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Modeling the Effects of the Quantity and Particle Size of Wheat Bran on Some Properties of Bread Dough using Response Surface Methodology

Abstract: The aim of this study was to find empirical models for some properties of bread dough as a function of bran concentration and particle size using D-Optimal made by Design Expert Software. Wheat flour was replaced with 0, 5, 10, 15 and 20% (w/w, flour basis) wheat bran at particle sizes of 170, 280, 425 and 750 μm. Increasing bran concentration and particle size enhanced dough water absorption. Dough arrival and development times increased, while dough stability time, tolerance to mixing and volume rising decreased as the bran particle size and concentration increased. The dough became darker, more reddish and yellower with increasing bran concentration and particle size. Dough hardness increased while cohesiveness decreased with addition of bran concentration and particle size. In general, strong correlations between dough properties with bran quantity and particle size were established. Bran concentration had stronger effect on dough properties compared to its particle size.

Keywords: bread dough, particle size, response surface methodology, rheological properties, wheat bran

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1 Introduction

Wheat bran contains nutritional compounds that can be beneficial for human health. It is a rich source of dietary fiber, proteins of high biological value and is a good source of B-group vitamins, some minerals and antioxidants. The major component of wheat bran is insoluble dietary fiber (46.85%) including cellulose and lignins and a small amount of soluble fiber such as β-glucan and arabinoxylan (2.80%) [1]. The positive effects of dietary fibers on human health have been well documented. Many common diseases such as constipation, diverticulosis, cardiovascular disease and cancer are related to the lack of adequate dietary fiber in the diet. Among different foods, bread has been recognized as a suitable food to convey dietary fibers in human diet due to its high consumption around the world [2]. Accordingly, many studies have been conducted to determine the effects of wheat bran on the quality of dough and bread. Sidhu et al. [3] reported that the toasts containing wheat bran and germ had superior nutrition value compare to the whole wheat toasts. Başman and Köksel [4] studied the properties and composition of a Turkish flat bread (Bazlama) supplemented with barley flour and wheat bran. Shenoy and Prakash [5] reported that inclusion of more than 5% wheat bran in unleavened flat breads could decrease the sensory attributes of the samples. Sanz Penella et al. [6] reported that bran concentration and particle size had great influence on dough and bread quality. Noort et al. [7] studied the effects of bran particle size on pan bread quality. They indicated that fiber–gluten interactions were the main cause for the negative effects of the bran. Hemery et al. [8] used ultra-fine wheat bran in bread recipe in order to increase the bio-accessibility of bran antioxidant. The effects of different particle sizes and levels of wheat bran on the quality of Barbari bread produced from wheat flour (87% extraction rate) were studied. The results showed that the maximum level of 15% bran with particle size of 280 μm resulted in a bread with improved nutrition quality and acceptable quality [9].

The considerable number of studies related to the addition of bran to bread recipe shows the interest in the development of bran-enriched breads and to find methods to overcome problems that occur as a result of bran inclusion in bread recipe including dough hardness, dark bread color, grainy bread texture and unpleasant mouthfeel. Described adverse effects can be diminished in variable extent with the addition of vital gluten, surfactants and surfactant/shortening blends, with the use of high-grade flours and with incorporation of hemicellulase enzymes [10, 11]. Removing of the epicarp hairs by pearling improved significantly the baking performance of the resulting flour [12]. Bran washing, grinding, dry heating, fermentation with yeast or yeast and lactic acid bacteria can improve texture, volume and shelf-life of the fiber-enriched bread [13, 14]. Addition of different fibers such as insulin, pea fiber and sugar beet fiber, particularly their combination can improve dough handling, machinability and gas retention [15].

One of the statistical methods for determination of the effects of multiple factors on product properties is the response surface methodology. Response surface methodology is a statistical–mathematical method which uses quantitative data in an experimental design to determine and simultaneously solve multivariate equations, to optimize processes or products [16]. Using this method, it is possible to evaluate multiple parameters and their interactions using quantitative data, effectively optimizing complex extraction procedures in a statistical way and reduce the number of experimental trials required. This method has been used already for optimizing processing condition, characterization or development of new products [17–19].

