DOI: 10.1111/j.1745-4603.2010.00237.x

DEVELOPMENT OF FIBER-ENRICHED BISCUITS FORMULA BY A MIXTURE DESIGN

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Accepted for Publication April 16, 2010

ABSTRACT

The present research studies the optimization of the textural properties of new fiber-enriched biscuit formulae. A mixture design was carried out in order to model the textural properties of dough and biscuit supplemented with Aestivum wheat bran (AWB) and durum wheat bran (DWB). The desirability function was used to determine the coordinates of fiber-enriched biscuit formulae characterized presenting textural properties of dough (hardness, cohesiveness and adhesiveness) and biscuit (maximum peak force) close to those of the commercial product without fiber. Two optimal biscuit formulae (Optimal formula 1 (OM1): 86.66% of wheat flour, 6.67% of DWB and 6.67% of AWB and Optimal formula 2 (OM2): 73.30% of wheat flour, 13.35% of DWB and 13.35% of AWB) were tested at the industrial scale and provided highly acceptable scores from the taste panelists.

PRACTICAL APPLICATIONS

Consumption of dietary fiber provides health benefits including protection against cardiovascular diseases, cancer and other degenerative diseases.

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Journal of Texture Studies **41** (2010) 472–491.

Wheat bran is a readily available and inexpensive source of dietary fiber. In this work, we developed new biscuit formulae enriched with both Aestivum and durum wheat brans. The substitution of wheat flour by wheat brans at their optimum levels led to dietary fiber-enriched biscuits with improved functional and nutritional properties and without undesirable changes in their sensory properties.

KEYWORDS

Biscuit, dietary fibers, mixture design, textural characteristics, wheat bran

INTRODUCTION

Biscuits are the most popularly consumed bakery items in Tunisia and other parts of the world (Hooda and Jood 2005; Sudha *et al*. 2007). Some of the reasons for such a wide popularity are the low cost among other processed foods, varied taste, easy availability and longer shelf life (Gandhi *et al*. 2001; Sudha *et al*. 2007; Ajila *et al*. 2008; Vitali *et al*. 2009). Several health products such as sugar-free, low-calorie and high-fiber products have now become available. One such recent trend is to increase the fiber content in cereal products to overcome health problems such as diverticular disease, constipation, diabetes, obesity, coronary heart disease and bowel cancer (Sudha *et al*. 2007). Several research workers have used fiber sources such as wheat bran, oat bran, rice bran, barley bran, apple, lemon and mango peel powder, among others, to make high-fiber biscuits (Sudha *et al*. 2007; Ajila *et al*. 2008; Vitali *et al*. 2009).

Being a readily available and inexpensive source of dietary fiber, wheat bran is one of the most important dietary fiber sources used in the baking industry (Vetter 1988). Durum and *Aestivum* wheat bran products are commercially available in Tunisia. However, it has also been known that wheat bran is not a standardized product with a defined quality and chemical composition (Zhang and Moore 1997). Indeed, the composition of commercial bran depends upon many factors, which include the wheat class, grain shape and size, thickness of the bran layers, milling system and type of flour produced (Bartnik and Jakubczyk 1989). Wheat bran has been reported to improve the nutritional value of the biscuit (Leelavathi and Rao 1993; Sudha *et al*. 2007; Uysal *et al*. 2007). However, its incorporation into a biscuit-making system at high levels usually alters the dough rheological properties and, hence, the quality and sensory properties of the end product (Larrea *et al*. 2005; Sudha *et al*. 2007). The preservation of the dough cohesiveness is of key importance, as it has been reported to be a good predictive parameter of bakery products' quality and keepability (Armero and Collar 1998). More cohesive doughs, with an internal structure resistant to high stress–strains, resulted in increased water absorption doughs with strengthened gluten and led to softer biscuits with longer shelf life (Collar *et al.* 2007).

As these properties are critical for consumer acceptance of the product, we conducted experiments in order to optimize the fiber-enriched biscuit formula using the mixture design methodology (Cornell 1981, 1983; Myers and Montgomery 1995; Khuri and Cornell 1996; Mathieu and Phan-Tan-Luu 1997; Goupy 2000; Voinovich *et al.* 2009). Mixture designs are among the most widely-used tools for product formulation. They provide polynomial equations and convenient graphical representations to easily predict responses for a wide range of mixtures. To the best of our knowledge, there is limited research on the optimization of fiber incorporation into cereal products formulation using response surface methodology (RSM) (Rosell *et al.* 2006; Collar *et al.* 2007).

Therefore, this study was undertaken to investigate the possibility to partially replace wheat flour with *Aestivum* wheat bran (AWB) and durum wheat bran (DWB) and to find, via RSM, optimum formulation of biscuits that would have rheological properties and consumer acceptance close to that of the commercial product (without fiber addition).

