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Optimization of sponge cake quality enriched with Beta-glucan and Triticale flour

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ABSTRACT

In this paper, the possibility of producing sponge cake by replacing triticale flour (TF) (0-30%) and beta-glucan fiber (BG) (0-10%) was investigated by utilizing a two-level factorial design containing central points. According to the results, by increasing TF and BG replacement ratio in the cake formulation, moisture content, water activity, ash, fiber, and antioxidant capacity increased, whereas carbohydrates, calories, and lightness of cases decreased. Moreover, the specific volume of cakes in those samples containing TF decreased, while adding the BG fiber can lead to improving it. Meanwhile, as BG and TF levels increased, the hardness of the samples increased while their cohesiveness and springiness decreased. On the other hand, BG replacement did not have a significant effect on the chewiness and gumminess, whereas TF may lead to increasing them. The overall acceptance of the samples increased with the simultaneous replacement of TF and BG. Furthermore, the numerical optimization confirmed that it is possible to produce enriched and desirable cakes through a combination of 30% TF and 8.3% BG.

1- Introduction

Recently, enriched and fortified foods have attracted much attention due to their health benefits and the acceptance of sensorial characteristics. As such, consumer demand has led to the expansion to produce high-fiber foods [1]. In this matter, cakes are one of the most conventional baked goods containing gluten, which is consumed by most people in the world. Thus, enriching cakes with new and healthy materials is satisfied for consumers and the grain industry [2]. There are several reports about the utilization of fibers such as carrot pomace powder in sponge cakes [3, 4], sugar beet fiber in cookies [5], apple, orange, and carrot pomace powder [6], Cocoa fiber [7], pomegranate seed powder [8] and vegetable waste [9] in cakes.

In this way, Beta-glucan is well known as one of the hydrocolloids and water-soluble fibers are composed of beta-D-glucose of (1→3) (1→4) units and are present in barley (3-11%), oats (7-3%), Avena sativa (2-7.8%) wheat (0.4-1.4%)seeds. The beneficial effects of dietary fiber are lowering the risk of colon cancer, lowering blood serum cholesterol and reducing glycemic reactions, post-meal glucose levels, insulin and constipation, and rapid bowel emptying [10]. However, fortification of baked goods with dietary fiber reduces their quality.

Triticale (*Triticosecale Wittmack*) is a relatively new, hybrid plant between wheat and rye [11], which contains a higher nutritional value than wheat and better baking properties than rye [12]. Triticale contains the same amount of protein as wheat, but its lysine by limiting amino acid in grain products is higher than wheat. Besides, triticale contains more massive amounts of arabinoxylan, soluble fiber, antioxidant compounds, Phytosterols, and B vitamins [13]. Todays, triticale is employed in several kinds of products such as cakes, cookies, breakfast cereals, pasta, pizza dough, and snacks. Regarding the role of essential amino acids and dietary fiber in human health, as well as the lack of these materials in grains such as wheat, this paper aims to enrich the sponge cake formulation using TF and BG fiber, as well as their effect on physicochemical, textural, and sensorial characteristics of the cake.

Materials and methods

Materials used in sponge cake formulation

Triticale flour (Agricultural Research and Extension Organization, Razavi Khorasan Province, Iran) beta-glucan barley (Prom Oat company, Swedish),

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lecithin soybean (Behpak industries, Bushehr, Iran), and cake flour (wheat flour), corn blend oil, sugar, Eggs, vanilla and baking powder prepared from a local store (Urmia, West Azarbaijan Province, Iran). The other chemicals used in the tests were from the Merck brand, Germany.

