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ORIGINAL RESEARCH PAPER

OPTIMIZATION OF BREAD QUALITY OF 650 WHEAT FLOUR TYPE WITH NATIVE INULIN BY RESPONSE SURFACE METHODOLOGY

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The aim of this study was to evaluate the effect of native inulin addition on the wheat flour bread quality. Since it is known the fact that inulin addition decreases wheat flour dough water absorption, we wanted to obtain an optimum formulation of wheat flour bread by response surface methodology considering independent process variables in fixed proportion of inulin fiber in wheat flour as 0, 2.5, 5 and 10% and water addition as 45, 50, 55 and 60 %. With respect to bread quality characteristics, loaf volume, porosity and elasticity were evaluated. The results showed that the optimum bread formulation was obtained for native inulin addition of 3.52% and water absorption of 55.62% for which predicted bread quality characteristics are 373.08cm^3/100g loaf volume, 85.07% porosity and 92.57% elasticity.

Keywords: native inulin, water absorption, optimization, bread quality

Introduction

Inulin is a soluble and fermentable dietary fiber that is not digested by the enzymes of the human digestive tract (Salinas and Puppo, 2015) and thus it could be utilized by colonic micro-flora (Ziobro *et al.*, 2013). By stimulating the colonic bifidobacteria and lactobacilli (Peressini and Sensidoni, 2008; Fahey, 2010) and suppressing the activity of undesirable bacteria of the large and even the small intestines, inulin has a prebiotic activity (De Souza Olivera *et al.*, 2009). Inulin has also some beneficial effects on health like increasing mineral absorption such as calcium, magnesium and iron (Azorín-Ortuño *et al.*, 2009). This is an important fact given that billions of people are iron deficient (Welch and Graham, 2004) and suffer of osteopenia and osteoporosis. Inulin consumption improves serum lipid profiles and reduces the risk of colon cancer (Ranawana, 2010).

Inulin is found in many vegetable products like banana, leek, onion, garlic, asparagus, Jerusalem artichokes, dahlia tubers, yacon, chicory and cereals like wheat rye and barley (Watzl *et al.*, 2005). Among them, chicory root and Jerusalem artichoke are the main sources of inulin used in food industry (Peressini and Sensidoni, 2008). From a structural point of view inulin is a polysaccharide consisting of a chain of fructopyranose molecules connected via β (2,1) - glycosydic bonds with a terminal glucose molecule (Juszczak *et al.*, 2012; Guggisberg *et al.*, 2009). From a commercial point of view, inulin presents a different degree of polymerization (DP) that varies from 2 to 60. The long chain of inulin presents a DP between 10 and 60, with an average of 25, and a DP less than 10 corresponds to oligofructose (Peressini and Sensidoni, 2008). The molecules length is important for its technological and prebiotic properties (Tarrega *et al.*, 2011).

Bread made of wheat flour is the major component of people's diet all over the world (Salinas and Puppo, 2015) and therefore it may be considered the main source to increase the dietary fiber content. It can easily be enriched with fibers like inulin in order to obtain a product with functional properties in order to prevent some chronic diseases of modern civilization.

Quality characteristics of wheat flour bread with inulin were previously studied (Brasil *et al*., 2011; Rubel *et al*., 2015; Poinot *et al*., 2010; Peressini and Sensidoni 2008). Most works showed that loaf volume decreased with inulin addition (Mandala *et al*., 2009; Poinot et al., 2010; Meyer and Peters, 2009) even more at high concentration and as the DP is higher (Meyer *et al.*, 2009). However some studies showed different results. An increase in bread volume was reported by Praznik *et al.* (2012) for all samples with 8%, 10% and 12% inulin with different DP addition, while Hager *et al.* (2011) found no significant changes with inulin addition. Regarding the effect of inulin chain length on bread volume, contrary to the Meyer and Peters' (2009) results, Rubel *et al*., (2015) found that lower inulin DP had greatest impact in reducing bread volume. Peressini and Sensidoni (2008) found that the specific bread volume varies function of flour type and inulin DP. For the addition of 5% and 7.5% of inulin with a higher DP, they obtained a decrease in specific volume, but for 2.5% addition they didn't notice any significant changes. For the inulin with a lower DP, for the same doses added in their bread recipe, specific volume increases or decreases function of the flour type used.