MATERIALS AND METHODS

Materials

Commercial Tunisian soft wheat flour (from wheat milling industry *Grand Moulin du Sud*, Tunisia) having 12.08% moisture, 14.72% protein and 0.60% ash was used in the study. All ingredients used in biscuit production (i.e., wheat flour, shortening sugar, common salt, sodium bicarbonate, ammonia and vanilla) were supplied from a local market in Tunisia. AWB (from soft wheat) and DWB, used to enrich the fiber content in the biscuits, were obtained from a wheat milling industry (Grand Moulin du Sud, Sfax, Tunisia).

Aestivum and durum wheat bran samples were powdered to pass through 350 μm sieve. Tunisian biscuit and corresponding dough (without fiber addition), supplied by "Kif Factory" were used in this work as references.

Methods

Physico-chemical Characteristics of Wheat Brans. Moisture, ash, protein and fat contents were analyzed using standard methods (AACC 2000).

Nitrogen content was estimated using the Kjeldhal method and was converted to protein using factor 5.7. Starch content was evaluated by an enzymatic colorimetric method (Rasmussen and Henry 1990). The amount of soluble dietary fiber (SDF), insoluble dietary fiber (IDF) and total dietary fiber (TDF) was determined according to the gravimetric enzymatic method as previously described by Prosky *et al.* (1988).

The fat absorption capacity was calculated according to the method described by Lin *et al.* (1974). Wheat brans (0.5 g) were mixed with 6 ml of corn oil in pre-weighed centrifuge tubes. The contents were stirred for 1 min with a thin brass wire to disperse the sample in the oil. After a holding period of 30 min, the tubes were centrifuged for 25 min at 3,000 rpm. The separated oil was then removed with a pipette and the tubes were inverted for 25 min to drain the oil prior to reweighing. The fat absorption capacity was expressed as g of oil bound per gram of the sample on a dry basis.

The water-holding capacity (WHC) was determined as described by Chen *et al.* (1988). 1 g of wheat bran was mixed with 50 ml of distilled water vigorously for 1 min and then centrifuged for 15 min at 10,000 rpm at 20C. The supernatant was discarded and the tube was kept inverted for 25 min at 50C. The WHC was expressed as g of water bound per gram of the sample on a dry basis.

Dough and Biscuit Preparations. The biscuits were prepared as described by Hooda and Jood (2005). The ingredients included wheat flour 100 g, sugar 10 g, fat 30 g, common salt 2 g, sodium bicarbonate 1.0 g, ammonia 50 g, vanilla 0.025 g and required amount of water. Wheat flour was replaced at different levels (up to 40%) by combinations of AWB and DWB according to the experimental design shown in Table 1. A control sample, including no fiber, was also prepared.

In order to ensure dough malleability (with acceptable consistency) and biscuits density and firmness, the dough moisture content was fixed at a constant level (15.0%) taking into account the water holding capacity of wheat flour, AWB and DWB.

After preparation, the dough was submitted to textural analyses. The dough was then shaped into biscuits and baked at 160C for 20 min. After cooling for 30 min, the biscuits were packed and used for evaluation of various chemical, textural and sensory characteristics.

Textural Properties of Dough. Cylindrical dough discs, 25 mm in diameter and 20 mm a thickness, were prepared with a circular shape cutter from the dough remaining at 27C.

The dough characteristics were evaluated by the texture profile analysis (TPA) method using a Texture Analyzer (Texture Analyzer: LLOYD instru-

TABLE 1.
MIXTURE DESIGN WITH 10 EXPERIMENTS AND THE MEASURED RESPONSES

	Pure components			Responses			
	X_1	X_2	X_3	H (N)	C (-)	A (Nmm)	MF (N)
Vertices							
1	100	0	0	47.24	0.134	5.71	48.22
				46.85	0.126	5.42	47.28
2	60	40	0	39.29	0.227	9.08	39.48
				41.01	0.227	9.36	38.50
3	60	0	40	35.77	0.155	5.39	34.66
				35.31	0.147	5.25	34.22
Edge centers							
4	80	20	0	43.50	0.164	6.39	43.46
				41.89	0.161	6.49	43.98
5	80	0	20	40.47	0.141	5.47	41.45
				40.71	0.142	5.49	40.59
6	60	20	20	32.48	0.181	6.83	36.88
				31.73	0.190	6.81	37.18
Centroid							
7	73,34	13,33	13,33	38.66	0.158	6.12	40.35
Checkpoints							
8	86,66	6,67	6,67	44.54	0.133	5.80	42.63
9	66,66	26,67	6,67	39.72	0.177	7.18	38.71
10	66,66	6,67	26,67	36.24	0.156	5.51	36.16

X_1, wheat flour; X_2, AWB; X_3, DWB; H, hardness (peak force during the first compression cycle of the dough); C, cohesiveness; A, adhesiveness and MF, maximum peak force (maximum force at the biscuit rupture).
Standard deviations: H: 0.74 (N); C: 0.004; A: 0.13 (Nmm); MF: 0.51 (N).

ments, England) equipped with a 1,000 (N) load cell, 0.05 (N) detection range. The parameters for the TPA procedures were as follows: plunger of 10 cm in diameter, constant cross-head speed, 0.8 mm.s^{-1}, compression of 40% of the original thickness, recovery period between the two strokes 5 s. The real time plots of the compressed doughs were analyzed for the following properties: (1) hardness (peak force of first compression cycle) (2) cohesiveness (ratio of positive areas of second cycle to area of first cycle) and (3) adhesiveness (negative force area of the first byte represented the work necessary to pull the compressing plunger away from the sample) (Bourne 1978). An average of 6 pieces of dough was recorded.