Sponge cake preparation

The cake formulation used in this study is based on 100g of WF, including 60g sugar, 65g eggs, 35g oil, 4g powdered milk, 3 g baking powder, 3g lecithin, 52.5g water, in which the amount of vanilla was negligible. TF at the level of 0-30% and BG at the level of 0-10% replaced the cake flour in the cake formulation, eleven types of cakes were cooked with different percentages of TF and BG, based on the experimental design shown in Table 1. At first, the oil, eggs, and sugar are mixed with an electric mixer for 5 minutes. Afterward, water is added and stirred for 2 minutes. In the next step, all the powdered ingredients that had previously been mixed and sifted were added to the mixture and then mixed until the uniform dough was obtained. Then, 50g of the obtained dough cake is poured into paper molds (50 ml in diameter and 40 ml in height) and then cooked in a rotary oven machine (Pak Andishan, model RO02) at 20° C for 20 minutes. After cooking, the samples were cooled to room temperature and then kept in polyethylene bags until testing.

Chemical tests

Moisture, ash, crude fiber, protein, fat of triticale, and cake flour and cake samples were determined according to AACC [14]. In the meantime, carbohydrates were obtained by subtracting the sum of moisture, fat, ash, and protein content from 100. The caloric content of the cakes was measured based on the following formula [15]:

Calorie (kcal) = (% protein × 4 + % CHO × 4 + % fat × 9)

Here, to specify the antioxidant activity of cakes and flours consumed, the DPPH free radical scavenging method was employed [16]. For this purpose, first,1ml of the sample extract (by dissolving one gram of each powdered cake sample in 10ml of methanol for 24 hours in the dark and at room temperature) was mixed with 4 ml of 90% methanol. Then 1 ml of DPPH methanol solution (0.004%) was added and then stirred well. After half an hour of keeping in a dark place, the samples absorption was read using a spectrophotometer (T60 UV-Visible Spectrophotometer, USA) at 517nm. The following formula calculated the antioxidant capacity of the samples:

$$(\%)\text{free radical scavenging} = \frac{A_c - A_s}{A_c} \times 100$$

Where A_s is the absorbance of the sample, and A_c is the absorbance control.

Physical tests of cake samples

The volume of the cake was determined by the rapeseed replacement method [17] and specific volume was calculated as the ratio of the cake volume to its weight. Water activity (aw)was obtained with aw measurement device (Decagon Devices Pullman, WA) while the color of the cake crumbs was measured based on light-dark (L*), green-red (a*), and blue-yellow (b*) parameters using CIE colorimeter (Minolta CR300 Series, Minolta Camera Co. Ltd., Osaka, Japan).

A texture profile analysis (TPA) test was performed on sliced samples from the central part of the cake via dimensions of 2× 2× 2 cm with a texture analyzer (TA-XT plus, Stable Micro System Ltd, Surrey, UK). The double-compression test was carried out with a p/75 probe. The customized settings included a test speed of 0.8 mm/s and a pressure of 50% [1]. The recorded texture parameters include hardness (maximum force of first compression, kg), cohesiveness (the area ratio of the work during the second and first compression), springiness (the time ratio of the work in the second and first compression), gumminess (hardness× cohesiveness, kg), and chewiness (gumminess×springiness, kg).

Sensorial evaluation

Sensorial evaluation of the cake samples was implemented by a linear scoring method (with a linear scale of 15 cm) by 30 evaluators on the first day after baking. Each evaluator determines the overall acceptance according to the color, taste, porosity, hardness, and dryness of the cakes [7].

Statistical analysis

The designed experiments were implemented using a two-level factorial design containing central points, using Design Expert 7.1.3 software under 11 treatments (see Table 1). ANOVA investigated the obtained results at the 95% confidence level in terms of whether the factors were significant or not. The data fit was estimated through the predictive models taking into account the coefficient of determination (R^2) and the adjusted coefficient of determination (adj-R^2) and the not significance of lack of fit. The contourplots depicted for predictive models are based on variable performance.