The main objective of this study was to introduce empirical models that determine the effects of wheat bran particle sizes (170, 280, 425, 750 µm) and concentrations (0, 5, 10, 15 and 20%, w/w, flour basis) on some physical properties of bread dough produced by straight dough method. This type of dough is commonly used for production of a number of loaf and flat breads. The main statistical method used to determine such effects was response surface methodology.

2 Materials and methods

2.1 Materials

Wheat flour with extraction rate of 87% (weight of flour obtained from 100 unit weight of clean grain × 100) and coarse wheat bran with average particle size of 1,000 µm was a gift by Sepidan milling factory in Zarghan, Fars, Iran. The flour used in this study is commonly used in production of some frequently consumed flat breads in Iran such as Lavash and Barbari. Active dry yeast (*Saccharomyces cerevisiae*) (Bakery Chef, France) and iodine free table salt (NaCl) were purchased from the local market. Other chemicals used in this study were purchased from Merck, Germany.

2.2 Production of bran with different particle sizes

Course wheat bran was first milled using a laboratory mill (Alexanderwerck, Model WEL82, Germany) and then sieved manually using a multi-tray sieve (ASTM E:11, Iran). The particles remained between the sieves with mesh size of 70–120 had particle sizes in the range of 125–210 µm (average particle size of 170 µm), those collected between the sieves with mesh size of 45–70 had particle sizes in the range of 210–354 µm (average particle size of 280 µm), the brans remained between the sieves with mesh size of 35–45 had particle sizes in the range of 354–500 µm (average particle size of 425 µm) and those obtained from the sieves with mesh sizes of 18–35 had particle size in the range of 500–1,000 µm with an average particle size of 750 µm. Total dietary fiber content of different particle sizes of the bran was determined according to the method described by Prosky et al. [20].

2.3 Water absorption and empirical rheological properties of the dough

A Farinograph (Brabender, FE022-NK, Germany) with a 50 g mixing bowel was used to evaluate the impact of the bran concentration and particle size distribution on the Farinograph parameters following the official standard method [21]. Water absorption (percentage of water required to yield a dough consistency of 500 BU), dough arrival time (the time for the curve to reach 500 BU of consistency), dough development time (the time to reach maximum consistency), dough stability time (the time that the dough consistency was kept at 500 BU), dough softening (the consistency difference between height at peak and that 12 min later) were determined.

2.4 Bread dough making procedure

The bread dough formula consisted of wheat flour replaced with bran at different concentrations for each particle size, wheat flour (300 g), yeast (3.0% flour basis), salt (2.0% flour basis) and water (based on the Farinograph water absorption). The dough was made according to the straight dough method procedure [22]. The ingredients were mixed for 10 min at speed of 2 in a laboratory dough mixer (Iypto, Model

EB12, Germany). After mixing the dough temperature was 22 ± 1°C. The dough was then divided into 50 g pieces, rounded by hand and placed in pre-greased pan. The dough was proofed in a cabinet prover for 1 h at 30°C with 80% relative humidity.

2.5 Volume rising during proofing

Before proofing, a piece of dough (50 g) was placed in a beaker and the top of the dough was flattened using a plastic spoon. Then it was placed in the proofing cabinet for 1 h at 30°C with relative humidity of 80%. The volume rise of the dough during proofing was determined from the difference between the final and initial volumes of the dough.

2.6 Dough machinability

Dough machinability was assessed using a texture analyzer (TA-XT2, Stable Micro Systems Ltd., Surrey, UK). An aluminum cylindrical plunger with smooth inside wall (20 × 20 mm) was prepared. The plunger was fully filled with about 7 g of the dough and then emptied by slowly pushing a plastic bar (1.8 × 2.0 mm) at one side of the plunger until the dough was removed and placed on the sample plate of the texture analyzer. The position of the dough wad adjusted carefully and a pre-test with speed of 5.0 mms^{-1} and a test speed of 1.0 mms^{-1} were performed to determine the textural properties of the dough. An aluminum cylindrical probe with 70 mm diameter was applied to measure the required compression force. Force required to compress 25% of the dough was recorded. From the force–distance curve, the ratio of the positive area under the first and second compression was defined as cohesiveness. Maximum force of first bite of texture profile analysis (TPA) test was taken as indications of dough hardness [23, 24].