Characteristics of Biscuit. *Color Measurement.* The surface color, *L** (brightness), *a** (redness) and *b** (yellowness) were measured using a Hunter Lab system with a colorimeter (Minolta CR-300, Osaka, Japan). An average of six values was taken for each set of samples.

Textural Measurement. The maximum peak force (N) at the biscuit rupture was measured in a Texture Analyzer (LLOYD Instruments, West Sussex, U.K.) as described by Goullieux *et al.* (1995). The force required to break each of 12 biscuits individually was recorded and the average value was reported.

Sensory Analysis. Fifty untrained panelists, who were familiar with biscuit quality attributes, were randomly selected from students and staff of the Department of Biological Engineering (Ecole Nationale d'Ingénieurs de Sfax, Tunisia). The biscuit samples were evaluated on a 5-point hedonic scale ($1 =$ disliked extremely, $5 =$ liked extremely) (Amerine *et al.* 1965). The samples were assigned three digit – codes and presented to judges on white plates. The order of presentation of samples to the panel was randomized. The tests were performed at 10 in the morning. Tap water was provided for the judges to rinse their mouths between evaluations (Akubor 2003).

Experimental Design and Data Analysis. An experimental design was used in order to study the effect of the substitution of wheat flour (X_1) by *Aestivum* wheat bran (X_2) and durum wheat bran (X_3) on dough and biscuit properties (Y). A mixture design was carried out to model the relationship between the response variables (Y) to the variation of the predictors (X_j) and also to optimize the fiber enriched biscuit formula (Cornell 1981; Fustier *et al.* 2008). In a mixture design, the factors are the mixture components and the response is a function of the proportions of each ingredient. The coordinate system for mixture proportion is a simplex coordinate system. In the case of three components, the factorial space constituted by all the possible fractions of the components is a triangle whose vertices correspond to pure components.

In the present research, the practical range of proportions of component variables was established based on preliminary work to yield dough and biscuits with acceptable properties. Hence, the wheat flour component proportion was constrained to a minimum of 60% to ensure dough malleability and biscuit density and firmness. The constrained region is a sub-region of the initial simplex described by an equilateral triangle of smaller dimensions.

The relationship between the dough/biscuit properties and the components composition can be represented using a mathematical equation, in general a polynomial model, in which the X_j represents the proportion of the *j*th ingredient, $0 \leq X_j \leq 1$, $j = 1,2, \ldots, q$. The sum of the components $\Sigma X_j = X_1 + X_2 + \ldots + X_q$ must be 1 or equivalent to 100%. Because of this restriction, the polynomial model, takes a canonical form. The Sheffe's canonical special cubic model for three components takes the form of the following "interaction model" (Cornell 1981; Khuri and Cornell 1996; Goupy 2000; Voinovich *et al.* 2009):

$$\eta = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3$$

where η represents the theoretical response and βj, βjk and βjkl are model coefficients.

The minimum number of runs (experiments) needed to contrast the canonical special cubic model is 7. In the present research, a mixture design with 10 experiments was carried out. The corresponding experimental design, defined in pure components, and the response results are shown in Table 1. Some design points (runs n° 1 to 6) were replicated twice in order to estimate the variance of the experimental error. Moreover, three checkpoints (runs n° 8 to10) were included in the experimental design, in order to check the adequacy of the fitted models.

Following the experimentation program, the data were used to fit the empirical model and to test the adequacy of the fitted model. This latter was used to plot the contours of the predicted responses and to determine the optimal settings of the component proportions.

In the present work, the NemrodW software (Mathieu *et al.* 1999) was used to build the experimental design and to conduct all data calculations and processing.

RESULTS AND DISCUSSION

Physicochemical Properties of Wheat Brans

The physicochemical characteristics of the two industrial by-product wheat brans (AWB and DWB) are presented in Table 2. The results show a difference in composition and properties of the wheat brans.

The protein and the ash content are slightly higher in the AWB than in the DWB whereas the quantity of starch is significantly lower in AWB. Similar trends in protein, ash and starch contents of such wheat milling by-products were reported by Zhang and Moore (1997). These results have been explained by the fact that the composition of commercial bran depends upon many factors, which include the wheat class, grain shape and size, thickness of the bran layers, milling system and, above all, type of flour produced.

