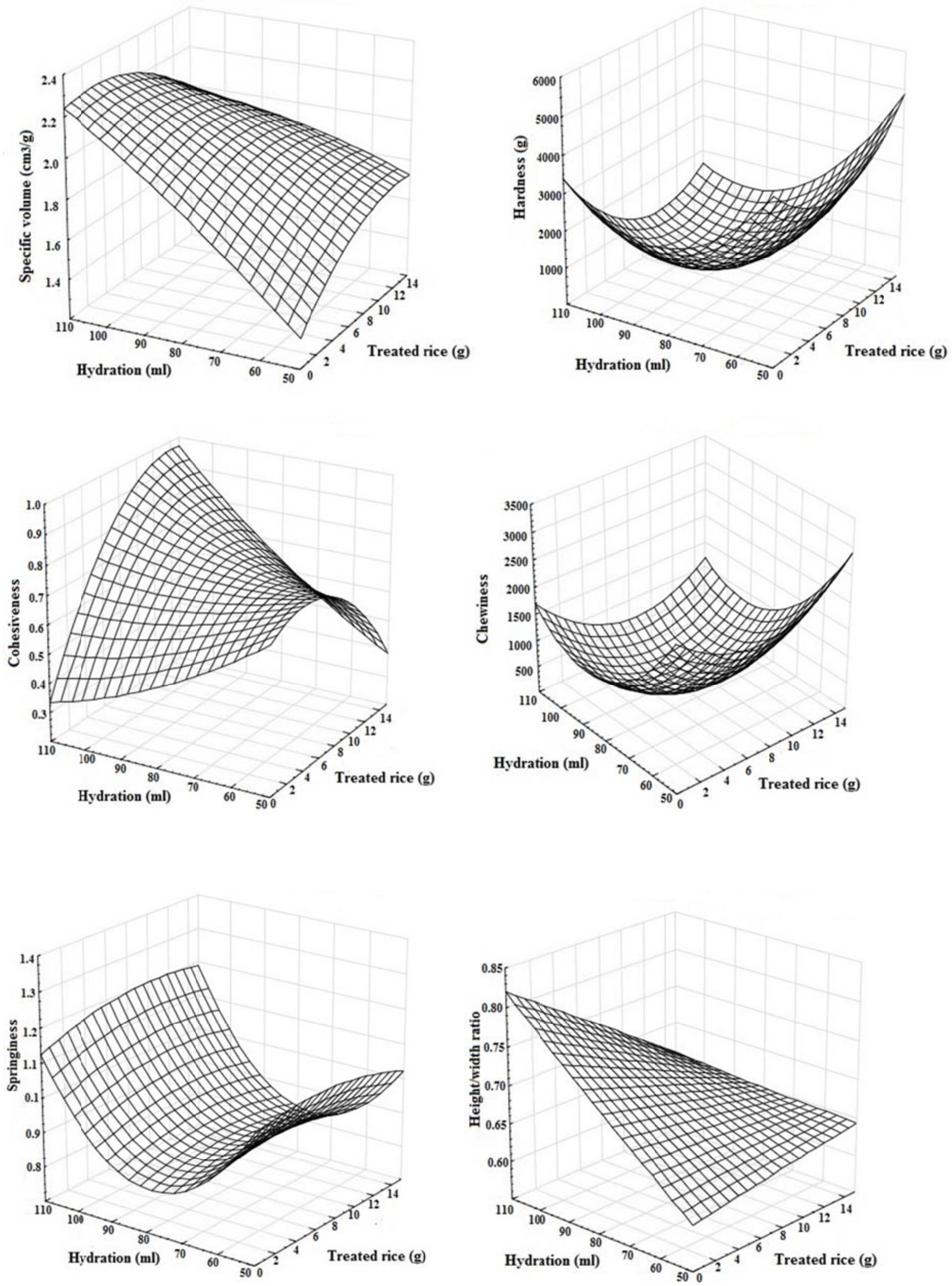


Figure 3.


Specific volume (cm3/g)
Hydration (ml)
Treated rice (g)
Hardness (g)
Hydration (ml)
Treated rice (g)
Cohesiveness
Hydration (ml)
Treated rice (g)
Chewiness
Hydration (ml)
Treated rice (g)
Springiness
Hydration (ml)
Treated rice (g)
Height/width ratio
Hydration (ml)
Treated rice (g)