2.7 Color of the dough

Color of the dough before proofing was evaluated using digital camera according to the method described by Afshari-Jouibari and Farahnaky [25]. High-resolution pictures were taken separately from whole dough surface by a digital camera (Canon PC-1251, Japan). Resolution, contrast and lightness of all images were set to 200 dots per inch (dpi), 62 (%) and 62 (%), respectively. The pictures were saved in JPEG format and analyzed quantitatively using the Adobe Photoshop 8 software installed on a computer and the color parameters of "L" (lightness), "a" (redness-greenness) and "b" (blueness-yellowness) were determined in the "Lab" mode of the software.

2.8 Modeling of data using response surface methodology

Software of Design Expert 6.0.2 (State Ease, USA) and D-optimal Response mode were used in order to model and estimate any non-linearity in the relationships between the concentration and particle size of the wheat bran and dough properties (i.e. water absorption, Farinograph parameters, volume rise, color and machinability) and to obtain the best model (i.e. quadratic model). All variables and their interactions with significant effect in each model were kept and any variable or interactions without significant effect were removed as indicated by the software [26]. Different concentrations of each particle size and the number of replicates as determined by the software are given in Table 1.

Table 1 Different treatments as determined by the Design Expert software for the effect of bran particle size and concentration on bread dough

Experiment number	Particle size (μm)	Bran concentration (%)
1	750	20
2[a]	–	0
3	750	10
4	750	20
5	750	15
6	750	5
7[a]	–	0
8	425	20
9	425	10
10	425	10
11[a]	–	0
12	425	5
13	425	15
14	280	10
15	280	10
16	280	10
17	280	5
18	280	20
19	280	15
20[a]	–	0
21	170	20
22[a]	–	0
23	170	10
24	170	20
25	170	15
26	170	5

Note: [a]Control sample.

3 Results and discussion

Total dietary fiber content of the bran with different particle sizes is given in Table 2. Based on the results with reducing bran particle size, the fiber content reduced significantly. The highest fiber concentration was 74.30% obtained for the bran with particle size of 750 µm, while the lowest amount of fiber was 59.10% for the finest bran (i.e. 170 µm). The results are in agreement with Majzoobi et al. [27, 28] who showed that the total fiber content of wheat bran reduced significantly with reducing bran particle size from 1,000 µm to 90 µm. This is mainly due to the differences in the chemical composition of different bran layers. Fine brans are obtained from inner layers of the bran which contain less fiber than the outer layers, while course brans are obtained from outer layers of the brans with higher fiber content. Changes in the chemical composition of the bran with reducing particle size particularly its fiber content can affect bran functional properties in the dough.

Table 2 Total dietary fiber content of the brans with varying particle sizes

Bran particle size (µm)	Total dietary fiber (%)
750	74.30 ± 0.30^a
420	68.20 ± 0.20^b
280	61.20 ± 0.40^c
170	59.10 ± 0.30^d

Notes: Values are the mean of triplicates ± standard deviation. Analysis of variance was performed to determine the statistical differences between the averages. Different letters indicate statistical differences ($p < 0.05$).

Determination of the water absorption of the dough samples containing different concentrations of bran with varying particle sizes (Figure 1) showed that the increase in bran concentration and particle enhanced dough water absorption mainly due to the increase in fiber content of the brans (see Table 2). The large number of hydroxyl groups of the bran hydrocolloids allows more water interactions through hydrogen bonding. Similar findings were reported for the dough containing wheat bran [6, 29], different hydrocolloids [30], carob and pea fibers [31] and barley fiber-rich fraction [32]. According to Zhang and Moore [33], the water-holding capacity of the bran decreased when the mean particle size decreased from 609 to 278 µm. Nevertheless, Sanz Penella et al. [6] applied bran with different particle sizes in the range of 1,000–300 µm in a bread recipe reported an increase in water absorption by reducing bran particle size that was related to the larger surface area of the finer bran. In the current study, it was found that the effect of bran concentration was more pronounced compared to that of bran particle size. The empirical model obtained from Design Expert software (Table 3) indicates the positive effects of bran particle size and concentration on water absorption of the dough with high correlation ($R^2 = 0.97$).