Table 2 also shows that AWB and DWB contain high amount of TDF (≥46 g/100 g of dry weight) mainly constituted by IDF. Similar results were reported by Sudha *et al.* (2007) for a AWB. They indicated that for a TDF content of 47.5 g/100 g of dry weight, 42.5 g were insoluble fibers and only 5.0 g were soluble fibers. Grigelmo-Miguel and Martin-Belloso (1999) also reported a relatively low amount of SDF in wheat bran (about 6.6 g/100 g of dry weight). For the two Tunisian varieties of wheat bran, the AWB was richer

TABLE 2.
PHYSICO-CHEMICAL AND NUTRITIONAL CHARACTERISTICS OF WHEAT FLOUR AND BRANS USED IN BISCUITS PRODUCTION (%, ON DRY MATTER BASIS, EXCEPT FOR MOISTURE)

Characteristics	Wheat flour	Aestivum wheat bran AWB	Durum wheat bran DWB
Moisture	12.08 ± 0.02	10.14 ± 0.05	12.97 ± 0.61
Protein ($N \times 5.7$)	14.72 ± 0.01	20.64 ± 0.05	18.27 ± 0.06
Fat	1.05 ± 0.06	3.63 ± 0.04	4.06 ± 0.03
Ash	0.60 ± 0.01	4.58 ± 0.02	3.04 ± 0.01
Starch	60.78 ± 0.15	12.20 ± 0.04	20.77 ± 0.07
Total dietary fiber (TDF)	10.5 ± 0.1	53.8 ± 0.1	46.8 ± 0.1
Insoluble dietary fiber (IDF)	9.6 ± 0.1	48.3 ± 0.1	42.5 ± 0.1
Soluble dietary fiber (SDF)	0.9 ± 0.1	5.5 ± 0.1	4.3 ± 0.1
Water-holding capacity (WHC)*	95.3 ± 0.1	447.1 ± 0.1	282.8 ± 0.1
Fat absorption capacity (FAC)**	39.0 ± 0.1	29.3 ± 0.1	33.2 ± 0.1

* (g water/g dry weight); ** (g fat/g dry weight).

in TDF than the DWB by 7.0 g /100 g of dry weight, where 5.8 g were IDF and 1.2 g was SDF. Wheat bran is typically used as a dietary-fiber enriching ingredient. Thus, using wheat bran with high TDF content, fiber enrichment objectives can be achieved by means of small amounts of bran. The incorporation of lower levels of bran means a less negative impact on the finished product quality (Pomeranz *et al*. 1977).

Functional properties were described by WHC and fat absorption capacity (FAC). Recall that WHC represents the ability of a product to associate with water (Singh 2001). AWB showed higher WHC (474.1 g/g dry weight) than that of DWB (282.8 g/g dry weight). The difference in hydrophilic constituents could explain in part this difference in WHC value. Indeed, according to Hodge and Osman (1976), flours with high water holding capacity have more hydrophilic constituents such as fibers.

FAC of AWB and DWB are presented in Table 2. The two sources of bran showed a slight difference for fat absorption capacity. Hydrophobic constituents were reported to be mainly responsible for FAC (Kinsella 1976).

Preliminary Study

The effect of the level of flour substitution by wheat brans on dough properties was tested. We partially replaced wheat flour in the formulation of biscuit dough by AWB and DWB at the levels of 20, 30, 40, 50 and 60%. The consequences showed that higher flour substitution levels generally resulted in increased water absorption leading to a decrease of the softness and elasticity of the resulting doughs. The effect can be explained by the great number of hydroxyl groups existing in the fiber structure, which allow more water interactions through hydrogen bonding, as was reported by Rosell *et al.* (2006).

To avoid these drawbacks, the maximum level of the wheat bran added was fixed at 40% and the dough moisture content was set at a constant level taking into account the water holding capacity of wheat flour, AWB and DWB.

The made biscuits prepared using 0% wheat bran, 40% AWB, 40% DWB and 40% wheat bran (20% AWB and 20% DWB) in the blends were evaluated for various physical and sensory characteristics (data not shown). The control samples (biscuits without wheat brans addition) had maximum overall acceptability, whereas biscuits containing 40% of wheat bran (AWB or DWB) were found to be unacceptable to the panelists. The use of wheat brans mixture (20% level of AWB and 20% level of DWB) produced samples with softer texture but reduced biscuit color acceptability. We supposed that it might be possible to improve the properties of the product by varying the proportions of wheat flour, AWB and DWB. Therefore, we performed a mixture design in order to study the effect of each of these three components on the rheological properties of the dough and biscuit quality and then to determine the conditions leading to biscuits meeting the consumer's satisfaction and that are similar to the commercial product.

Predictive Models

Ten experiments were carried out according to the experimental conditions indicated in Table 1. The measured values were reported in the last columns of Table 1. For all experiments, the water activity (aw) was in the range of 0.50 to 0.59.