Table 1: Experimental design used in cake formulation

Run	TF (%)	BG (%)
1	30	10
2	15	5
3	30	10
4	15	5
5	0	10
6	30	0
7	0	0
8	0	10
9	0	0

10	0	0
11	30	0

Results and discussion

Chemical analysis

Triticale flour and cake flour, respectively, containing 4.54, 7.89% moisture, 1.6%, 0.6% ash, 12.42, 7.57% protein, 2.1, 1.6% fat, and 9.1, 0.45%crude fiber. The antioxidant capacity of triticale flour and cake flour was 75% and 15.6%, respectively. The ANOVA and coefficients of predictive regression models are also reported in Table 2. As can be seen, most of the resulting models were significant at the 5% confidence level, based on having high and acceptable R^2 and adj-R^2 values. According to the results, with the replacement of TF and BG, the moisture content of samples was increased significantly ($p < 0.05$). The increase of moisture content with substitution of the TF can be attributed to its higher fiber than WF causing more water absorption. The increase in moisture content with the addition of BG is related to molecular weight and high water absorption of BG fiber [18]. The same results have been reported with the addition of banana and bean flour [19] and spinach powder [20] in biscuits. On the other hand, both the fiber and ash levels of the samples increased significantly by increasing TF and BG replacement ($p<0.05$). Besides, the protein content of samples increased and decreased by increasing TF and BG replacement, respectively ($p < 0.05$). Such an increase in ash and protein in samples may be related to the higher amount of ash and protein in TF than WF [21]. Besides, the decrease in protein content of samples, with the increase in BG replacement, is related to the dilution of the protein content of the cake due to the lack of protein in beta-glucan. Similar results have been reported in cake with the addition of mango pulp and peel powder [22] and apple, orange, and carrot pomace powder [6].

The carbohydrate and caloric content of the samples decreased significantly with increasing TF and BG replacement ($p < 0.05$). Furthermore, this replacement did not affect the fat content of the cake samples ($p > 0.05$). Avila et al. [23] reported similar results on reducing carbohydrates and calories, by replacing a mixture of flours (quinoa, rice, blue-eyed pee, millet, and flax) with wheat flour in cakes.

According to the results of statistical analysis, the single effect of TF, as well as the interaction effect of TF-BG was significant on the cake antioxidant capacity ($P<0.05$). As can be seen in Fig 1, the antioxidant capacity of the samples increased significantly with the replacement of TF. It is due to the high antioxidant and phenol contents in TF. On the other hand, BG had a reverse effect on the antioxidant capacity of samples due to its low antioxidant capacity compared to WF and TF ($P<0.05$). The ANOVA and coefficients of the regression model of the antioxidant activity of the samples were listed in Table 2. Similar results have been reported in increasing antioxidant capacity by adding buckwheat flour to bakery products [24] and adding ripe banana flour to layered and sponge cakes [16].

Physical tests

According to the results, the single effect of TF and BG and their interaction effect on the water activity of cake samples were significant ($P <0.05$). The results of ANOVA and coefficient of regression models for water activity are listed in Table 2.As can be observed in Fig. 1, by increasing the replacement of TF as well as BG with cake flour, the water activity of cake samples increased, so that the highest water activity was related to high levels of TF and BG fiber, simultaneously. The reason for such an increase in water activity of the samples was maybe the hydrocolloid property of BG and the high fiber content of TF, which increased water absorption and water activity of cake samples.

The ANOVA and coefficients of regression models of specific volume are reported in Table 2. The single effect of TF and the interaction effect of TF-BG were significant on specific volumes ($P <0.05$). As can be seen in Fig.1, the specific volume of samples was reduced by increasing TF replacement. The effect of BG on the cakes' specific volume is depended on the TF replacement. Meanwhile, by increasing BG in control samples and samples with low triticale levels, no significant change was observed in specific volume. While by replacing BG at the middle and upper TF levels, the specific volume of samples increased significantly.