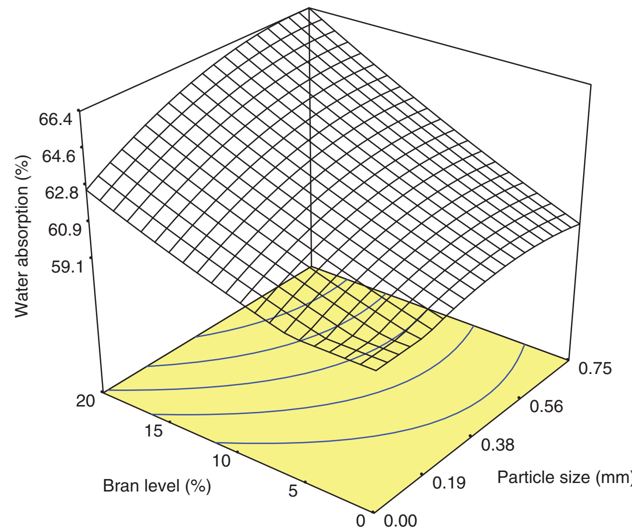

Figure 1 Water absorption of the dough as a function of quantity and particle size of the bran

Dough arrival time is the time when the curve touches the 500 BU line and indicates the rate of flour hydration. Dough development time is reached when the Farinograph is at the highest point on the curve and indicates when the dough has reached its maximum consistency before gluten strands begin to break down. The results showed that dough arrival and development times increased as the bran concentration increased particularly to above 10% (Figure 2A and B). This is in agreement with the previous results of Zhang and Moore [33], Laurikainen et al. [10] and Sanz Penella et al. [6]. Dough arrival and development times increased slightly as the bran particle size increased. It may be attributed to the interactions between fibers and gluten that prevents protein hydration and affects aggregation and disaggregation of the high molecular weight proteins in the dough [15]. The empirical models obtained from Design Expert software for the effects of particle size and concentration on dough arrival and development times are given in Table 3. High correlations between bran concentration and particle size with dough arrival time ($R^2 = 0.97$) and dough development time ($R^2 = 0.83$) were found.

Table 3 Equations obtained in the D-Optimal mode of response surface methodology (given by Design Expert software) in terms of actual factors: effect of wheat bran concentration (%) and particle size (μm) on each measured parameter of the bread dough. Squared regression coefficient (R^2) between the actual and predicted values is given

Parameter	Equations in terms of actual factors: effects of bran concentration and particle size on dough properties	R^2
Water absorption (%)	$58.10 + 7.30\text{PS}^{a} + 0.16\text{BL}^{b}-7.5\ \text{PS}^2 + 3.05 \times 10^{-3} \times \text{BL}^2 + 0.16\text{PS} \times \text{BL}$	0.97
Dough development time (min)	$2.90 + 3.76\text{PS}-0.26\text{BL}-3.04\text{PS}^2 + 0.01\text{BL}^2 + 0.05\text{PS} \times \text{BL}$	0.83
Dough stability time (min)	$8.72-6.4\text{PS}-0.11\text{BL} + 10.75\text{PS}^2 + 9.5 \times 10^{-3}\text{BL}^2-0.05\text{PS}^2 \times \text{BL}-5.39\text{PS}^3-4.8 \times 10^{-4}\text{BL}^3-0.05\text{PS}^2 \times \text{BL} + 0.015\text{PS} \times \text{BL}^2$	0.98
Dough arrival time (min)	$1.17 + 1.85\text{PS}-0.12\text{BL}-2.00\text{PS}^2 + 7.06 \times 10^{-3}\text{BL}^2 + 0.11\text{PS} \times \text{BL}$	0.97
Dough softening (BU)	$59.9 + 31.35\text{PS}-2.05\text{BL}-22.44\text{PS}^2 + 0.10\text{BL}^2 + 1.87\text{PS} \times \text{BL}$	0.91
Volume rising (mL^3)	$122.13 + 2.85\text{PS}-0.45\text{BL}-17.51\text{PS}^2 + 0.04\text{BL}^2-2.81\text{PS} \times \text{BL}$	0.95
L-value	$66.15-5.15\text{PS}-0.23\text{BL} + 3.08\text{PS}^2-5.01 \times 10^{-3}\text{BL}^2-0.13\text{PS} \times \text{BL}$	0.97
a-value	$-3.70 + 12.27\text{PS} + 0.29\text{BL}-12.70\text{PS}^2-6.13 \times 10^{-3}\text{BL}^2 + 0.11\text{PS} \times \text{BL}$	0.93
b-value	$22.92 + 17.92\text{PS} + 38.00\text{BL}-9.38\text{PS}^2 + 2.72 \times 10^{-3}\text{BL2}-0.72\text{PS} \times \text{BL}$	0.45
Hardness (*N*)	$1.56-0.52\text{PS} + 3.89\text{BL} + 0.77\text{PS2}-1.90 \times 10^{-4}\text{BL}^2 + 0.63\text{PS} \times \text{BL}$	0.97
Cohesiveness	$0.90-0.36\text{PS}-9.77\text{BL} + 0.32\text{PS}^2 + 9.99 \times 10^{-5}\text{BL}^2-0.011\text{PS} \times \text{BL}$	0.93