Inulin enrichment also increases crumb hardness (Poinot *et al*., 2010; Hager *et al*., 2011; Rubel *et al*., 2015) even more if chain length inulin type is longer (Rubel et al., 2015; Peressini and Sensidoni, 2009). This increased crumb hardness was attributed to the reduction in the dough gas retention capacity due to the interaction of the fibres with the gluten network (Mandala *et al*., 2009; Morris and Morris, 2012). However Wang *et al.* (2002) found that inulin addition has no significant effect on cohesiveness and springiness but increases breadcrumb chewiness. Regarding crumb grain uniformity, Rubell *et al.* (2015) found that it decreases up to 2.5 g inulin addition, probably due to a disproportionate growth of gas cells during fermentation and/or baking and increases to 5.0 g inulin addition or has no effect determined by inulin chain length.

Because different authors find different results regarding bread quality function of level of inulin addition, the objective of the present work was to determine the optimum level of inulin and water addition in order to obtain bread with a high quality by using Response Surface Methodology. We vary water addition in bread recipe because different studies reported that dough water absorption decreased with increasing inulin contents (Wang *et al*., 2002; Hager *et al*., 2011; Meyer and Peters, 2009; Peressini and Sensioni, 2009) even more with the increased dose of inulin addition, probably due to low molecular weight sugars and oligosaccharides from commercial inulin, which reduces dough consistency (Perssini and Sensiodni, 2009). Therefore it is important to study the effect of water-inulin systems on bread-making quality of wheat flour and to optimize a formulation of wheat bread with inulin addition at different water levels. To the author's knowledge, there is no published work on the optimum inulin-water addition that may be used in the bread in order to obtain an optimum bread quality by using general factorial design.

Materials and methods

Basic ingredients

The research has been carried on 650 flour type (harvest 2012) obtained from S.C. Oltina Impex Prod Com SRL (Urlaţi, Prahova, Romania). The flour used in the experiments presents the following characteristics: moisture content 14.5%, ash content 0.65%, protein content 12%, wet gluten content 30%, gluten deformation index 5 mm, falling number 350 s. The chemical composition of the flours was determined according to Romanian or international standard methods: moisture (ICC-Standard Method No. 110/1, 1982), wet gluten content (ICC-Standard Method No. 106/1, 1984), gluten deformation index (SR-Romanian Standard Method No. 90, 2007), ash content (ICC-Standard Method No. 104/1, 1990) and falling number index (ICC-Standard Method No. 107/1, 1995).

As an inulin product, an instant inulin was used (with its commercial name Fibruline Instant), with a soluble fibre content of 88% derived from chicory root produced by Cosucra (Belgium).

Baking process and bread analysis

The bread formula contained flour (100 g), dried yeast (2 g), sodium chloride (2 g), inulin (0, 2.5, 5 and 10%) and deionized water (45, 50, 55 and 60%). The ingredients were added into a mixer and were kneaded for 20 minutes, then subjected to resting for 3 minutes prior to rounding and sheeting by hand fermented at 38^{o}C for 70 min and RH 95% and baked at 200^{o}C for 30 min. Bread quality was evaluated 1 h after baking. With respect to bread quality characteristics, we determined loaf volume, porosity and elasticity according to SR-Romanian Standard Method No. 91 (2007).

Design of the experiment

The effect of the four levels (0, 2.5, 5 and 10%) for the dose of Firuline Instant added in wheat flour and the effect of four levels (45, 50, 55 and 60%) for water absorption of wheat flour dough on some physical parameters of bread, i.e. loaf volume, porosity and elasticity, as dependent variables, were investigated using the response surface methodology (RSM) by means of general factorial design with two independent variables. The complete experimental design required 16 experimental runs (Table 1). RSM and factorial design with two factors and four different levels were generated by the Stat-Ease Design Expert 7.0.0 software package (trial version). Based on the experimental design results, the quadratic models were developed to predict the loaf volume, porosity and elasticity of samples as a functional combination of design variables, Fibruline Instant levels added in wheat flour and level of water absorption of wheat flour dough. The models obtained for physical parameters of bread were statistically validated using *F*-ratio test. The graphical response surfaces analysis was employed to identify and discuss the main interaction effects of independent variables on dependent variables or responses (*Y*).