Fitted to the response values of the first seven runs in Table 1, the canonical special cubic models for the dough hardness, cohesiveness, adhesiveness and biscuit maximum force are represented by the following equations (1–4):

(1) Dough hardness (H)

$$H = 47.04X_1 + 43.35X_2 + 28.82X_3 - 22.57X_1X_2 - 17.56X_1X_3 - 399.95X_2X_3 + 427.40X_1X_2X_3$$

(2) Dough cohesiveness (C)

$$C = 0.13X_1 + 0.61X_2 + 0.17X_3 - 0.40X_1X_2 + 0.02X_1X_3 + 0.70X_2X_3 - 1.31$$

TABLE 3.
THE NUMERICAL RESULTS FOR CHECKPOINTS

Exp.	y_i	$\hat{y}_i$	$d = (y_i - \hat{y}_i)$	t exp.	Signifiance
Dough hardness					
8	44.54	43.13	1.41	1.644	N.S.
9	39.72	38.01	1.71	2.002	N.S.
10	36.24	35.77	0.47	0.551	N.S.
Dough cohesiveness					
8	0.133	0.141	–0.008	–1.625	N.S.
9	0.177	0.188	–0.011	–2.230	N.S.
10	0.156	0.156	0.000	0.055	N.S.
Dough adhesiveness					
8	5.80	5.69	0.11	0.753	N.S.
9	7.18	7.35	–0.17	–1.184	N.S.
10	5.51	5.73	–0.22	–1.524	N.S.
Biscuit maximum force					
8	42.63	44.08	–1.45	–2.437	N.S.
9	38.71	39.83	–1.12	–1.881	N.S.
10	36.16	37.41	–1.25	–2.106	N.S.

y_i, measured response value; $\hat{y}_i$, estimated response value; d, difference between measured and estimated response values; t exp., student experimental value; N.S., non significant.

(3) Dough adhesiveness (A)

$$A = 5.56X_1 + 28.99X_2 + 4.39X_3 - 23.81X_1X_2 + 0.94X_1X_3 - 17.59X_2X_3 + 10.57X_1X_2X_3$$

(4) Biscuit maximum force (MF)

$$MF = 47.750X_1 + 20.600X_2 + 15.600X_3 + 8.750X_1X_2 - 1.875X_1X_3 + 85.147X_2X_3 - 128.786X_1X_2X_3$$

The corresponding coefficient of determination (R^2) value was 0.988, 0.991, 0.996 and 0.993, respectively.

The analysis of variance for the fitted models indicates that, in all cases, the regression sum of squares is statistically significant when using the *F* test at the 95% probability level (Mathieu *et al.* 1999). The results of the check points were used to validate the accuracy of the models as shown in Table 3. The differences between calculated and measured responses are not statistically significant when using the *t*-test. Thus, we can conclude that the canonical special cubic models are adequate to describe the four-response surfaces and can be used as prediction equations.

Contour Plots for Dough Rheological Parameters and Biscuit Quality Attributes

Model equations are used for generating contour plots over the constrained region as shown in Fig. 1. The contour plots are represented in a sub-region of the initial simplex described by an equilateral triangle of smaller dimensions, whose vertices correspond to the mixtures:

(1) Pseudocomponent 1: 1/0/0 (wheat flour 100%, AWB 0%, DWB 0%);

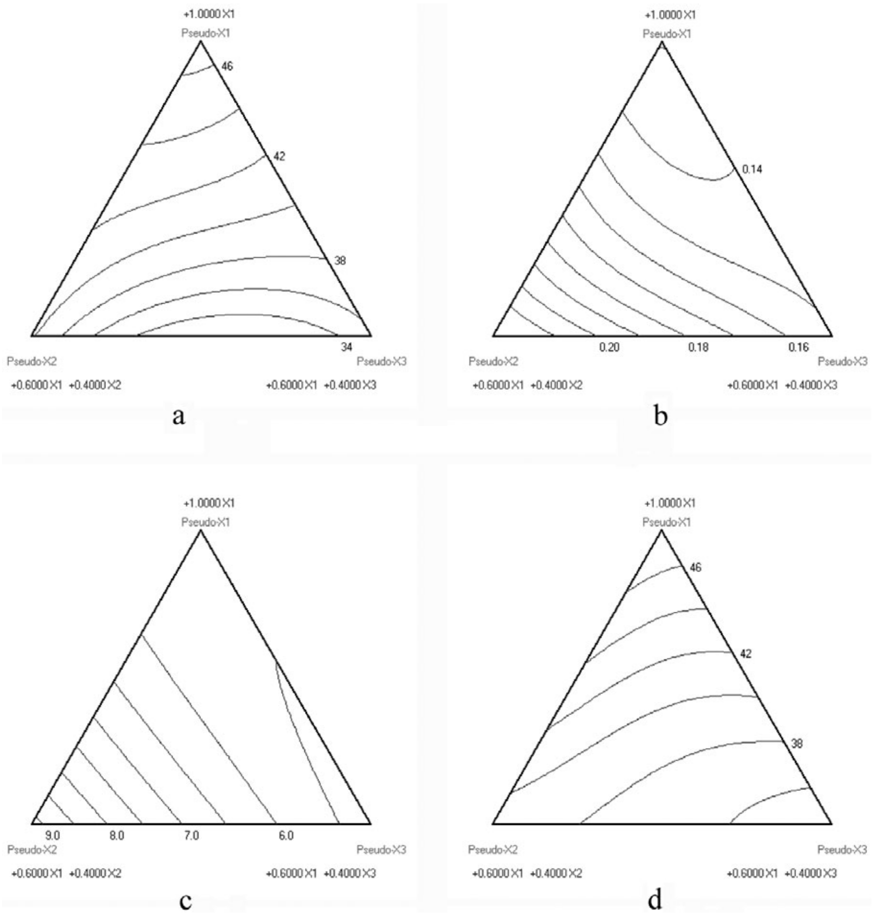

FIG. 1. CONTOUR PLOTS OF PREDICTED RESPONSES AS A FUNCTION OF PSEUDOCOMPONENTS
(a) dough hardness (b) dough cohesiveness (c) dough adhesiveness and (d) biscuit maximum peak force