Notes: [a]Particle size; [b]Bran concentration.

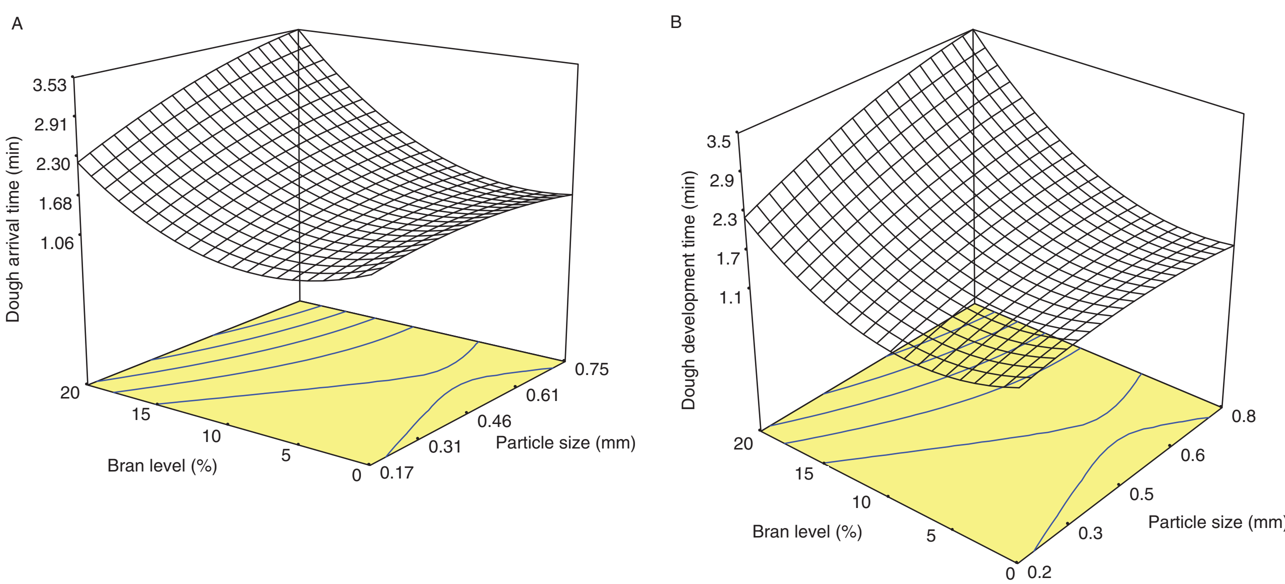

Figure 2 Dough arrival time (A) and development time (B) as a function of quantity and particle size of the bran

Dough stability time corresponds to the time that the dough maintains on its maximum consistency of 500 BU and is a good indication of dough strength. Dough stability decreased by increasing bran concentration and particle size (Figure 3); however, the effect of bran concentration was more pronounced. The results are in agreement with Sudha et al. [34], Zhang and Moore [33], Rosell et al. [15] and Sanz Penella et al. [6]. Increasing bran concentration may have diluting effect on gluten content of the dough, thus reducing the strength and stability of the dough. Increasing bran particle size may inhibit association and formation of gluten network reducing dough stability time. Rosell et al. [15] indicated that dough stability time has negative correlation with dough softening which was also observed in this study by comparing Figures 4 and 5. The empirical models obtained from Design Expert software for the effects of particle size and concentration on dough stability time are given in Table 3 with high correlation coefficient ($R^2 = 0.98$).