Table 1. General factorial design: coded and actual values of independent variables

Experimental design points	Independent variables			
	Fibruline Instant		Water absorption	
	Coded value	Actual value (%)	Coded value	Actual value (%)
1	-0.50	2.50	0.33	55.00
2	0.00	5.00	0.33	55.00
3	-1.00	0.00	0.33	55.00
4	-1.00	0.00	1.00	60.00
5	1.00	10.00	-0.33	50.00
6	0.00	5.00	-1.00	45.00
7	1.00	10.00	0.33	55.00
8	-1.00	0.00	-1.00	45.00
9	0.00	5.00	-0.33	50.00
10	1.00	10.00	-1.00	45.00
11	-1.00	0.00	-0.33	50.00
12	-0.50	2.50	-1.00	45.00
13	0.00	5.00	1.00	60.00
14	-0.50	2.50	1.00	60.00
15	-0.50	2.50	-0.33	50.00
16	1.00	10.00	1.00	60.00

Statistical analysis

A second order regression equation (Eq. (1)) was fitted to the data by a multiple regression method. The result is an empirical model that related the response measured to the independent variables of the experiment.

$$Y = \beta_o + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \beta_{11} \cdot X_1^2 + \beta_{22} \cdot X_2^2 + \beta_{12} \cdot X_1 \cdot X_2 \quad (1)$$

where Y is the response variable; β_o is a constant; β_1, β_2, β_{11}, β_{22} and β_{12} are the linear, quadratic and interaction coefficients, respectively, and X_1, X_2 are the independent variables. The Stat-Ease Design Expert 7.0.0 software (trial version) was employed for the regression analysis, analysis of variance (ANOVA) and to build the response surface, at a 95% confidence level. The models of each response were expressed in terms of coded values of the independent variables and only the statistically significant terms ($p < 0.05$) have been used to analyze the behavior of the fitted mathematical models.

The optimal value of the independent variables level of Fibruline Instant adding in wheat flour and level of water absorption wheat flour was performed by the multiple-response analysis called desirability function, proposed by Derringer and Suich (Derringer and Suich, 1980). The desirability functions involve transformation of each predicted response into an individual desirability function, d_n, which includes the desires and researcher's priorities when building the optimization procedure for each of the independent variables (Myers and Montgomery, 1995). The individual desirability functions are then combined into a single composite response, namely overall desirability function, D ($0 \leq D \leq 1$), computed as the geometric mean of the individual desirability function d_n. A high value of D indicates the more desirable and the best combination of independent variables, which is considered as the optimal solution of this formulation that generated the best results for physical parameters of bread.

Results and discussion

Statistical analysis and response surface

The experimental data obtained, after Response Surface Methodology (RSM) using general factorial design with two independent variables were applied, and were evaluated by multivariate regression methodology for fitting the second-order regression model. The regression analysis was carried out to examine the significant or non-significant effects of the process variables, level of Fibruline Instant addition in wheat flour and level of water absorption wheat flour on the responses measured, physical parameters of bread, at $p < 0.05$ significance level.

The ANOVA results highlight that the regression models obtained for dependent variables were statistically relevant, with a significance level ranging from $p < 0.0001$ to $p < 0.001$.

The fitted models represented well the experimental data with high coefficients of determination (R^2). The values of R^2 indicated that above 80% of the variability in response could be explained by each model. These results show that the models fitted for the loaf volume, porosity and elasticity of bread lead to significant regression, low residual values and no lack-of-fit. Figures 1, 2 and 3 show the effect of level of Fibruline Instant added in wheat flour and water absorption level of wheat flour on loaf volume, porosity and elasticity of bread.

Loaf volume of bread samples

The regression model calculated for loaf volume of the bread was:

$$Y_1 = 371.73 - 7.59\, X_1 - 16.64\, X_1X_2 - 10.30\, X_1^2 - 11.39\, X_2^2 \quad (2)$$

where Y_1 is the loaf volume response (cm^3/100g) and X_1 and X_2 are the real values of Fibruline Instant level added in wheat flour (%) and water absorption level (%), respectively. The regression model (Eq. 2) indicated that loaf volume was highly significant ($p < 0.0001$) for the linear term of Fibruline Instant level and for the interaction term between Fibruline Instant level added in wheat flour and water absorption level. The negative coefficient of the first order term of Fibruline Instant level indicated that loaf volume of sample decreased with the increase of Fibruline Instant level added in wheat flour. ANOVA for the quadratic model as fitted to experimental results showed significance ($p < 0.05$), whereas lack-of-fit was insignificant ($p > 0.05$). The loaf volume of bread ranged from 320 to 375 cm^3/100g for the samples formulation. Decrease in loaf volume of bread with the increase in Fibruline Instant level added in wheat flour may be attributed to the dilution effect due to the interaction of the inulin with the gluten network (Mandala *et al.*, 2009).

The effect of Fibruline Instant level and of water absorption of wheat flour formulation on loaf volume of bread samples is shown in Figure 1. An increase in Fibruline Instant level value added in wheat flour led to a decrease in the loaf volume of bread value.