(2) Pseudocomponent 2: 0.6/0.4/0 (wheat flour 60%, AWB 40%, DWB 0%);
(3) Pseudocomponent 3: 0.6/0/0.4 (wheat flour 60%, AWB 0%, DWB 40%).

These graphs are readily interpreted as follows:

The contour plots of Figs 1a,d reveal that increasing in the level of both brans (AWB and DWB) leads to a reduction of the dough hardness and the biscuit maximum peak force, respectively. The two responses decreased, respectively, by about 15% and 26% when AWB and DWB were incorporated at their maximum levels (40%). The differences in the results could be attributed to the wheat class and the method of bran sample preparation.

The effect of the DWB to decrease more than AWB the dough hardness and the biscuit maximum peak force may result from possible complex formation between the fiber components added and the protein fraction of the samples. The mechanism of these possible interactions requires further research.

The contour plots (Fig. 1b) show that the dough cohesiveness is very sensitive to changes in the amount of AWB. They clearly indicate that the high level of AWB induces a high increase in the response. Our findings are in line with the observations made by Tyagi *et al.* (2007) who reported an increase in the cohesiveness of the dough used in the biscuit preparation by incorporating mustard flour (the crude fiber content in mustard flour was 12%).

The graph of the dough adhesiveness (Fig. 1c) clearly shows that a small increase in the amount of the AWB can produce a sharp increase in the dough adhesiveness. The curves, corresponding to the DWB indicate that this component has no significant effect on the response. DWB minimized dough adhesiveness is a suitable trend to fit textural requirements providing a good making performance (Collar *et al.* 2007).The effect of AWB on the dough adhesiveness is in line with that previously reported for other fibers which increase the adhesiveness value with the increasing fiber levels (Ayadi *et al.* 2009).

AWB results in higher dough cohesiveness and adhesiveness than dough containing DWB. This result can be explained by the difference in the chemical composition and functional properties of AWB and DWB or by the wheat class, grain shape and size, thickness of the bran layers, milling system and above all, type of flour produced Zhang and Moore (1997). Collar *et al.* (2007) showed that flour replacement with different fibers significantly change the dough handling ability and extensional behavior, the trend and the extent of the effects on the dough viscoelastic parameters being variable (beneficial/adverse) and closely dependent on the nature of the fibers in the blend and on the extent of the flour substitution.

Determination of Optimum Biscuit Composition

To determine experimental conditions that satisfy the manufacturer requirements simultaneously:

(1) a dough hardness higher than 38 N;
(2) a dough cohesiveness in the range of 0.11 to 0.16;
(3) a dough adhesiveness of about 5.0 to 6.5 Nmm;
(4) a biscuit maximum force higher than 38 N.

the desirability function was used as proposed by Derringer and Suich (1980).

The method consists in transforming each measured response to a dimensionless desirability scale d_i defined as a partial desirability function. This makes possible the combination of the results obtained for properties measured on different scales. The scale of the desirability function ranges between $d = 0$, for a completely undesirable response, and $d = 1$, if the response is at the target value. Once the individual desirability function d_i is defined for each of the responses of interest, they are combined into an overall desirability function, D ($D = (d_1.d_2.d_3.d_4)^{1/4}$), that weights the responses together, with one single criterion. The values of D computed from the observed responses allow to locate the optimum region (Myers and Montgomery 1995; Lewis *et al.* 1999).

Figure 2 shows the individual desirabilities of the four responses. Figure 3 shows the isoresponse curves of the global desirability function. The maximum of this function gives the best global compromise in the studied domain and corresponds to optimum biscuit composition.

The isoresponse curves (Fig. 3) clearly show that the best conditions, which assure acceptable textural properties of dough and biscuit samples are located in a relatively large domain within the subregion of interest. In this domain, the maximum flour substitution level does not exceed 20% when using AWB and 27% when using DWB.

Application at the Industrial Scale

In order to evaluate the effect of the high substitution level on the quality and sensory properties of the end product prepared at the industrial scale, we selected two compositions from the optimal domain. These compositions are designated by OM1 and OM2. They correspond to experiments 8 and 7, respectively.

(1) OM1: 86.66% of wheat flour, 6.67% of *Aestivum* wheat bran and 6.67% of durum wheat bran
(2) OM2: 73.30% of wheat flour, 13.35% of *Aestivum* wheat bran and 13.35% of durum wheat bran.