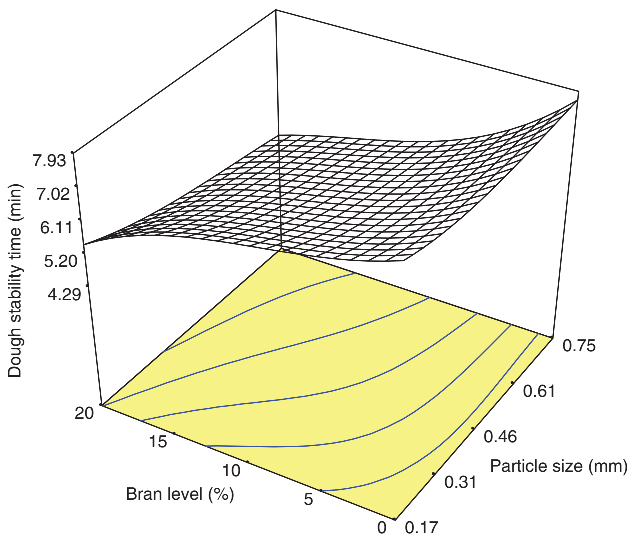

Figure 3 Dough stability time as a function of quantity and particle size of the bran

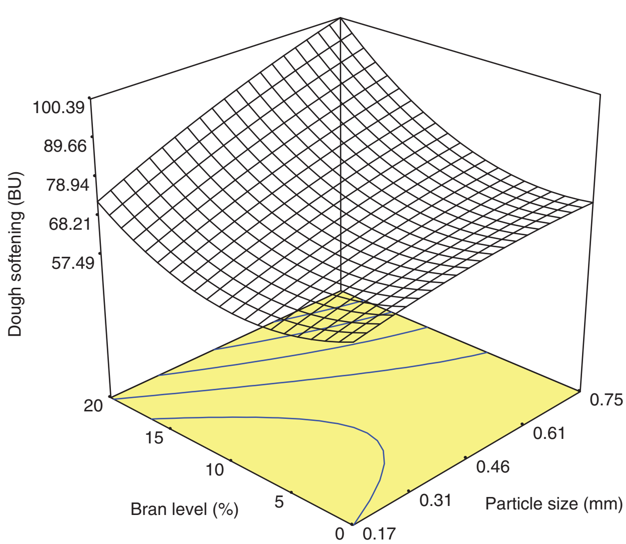

Figure 4 Dough softening as a function of quantity and particle size of the bran

Dough softening is obtained by taking the difference between the peak time point and 12 min after peak time is reached. This is used to determine the amount that a dough will soften over a period of mixing. Higher dough softening is expected for softer and weaker dough. The results (Figure 4) showed that increasing the bran particle size and concentration increased dough softening which means that the dough became less tolerant to mixing. Sanz Penella et al. [6] also found similar effect with bran concentration while they found negative effect of bran particle size on dough softening. The empirical model

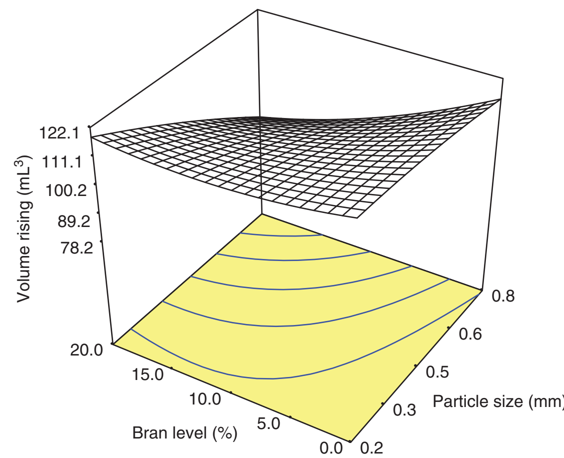

Figure 5 Volume rise of the dough as a function of quantity and particle size of the bran

obtained from Design Expert software for the effects of particle size and concentration on dough softening is given in Table 3 with strong correlation ($R^2 = 0.91$).