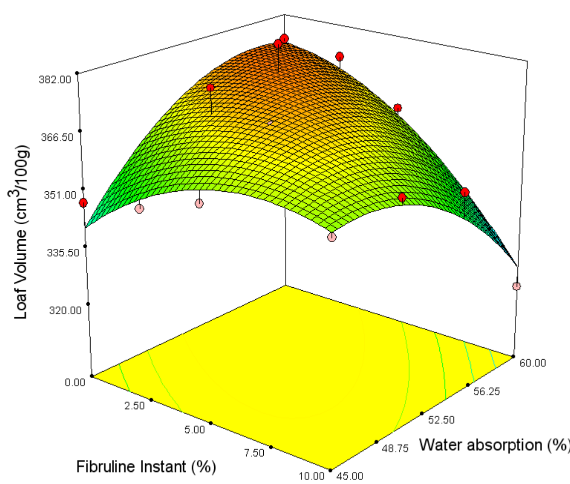

Figure 1. Response surface plot showing the combined effects of Fibruline Instant level and water absorption level of wheat flour on loaf volume of bread samples

Porosity of bread samples

The quadratic model describing bread porosity as a simultaneous function of Fibruline Instant added in wheat flour and of water absorption is presented as follows:

$$Y_2 = 84.16 + 3.02\ X_2 - 4.96\ X_1X_2 - 3.550\ X_1^2 - 3.80\ X_2^2 \qquad (3)$$

where Y_2 is the porosity response.

Porosity of bread sample was significantly affected ($p < 0.0001$) by water absorption (X_2) and by the interaction term between the level of Fibruline Instant added in wheat flour and the level of water absorption (X_1X_2). The quadratic terms of Fibruline Instant level and water absorption level were found to be significant ($p < 0.05$). The regression model (Eq. (3)) fitted to the experimental results of bread porosity showed higher coefficient of determination ($R^2 = 0.8098$). The *F*-value for porosity was significant ($p < 0.01$). The porosity of bread samples increased significantly ($p < 0.01$) as the level of water absorption increased. This may be probably caused by the gelatinization delay due to inulin addition which will lead to a faster bubble inflation that gives a higher proportion of finer cells (Peressini and Sensidoni, 2008). A later gelatinization onset is also likely to have an impact by failing to trap the gas bubble as they form (Morris and Morris, 2012). Also, native inulin contains large molecules which form relatively strong gels according to Chivarro *et al.* (2007). It may be integrated in bread cellular structure which will improve its stability and gas-holding capacity (Rosell *et al.*, 2010) and, therefore, its porosity.

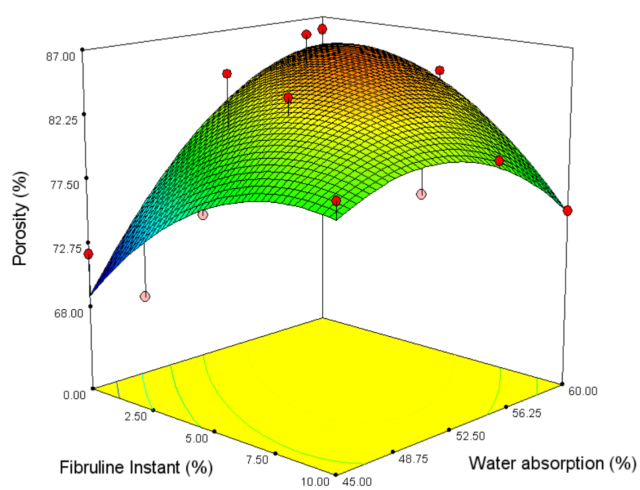

Figure 2. Response surface plot showing the combined effects of Fibruline Instant level and water absorption level of wheat flour on porosity of bread samples

The effect of wheat flour and Fibruline Instant levels added in wheat flour and of water absorption levels on bread porosity is shown in Figure 2. Response surface plot showed that an increased level of water absorption increased bread porosity. The results obtained are in agreement with those obtained by Karolini-Skaradzińska *et al.* (2007).

Elasticity

The model of response surface for bread elasticity is represented by the equation (4):

$$Y_4 = 92.87 + 3.20\ X_2 - 7.42\ X_1X_2 - 7.23\ X_1^2 - 6.47\ X_2^2 \qquad (4)$$

where Y4 is the bread elasticity response. The results of the regression analysis for the elasticity demonstrated that the linear term of water absorption level value as well as the interaction term between Fibruline Instant level and water absorption level were statistically significant. All quadratic regression coefficients showed the negative effect on bread elasticity. The increased level of water absorption led to an increase in bread elasticity value as shown in Figure 3.