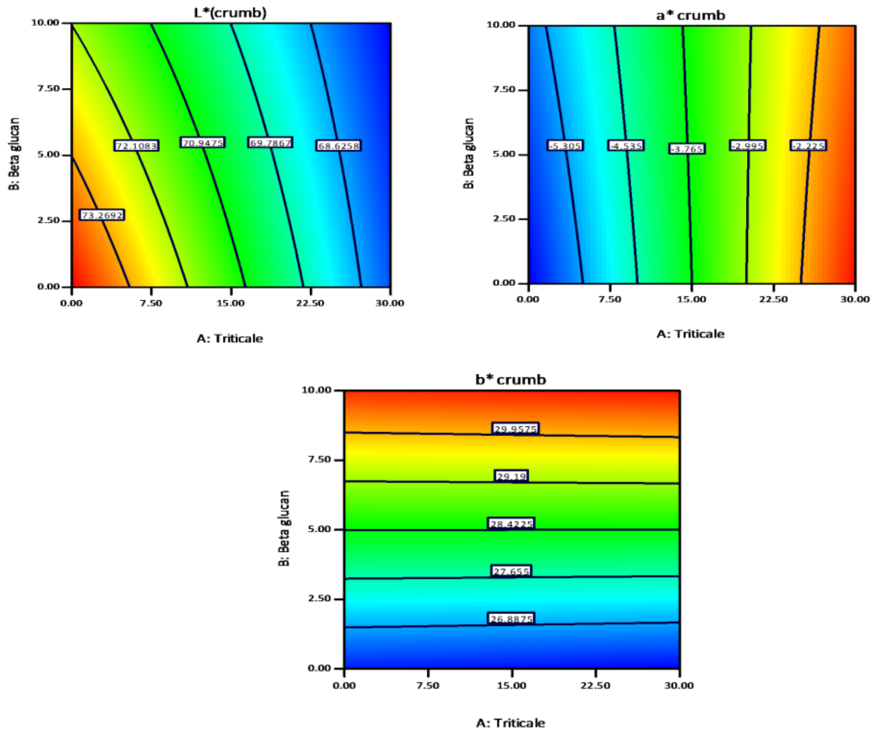

Figure1. The counterplot of the TF and BG fiber replacement effect on cake antioxidant, aw and specific volume

The reason for this increase in volume can be attributed to the absorption of moisture by BG and generating more viscosity in the dough. As a result, better maintenance of gas bubbles produced in cake samples containing beta-glucan than non-beta-glucan samples [7, 18]. It is worthwhile to mention that the results were in accordance with the ones of Lee et al. [26], who stated that the specific volume of cakes increased by replacing oat beta-glucan with wheat flour. Sanchez-Parado et al. [27] also found similar results for beta glucan-enriched cake.

One of the critical quality characteristics in cake acceptance is its color. The ANOVA and coefficients of the color regression models of the samples were listed in Table 2. As can be seen in Fig.2, TF replacement significantly reduced the L* of the crumb ($P < 0.05$). On the other hand, an increase in BG also caused a small decrease in the crumb lightness of the samples, but this decrease was not statistically significant ($P < 0.05$). Moreover, a* of the samples increased by increasing TF in the presence or absence of BG ($P < 0.05$). This could be related to the natural color and also the existence of higher amounts of both free amino acids and free sugars in TF leading to the reaction of caramelization and Millard [28]. Likewise, among the studied factors, the single effect of BG on crumb b* was significant ($P < 0.05$), based on which by increasing BG in all samples, the amount of b* increased significantly, while replacing TF did not have a significant effect on b* of crumb. The results were in accordance with the results of Oliete et al. [28] so that by increasing TF, the a* of the layered cake samples increased while their L* decreased.