The results (Figure 5) showed that increasing the quantity and particle size of the bran (up to 20% and 750 μm, respectively) had negative effect on dough volume rising during proofing. Wang et al. [31] suggested that the interactions between proteins and bran prevent the free expansion of the dough during proofing, which decreased the dough height. Decrease in the dough height and gas retention may also be due to the collapse of dough structure during fermentation by incorporation of bran. It is probable that particulate components could create areas of weakness in the expanding dough resulting in lower height [35]. Additionally, dilution of the gluten as the main component to hold CO_2 produced during fermentation, maybe another reason retarding dough rising. Furthermore, increasing the hardness of the dough by inclusion of the bran (see Figure 7) may prevent dough rising. Negative correlation between bran concentration and particle size with dough rising ($R^2 = 0.95$) was found and the empirical model obtained from Design Expert software is given in Table 3.

Color of the dough can affect the color of the bread. The results showed that the L-value of the dough decreased which means that the dough became darker as the bran quantity and particle size increased (Figure 6A). In addition, the a-and b-values increased with increasing bran concentration and particle size indicating that the dough became more reddish and yellower (Figure 6B and C). The natural pigments of the bran are responsible for such changes. Table 3 shows the empirical model obtained from Design Expert software. Strong

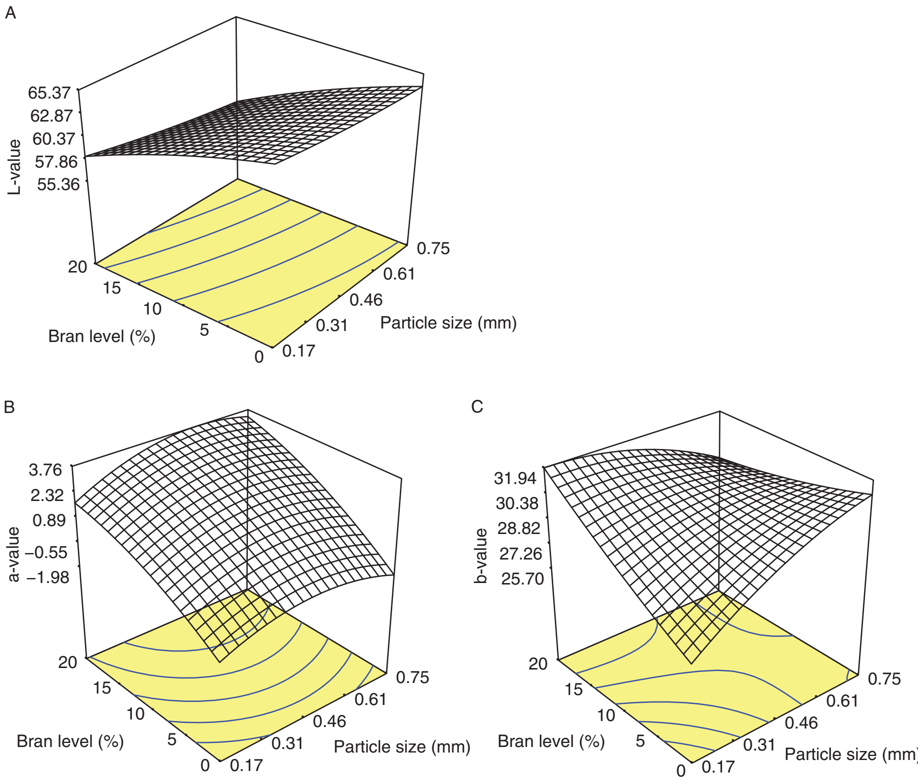

Figure 6 Color parameters of the bread dough containing different concentrations and particle sizes of wheat bran. A: lightness (L-value); B: redness-greenness (a-value) and C: blueness-yellowness (b-value)

correlations between bran concentration and particle size with L-and a-values were found ($R^2 = 0.97$ and 0.93, respectively) while this correlation was weak for b-value ($R^2 = 0.45$).