Also, it was observed that the decreased value of interaction between Fibruline Instant level and water absorption level increased bread elasticity probably due to changes that occurred in starch structure. Inulin competes for water with starch and showed preferential water binding effects (Collar *et al.*, 2006). It is known that inulin is highly hygroscopic and reduces water availability for dough constituents (Genaro *et al.*, 2000). This will affect the pasting and gelatinization characteristics of the dough system. The replacement of starch with inulin leads to a decrease in water absorption and reduction of dough consistency (Peressini, 2005). Therefore an increase of water content will conduct to equilibrium of dough system and it will improve dough rheological characteristics and therefore bread quality including its elasticity in agreement with results obtained by Salinas and Puppo (2015).

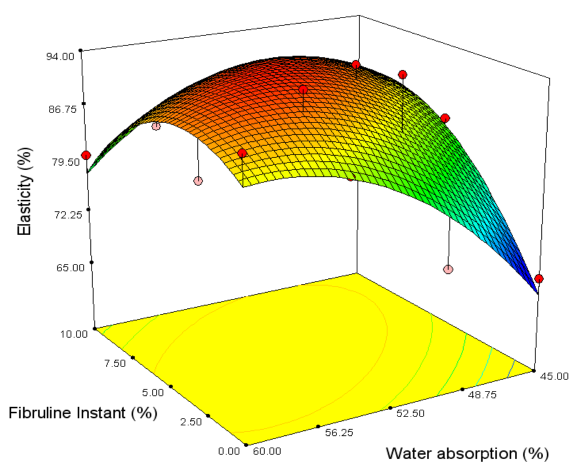

Figure 3. Response surface plot showing the combined effects of Fibruline Instant level and water absorption level of wheat flour on elasticity of bread samples

Optimization

Multiple response optimizations were performed to determine the optimum levels of Fibruline Instant and water absorption to achieve the desired response goals. Simultaneous optimization was performed by imposing some constraints such as maximum loaf volume, maximum porosity and elasticity. The best combinations between these independent variables used in the study in order to obtain optimum values for some physical parameters of bread were extracted by State-Ease Design Expert software that performs from the thousands of iterations and calculations the maximum desirability value and the final conditions. On account of these calculations, a total desirability value (D) of 0.895 was obtained for the optimum level of independent variables that indicate a Fibruline Instant level of 3.52% added in wheat flour and water absorption of 55.62%. The response-surface plot corresponding to D value is represented in Figure 4, where the coordinates of D value represent the optimum conditions. The best combination of independent variables used in this study is obtained at the top of the graph. Under these optimum conditions, the predicted loaf volume of 373.08cm^3/100g, bread porosity of 85.07 and elasticity of 92.57 were obtained.

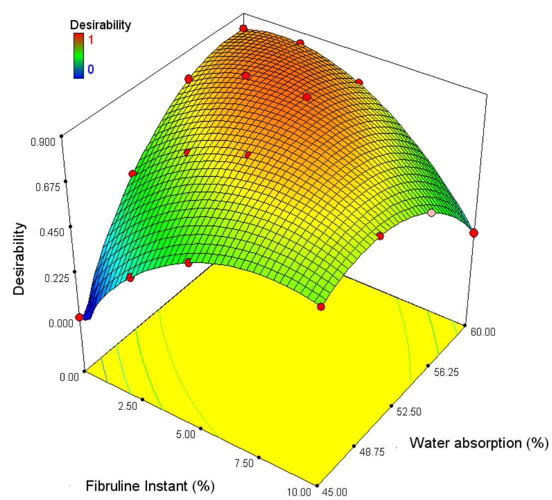

Figure 4. Response surface plot of the total desirability function

Conclusions

Fibre enrichment of wheat flour bread with different doses of native inulin produced significant changes in bread quality characteristics, due to the diluting effect, producing bread of unacceptable quality at high doses of native inulin addition. However, additions of a lower concentration of native inulin improve significantly bread quality characteristics, i.e. loaf volume, elasticity and porosity. In order to obtain an optimum of fiber native inulin bread quality by varying the level of water addition, the response surface methodology was effective. Optimum bread at 3.52% native inulin addition at 55.62% water absorption could be obtained. Values of bread quality characteristics were experimentally validated by the regression models based on desirability functions.

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