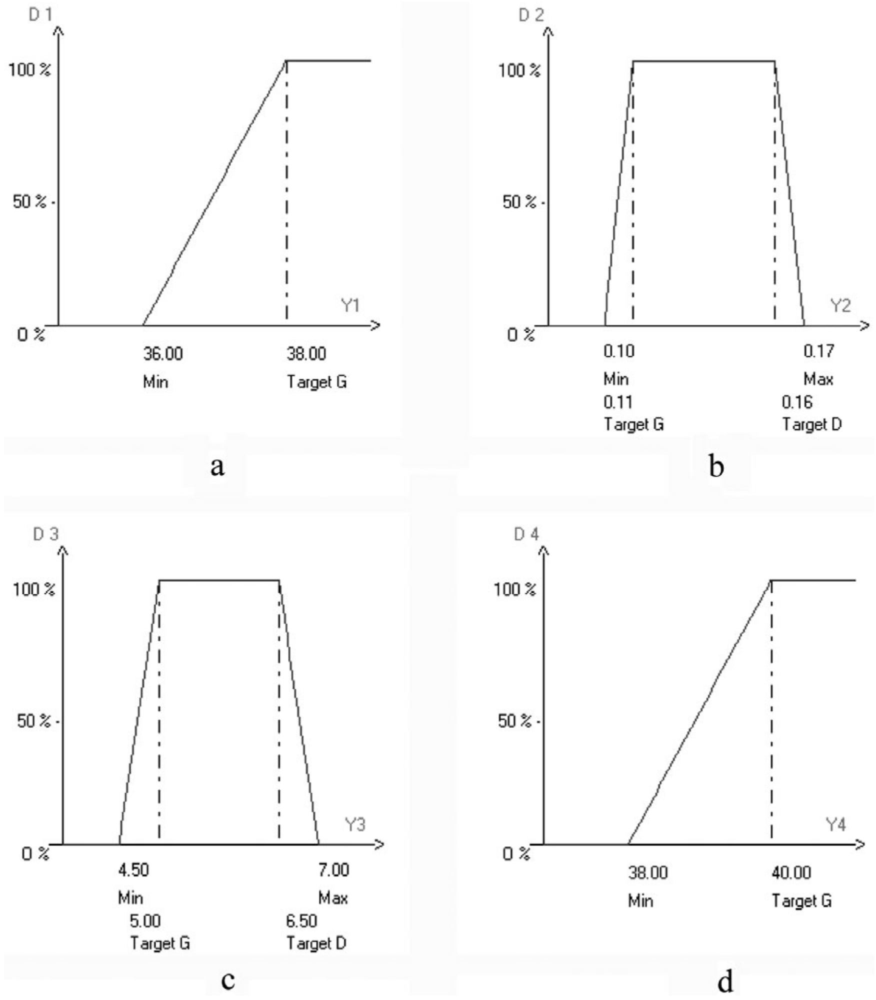

FIG. 2. INDIVIDUAL DESIRABILITY FUNCTION OF THE RESPONSES: (a) DOUGH HARDNESS (b) DOUGH COHESIVENESS (c) DOUGH ADHESIVENESS AND (d) MAXIMUM PEAK FORCE AT BISCUIT RUPTURE

The first one is situated at the center of the optimal domain with a flour substitution level of 13.34% whereas the second one is situated at the limit of this domain with a high flour substitution level (26.70%).

We applied these experimental conditions at the industrial scale and we compared the properties of the corresponding high fiber biscuits to those of the control biscuit.

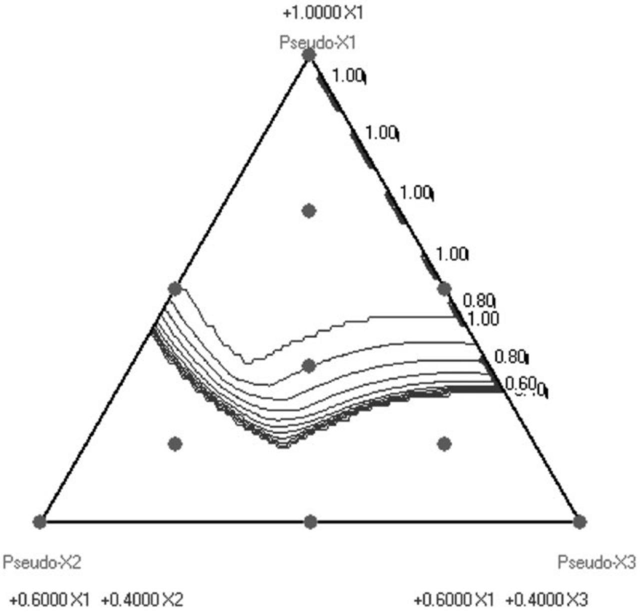

FIG. 3. CONTOUR PLOT OF THE GLOBAL DESIRABILITY FUNCTION

Biscuits Color. The effects of wheat bran addition at optimum levels (OM1 and OM2) on the biscuits color are shown in Table 4. Insignificant a^* and b^* differences were observed between the control biscuit and the wheat flour substituted biscuits (OM1 and OM2). In terms of brightness, the control biscuit gave higher L^* values compared to those of the optimized biscuit samples. Decreases in L^*, respectively, by 14% and 7% were shown with biscuits OM1 and OM2. This is mainly due to Maillard and caramelization reactions. Similar results were reported by Ayadi *et al*. 2009 who showed that the higher fiber addition in cake formulation promoted severely the nonenzymatic browning reactions as evidenced by the low L^* value. Figure 4 shows photos of optimized fiber enriched biscuits OM1 and OM2. The biscuit color of these biscuits was relatively more acceptable than that prepared without a fiber addition.