Determination of the mechanical properties of the dough showed that the hardness increased while cohesiveness decreased as the bran concentration and particle size increased (Figure 7A and B). High correlations between bran particle size and concentration with dough hardness ($R^2 = 0.97$) and cohesiveness ($R^2 = 0.93$) were obtained which is in accordance with Collar et al. [23] who studied the effects of different concentrations (6–34%) of

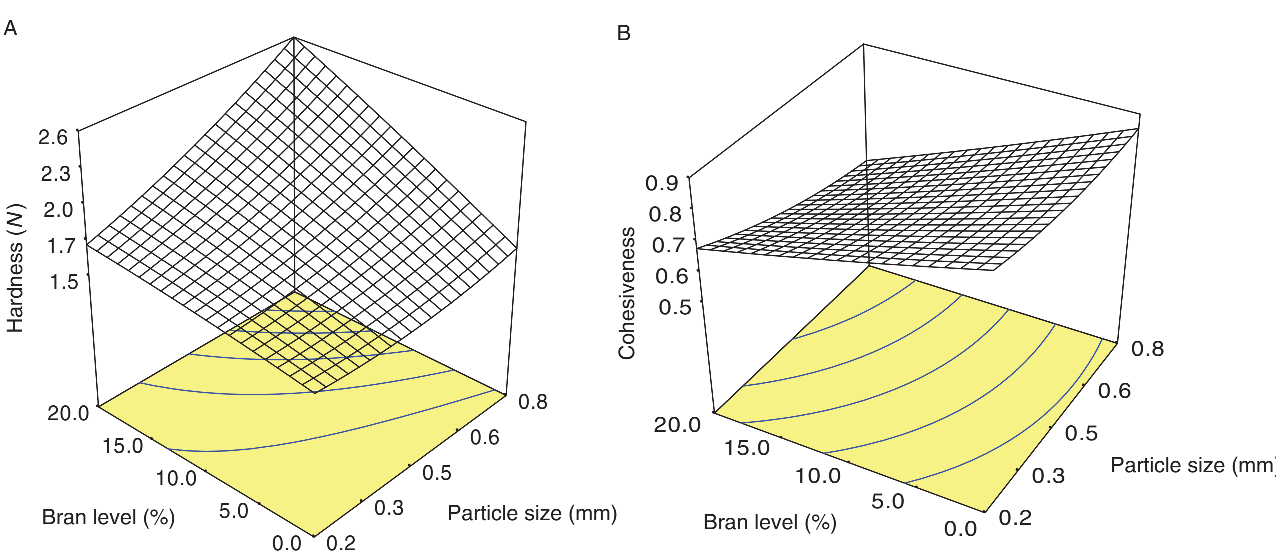

Figure 7 Hardness (A) and cohesiveness (B) of the dough as a function of bran quantity and particle size

various fibers including inuline, pea cell wall and pea hull on bread dough textural profile. Harder dough requires more energy for handling and shaping. Preservation of dough cohesiveness is of great significance since it has been reported as a good predictive parameter of fresh bread quality and keepability [36]. The empirical models obtained from Design Expert software are presented in Table 3. The components present in the dough have great influence on its rheological properties, among them water plays an important role. Bran hydrocolloids such as cellulose and pentosans can absorb water and decrease lubricating effect of water resulting in hardness of the dough. In addition, they can interact with gluten protein and limit its network formation that would limit dough viscoelasticity. The presence of bran particles in the dough can negatively affect homogeneity and cohesiveness of the dough. Dough rise during fermentation is also hindered with dough that is too strong that was observed in the previous results of this study (see Figure 5). It is expected that the handling and shaping of hard dough to be difficult as compared to the control.

4 Conclusion

The effect of concentration of addition and particle size of wheat bran on some characteristics of bread dough produced by straight dough method was investigated and empirical models were obtained. The parameters that define dough properties were affected by bran supplementation concentration and particle size. Nevertheless, bran concentration had stronger effect on dough properties compared to its particle size. The concentration and particle size of the bran used in this study have been commonly applied to produce bran bread. Using the empirical models obtained in this study, it is possible to predict dough properties containing other bran concentrations and particle sizes and relate them to some of the properties of the produced bread.

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