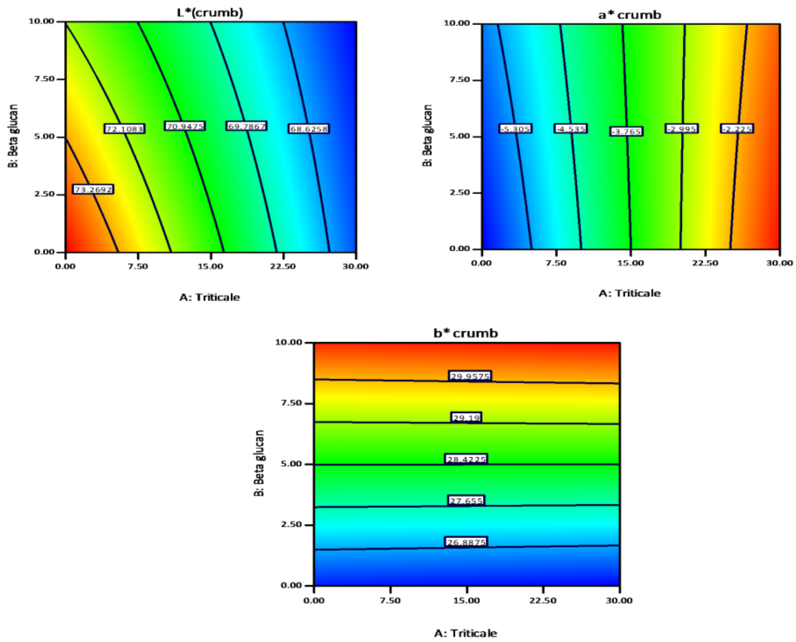

Figure2. The counterplot of the triticale flour and beta-glucan effect on cake crumb color.

It should be mentioned that texture is a critical feature used as an indicator to determine changes in the structure of the crust and crumb during storage. According to Table 2, the single effect of TF and the interaction effect of TF-BG on the hardness of the cake was significant (P <0.001). As can be seen in Fig 3-a, the hardness of the samples increased significantly by increasing TF replacement (p <0.05). Overall, the highest hardness was observed in samples via a maximum TF replacement. It may be related to the low gluten content in the triticale and the formation of a weak gluten network, which results in fewer air bubbles and the hardness of the cake texture. The increased hardness was also associated with decreased cake volume [29]. The hardness of TF-containing samples at high BG levels was significantly higher than BG-free samples (p<0.05). The reason for this increase in hardness because of the addition of BG could be concluded due to the molecular reactions between the fiber and the gluten protein. Besides, the increased hardness may be due to limited water content by polysaccharides and the lack of access to the development of starch and gluten network [9] or because of the thickening of the gas cell wall [18]. Similar results have been reported in increasing hardness for bread with the addition of beta-glucan [18] layered cake with the addition of hydrochloric fiber [25] and sponge cake with green tea leaves [30], coffee skin [1] and carrot pomace powder [4]. In this way, cohesiveness is defined as the internal resistance of a food structure. The single effects of the studied factors on the cohesiveness were significant ($P<0.05$). By increasing the levels of TF replacement as well as BG in cake formulations, cake cohesiveness decreased significantly ($P <0.05$). The lowest cohesiveness was for samples containing TF and BG (Fig.3-b). Similar results have been reported for reduced cohesiveness by adding cocoa fiber to muffins [7], carrot pomace powder [4], and green tea leaves to cakes [30].

The springiness measures the amount of elasticity by determining the amount of texture recovery between its first and second compression. The springiness is an appropriate characteristic of a cake associated with elasticity and freshness [31]. The springiness ranged from 0.76 (samples with maximum BG levels as well as TF) to 0.83 (control samples).

The effect of replacing WF with TF on the springiness of the case depended on the beta-glucan contents. Here, by increasing TF in BG-free samples, the springiness of the samples decreased significantly ($P <0.05$), but no significant effect was observed in the samples with maximum BG (10%), ($P>0.05$). By replacing BG, the springiness decreased noticeably (Figure 3-c). A decrease in springiness is associated with increased hardness [8]. Adding fiber may also weaken the bonds between starch and gluten; thereby, reducing the springiness. Similar results were provided by Fendri et al. [32], who found that adding chickpea fiber could reduce the springiness of bread .Besides, Garcia-Segovia et al. [33] reported a decrease in springiness by replacing wheat flour with a mixture of quinoa, walnut, carrot, and pea flour. The amount of gumminess and chewiness depends on the hardness of the cake texture [4]. According to the results of ANOVA, the single and interaction effect of TF-BG on gumminess and chewiness of samples was significant ($P<0.05$). As can be seen in Fig.4, by increasing TF levels in BG-free cake formulations, the amount of these two parameters increased significantly ($P<0.05$), but increasing TF levels in samples with 10% BG had not a significant effect on gumminess and chewiness ($P <0.05$). By increasing BG in samples containing a maximum of 7.5% TF, gumminess and chewiness increased slightly ($P <0.05$), however at high levels of TF, it significantly reduced the amount of these two parameters (P<0.05). The increase in the gumminess and chewiness depends on the hardness of the samples. Molavi et al. [34] provided similar results by replacing oak flour and Gularte et al. [35] by adding legume flour to the cake.