Sensory Characteristics. The results of the sensory evaluation of the optimized biscuits are given in Table 4. The results showed that the quality of biscuits was acceptable for OM1 and OM2, which did not present dry mouthfeel. Among the biscuits tested, the panelists gave higher scores for fiber-enriched biscuit OM1 as compared to biscuit OM2. Sudha *et al*. (2007)

TABLE 4.
EFFECT OF AWB AND DWB ADDITIONS ON THE COLOR AND SENSORY CHARACTERISTICS OF THE BISCUITS

	Control biscuit	OM1 biscuit	OM2 biscuit
Color characteristics			
*L**	46,21 (a)	52,68 (b)	49,66 (c)
*a**	12,53 (a)	11,87 (a)	12,16 (a)
*b**	32,38 (a)	33,08 (a)	32,74 (a)
Sensory characteristics (1-dislike extremely, 3-acceptable, 5-like extremely)			
Color	3.12 (a)	3.64 (b)	2.82 (c)
Taste	3.55 (a)	3.23 (b)	2.68 (c)
Texture	3.65 (a)	3.64 (a)	3.08 (b)
Overall acceptability	3.66 (a)	3.84 (a)	3.09 (b)

* Figures in the same column sharing a common letter in parentheses are not significantly different ($P < 0.05$).

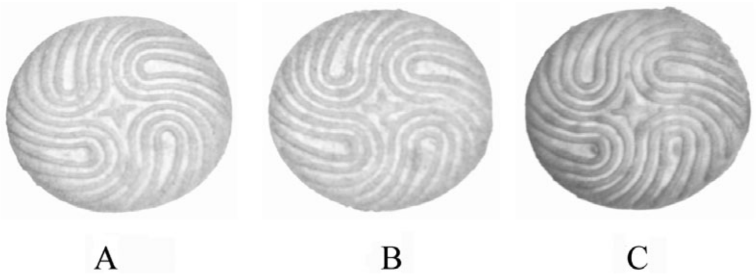

FIG. 4. OBSERVATIONS OF SWEET BISCUITS PREPARED WITH (a) OM1; (b) OM2 AND (c) CONTROL (WITHOUT FIBER ADDITION)

prepared biscuit using wheat bran, rice bran, oat bran and barley bran fiber. They showed that at 10% incorporation, each bran sample did not affect the biscuit quality. The quality of their biscuits was acceptable at 20% for wheat bran and barley bran and 30% for oat bran only.

Dietary Fiber Composition. Dietary fiber was estimated for control biscuits (100% wheat flour) and biscuits OM1 and OM2. As seen in Table 5, the total dietary fiber content of biscuits OM1 and OM2 was higher than that of the control. OM1 and OM2 increased the total dietary fiber content by 1.6 and 2.3-fold, respectively. Soluble dietary fiber and insoluble dietary fiber were at their maximum in biscuits OM2. These results were in agreement with others, for example Sudha *et al.* (2007) reported an increase in total dietary

TABLE 5.
BISCUITS DIETARY FIBER COMPOSITION (%, ON DRY MATTER BASIS)

Biscuit	SDF (%)	IDF (%)	TDF (%)
Control	1.08	0.72	2.26
OM1	1.72	2.89	3.71
OM2	2.39	4.14	5.26

SDF, soluble dietary fiber; IDF, insoluble dietary fiber; TDF, total dietary fiber.

fiber content of biscuits from 1.6 to 6.9% by incorporating 20% of wheat bran in the formulation.

CONCLUSION

A fiber-enriched biscuit was successfully formulated using a mixture design. The dietary fiber composition of the two optimized biscuits (OM1: 86.66% of wheat flour, 6.67% of DWB and 6.67% of AWB and OM2: 73.30% of wheat flour, 13.35% of DWB and 13.35% of AWB) showed that *Aestivum* and durum wheat bran could be used for enriching the biscuit fiber content without undesirable changes in their textural and sensory properties.

ACKNOWLEDGMENTS

We are grateful to Amar Kamoun, Chairman and Managing Director of the Kiff “Biscuit” company (Sfax, Tunisia) for the facilities provided for the biscuit preparation. Our thanks are also due to LPRAI – Marseille Company for supplying us with the software package NemrodW.

We extend our tanks to Mr. Jamil Jaoua, Head of the English Unit at Sfax Faculty of Science, for having proofed this paper.

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