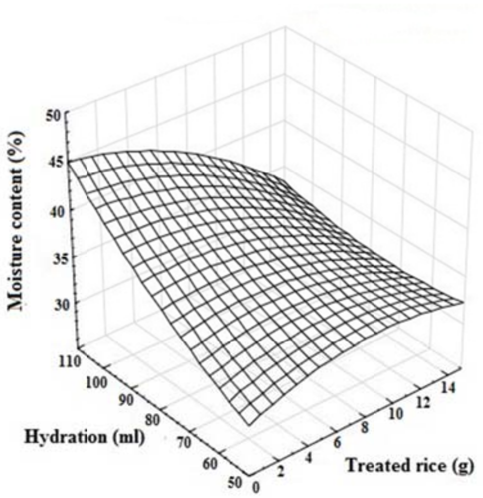
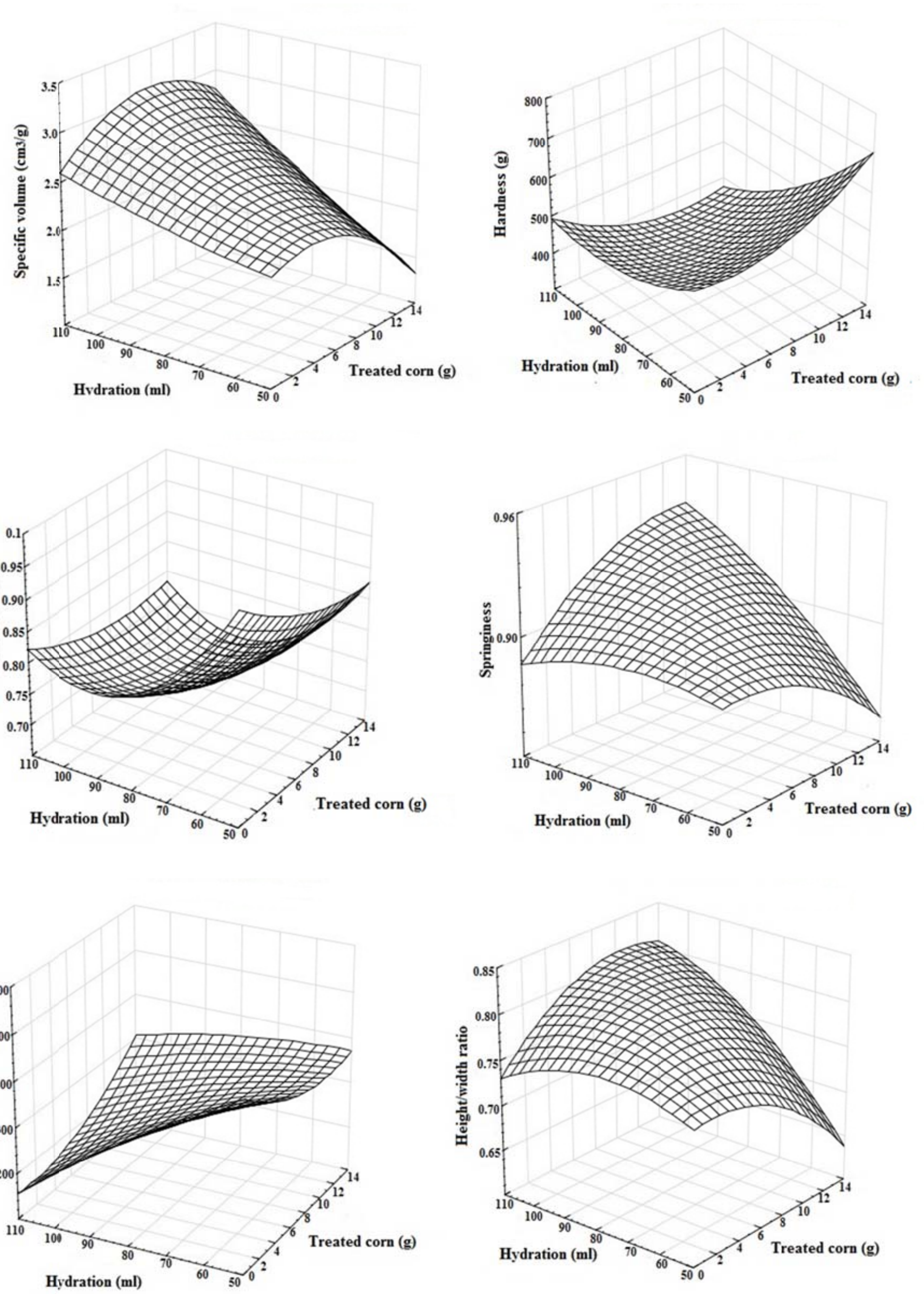

Moisture content (%)
50
45
40
35
30
Hydration (ml)
110
100
90
80
70
60
50
Treated rice (g)
0
2
4
6
8
10
12
14

Figure 4.



Specific volume (cm3/g)
Hydration (ml)
Treated corn (g)
Hardness (g)
Hydration (ml)
Treated corn (g)
Cohesiveness
Hydration (ml)
Treated corn (g)
Springiness
Hydration (ml)
Treated corn (g)
Chewiness
Hydration (ml)
Treated corn (g)
Height/width ratio
Hydration (ml)
Treated corn (g)

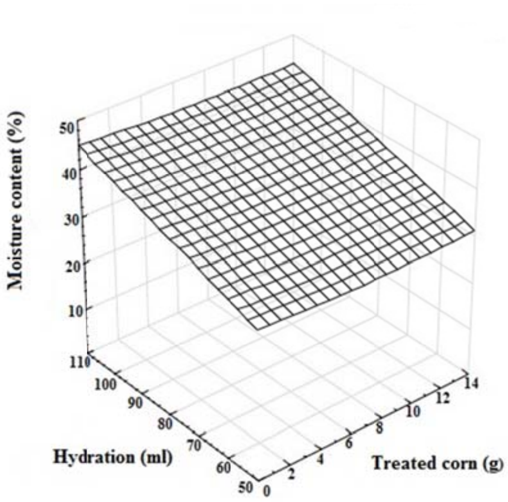

Moisture content (%)
50
40
30
20
10
110
100
90
80
70
60
50
Hydration (ml)
0
2
4
6
8
10
12
14
Treated corn (g)

Figure 5.