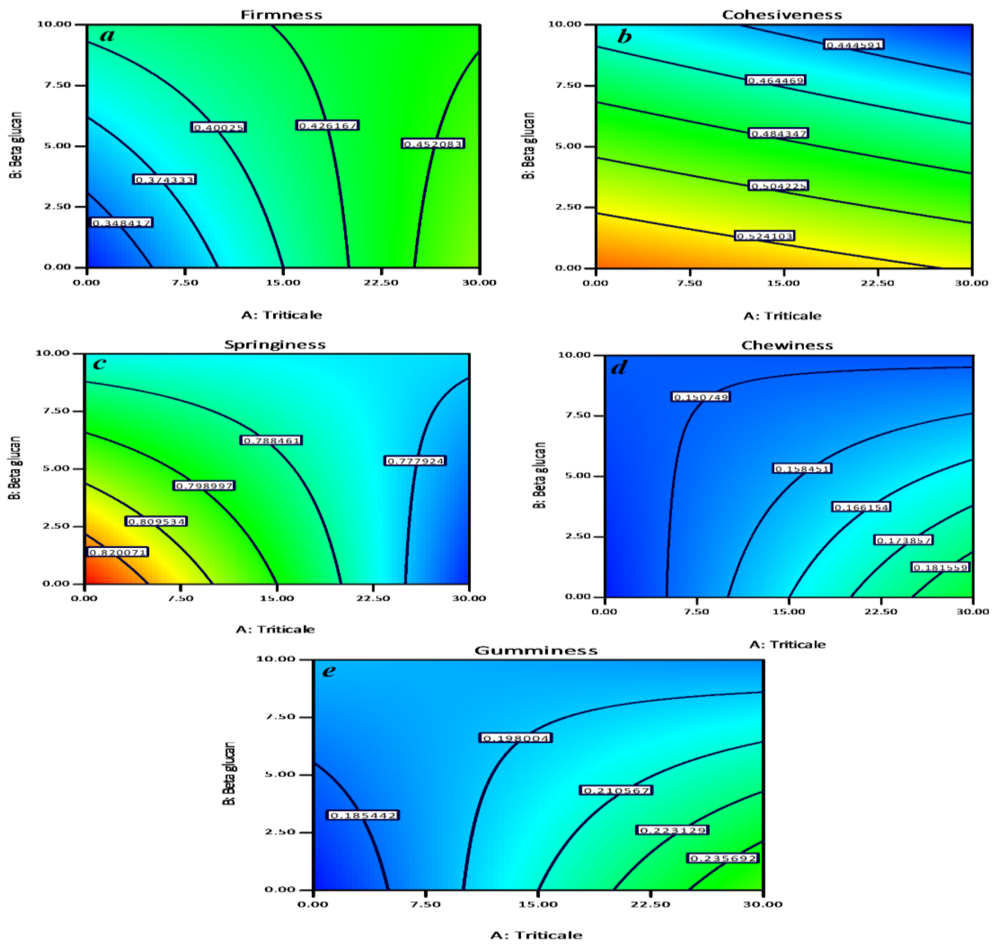

Figure3. The counterplot of TF and BG replacement effect on (a): hardness, (b): cohesiveness, (c): springiness, (d): chewiness, (e): gumminess of cakes

Table 2: Regression coefficients and ANOVA of fitted models for cake samples

Factors	Model	A	B	A*B	R^2adj	R^2	C.V%
Ash	1600.03**	0.03**	0.05**	-0.0004**	0.99	0.99	1.04
Fiber	95211.53**	0.16**	0.54**	0.01**	0.99	0.99	0.32
Protein	498.13**	0.01**	-0.02**	0**	0.99	0.99	0.23
Lipid	1.50^{ns}	0.02^{ns}	80.85^{ns}	-2.69^{ns}	0.42	0.14	286.4
Carbohydrate	1228.13**	-0.32**	-0.78**	-0**	0.99	0.99	0.82
Calorie	768.7**	-1.08**	-2.11**	-0.03**	0.99	0.99	0.41
Moisture	27926.66**	15.95**	34.69**	2**	0.99	0.99	0.10
aw	416.11**	0.0010**	0.0018**	-3.3×10^{-5}**	0.99	0.99	0.13
AO	170.81**	-0.03**	-0.40^{ns}	0.02**	0.98	0.98	0.38

Specific volume	301.06**	-0.05**	-0.02**	0.004**	0.99	0.99	2.22
L*	14.02**	-0.21**	-4.24^{ns}	0^{ns}	0.87	0.81	1.78
a*	160.88**	0.15**	0.05^{ns}	-0**	0.98	0.98	7.58
b*	728.95**	-0**	0.43**	0^{ns}	0.99	0.99	0.47
Firmness(g)	16.07**	0.0051**	0.0083**	-0.0004*	0.89	0.83	5.37
Cohesiveness (%	21.83**	-0.0007^{ns}	-0.0087**	-0.00005*	0.92	0.87	3.37
Springiness (%)	52.01**	-0.0021**	-0.0048**	0.0002**	0.96	0.94	0.69
Gumminess	17.28**	0.0025**	0.0023**	-0.0003**	0.89	0.80	4.91
Chewiness	14.38**	0.0015**	0.00069*	-0.00016**	0.88	0.82	4.42

A:TF, B: BG, P>0.05 (Non significant: ns), P<0.01:**, P<0.05:* AO: Antioxidant, S.V: specific volume

Sensorial evaluation

According to the results, the fitted linear model, as well as the effect of the studied factors on the overall acceptance of the samples based on taste, color, porosity, and texture were insignificant ($p>0.05$). The experimental results indicated that among the studied factors, the effect of TF-BG interaction on the overall acceptance was significant ($p<0.05$). So that substitution of the TF and BG at low levels did not have a significant effect on the overall acceptance. Nevertheless, at high replacement levels, by increasing TF together with BG, the overall acceptance of the samples increased considerably. As such, the highest overall acceptance score was for samples with the highest amount of TF and BG (Fig.4-A). The results are in accordance with ones carried out with the addition of carrot pomace powder in the cake [3], quinoa flour in bread [36], and barley, buckwheat, and oat flours and beta-glucan in baked products [24].

Numerical optimization

Now, the resulting models were numerically optimized for different responses to determine the optimal processing conditions. For this purpose, desirability (D) is a practical method to optimize the multiple responses. Some design variables were chosen to maximize the overall desirability D = (d1 × d2 × d3 3. × dn). The maximum desirability (0.64) was obtained by considering the maximum replacement of TF and BG, the maximum value of cohesiveness, springiness, and overall acceptance, and the minimum hardness for samples via 30% TF together with 8.3% BG (as shown in Fig 4-B).

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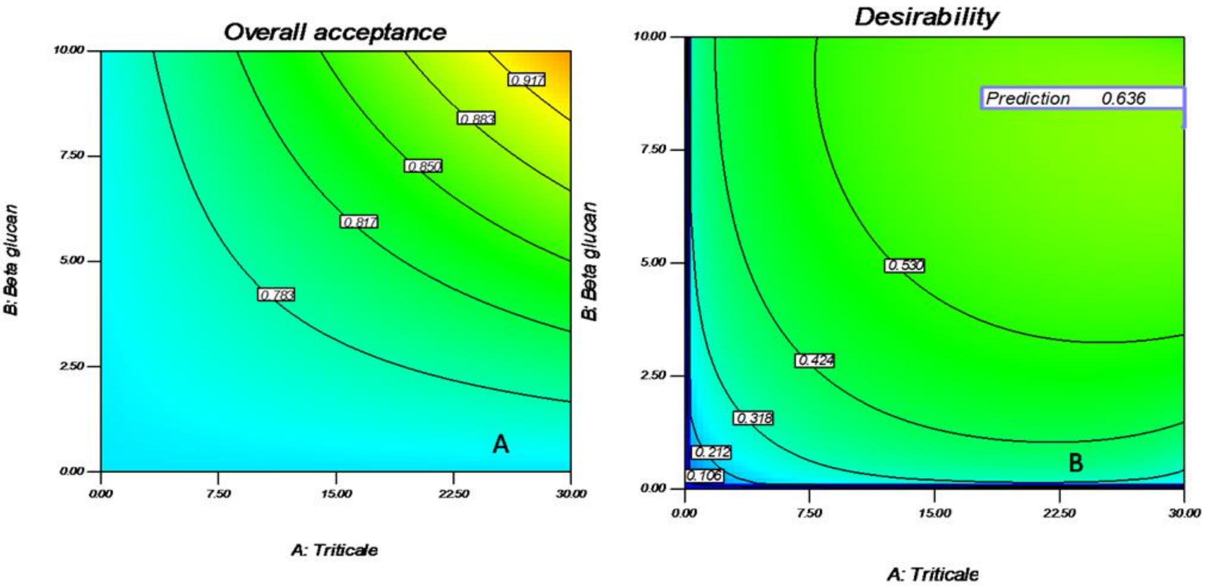

Figure4. The counterplot of TF and BG effect on the overall acceptance score (A) and desirability functional plot for the optimal value of the variables (B)

Conclusion

Both TF and BG contain some nutrients in terms of health. The results of ANOVA showed that in most of the investigated parameters, the estimated model had the best fitness with the experimental data, in which R^2 was acceptable in most models. According to the results, the substitution of TF led to an increase in moisture content, water activity, fiber, ash, protein, antioxidant capacity, hardness, gumminess, chewiness, and a* of the samples. Besides, the addition of TF reduced carbohydrate, calorie, specific volume, lightness, cohesiveness, and springiness of the samples. On the other hand, replacing BG with WF had some similar effects to triticale in the cake characteristics except for gumminess, chewiness, specific volume, and b^*. Meanwhile, the overall acceptance of the cakes increased by raising TF and BG levels. However, the sensorial score for all samples was higher than the acceptable level (>0.69). The maximum desirability was obtained based on the physical, textural, and sensorial characteristics of the cake with the simultaneous replacement of 30% TF and 8.24% BG. Therefore, replacing WF with TF and BG in cake formulation is possible to produce new products via high nutritional value, low calories, and appropriate sensorial characteristics, which is an effective useful step to enhance the nutritional quality of consumers.

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چکیده

در این مقاله، امکان تولید کیک اسفنجی با جایگزینی آرد تریتیکاله (TF) (٪ ۳۰-۰) و فیبر بتا گلوکان(BG) (٪ ۱۰-۰) با استفاده از طرح فاکتوریل دو سطحی حاوی نقاط مرکزی بررسی شد. بر اساس نتایج، با افزایش نسبت جایگزینی TF و BG در فرمولاسیون کیک، میزان رطوبت، فعالیت آب، خاکستر، فیبر و ظرفیت آنتی اکسیدانی افزایش و کربوهیدرات، کالری و روشنی کیک کاهش یافت. علاوه بر این، حجم ویژه کیک ها در نمونه های حاوی TF کاهش یافت، در حالی که افزودن فیبر BG منجر به بهبود آن گردید. در همین حال، با افزایش سطوح BG و TF، سختی نمونه ها افزایش و چسبندگی و ارتجاعیت کاهش یافت. از سوی دیگر، جایگزینی BG تاثیر قابل توجهی بر قابلیت جویدن و صمغیت نداشت، در حالی که TF ممکن است منجر به افزایش آنها شود. پذیرش کلی نمونه ها با جایگزینی همزمان TF و BG افزایش یافت. علاوه بر این، بهینه‌سازی عددی تأیید کرد که می‌توان کیک‌های غنی‌شده و مطلوب را از طریق ترکیبی از ٪۳۰ TF و ٪۸/۳ BG تولید کرد.