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Optimization of a new sponge cake to investigate the replacement of acorn flour and a corn syrup with wheat flour and sugar

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The present study aimed to investigate acorn flour (0-30%) and acorn syrup (0-100%) substitutions with wheat flour (cake flour) and sugar respectively on the properties of sponge cake based on combined design. The results showed that replacing acorn flour (AF) with wheat flour increased the dough density and baking loss% and decreased cohesiveness, lightness (L*), and redness (a*). Incorporating acorn syrup darkened the color of the crust. The Moisture content and specific volume were not affected by the replacement of flour and syrup of acorn. Addition of the acorn flour and acorn syrup enhanced water activity, firmness, chewiness, and diminished springiness. Sensory evaluation showed that with the replacement of acorn syrup, the overall acceptability of samples decreased, but acorn flour had no significant effect on it. According to the optimization results, it is suggested to substitute 11% acorn flour along with 25% or 45% acorn syrup to produce a high nutritional product with desirable textural and sensory characteristics.

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1- Introduction

Flour products are one of the most consumed food products in the world. Among these products, the cake has been accepted by most consumers due to its excellent organoleptic properties (1). Moreover, nowadays with increased urbanization, consumption of baking products has expanded significantly because of affordable prices, convenient preparation of products, and the availability of various products (such as cakes, bread, and biscuits) with different tastes and textural characteristics and high shelf life (2). Due to the high sugar and fat in cake formulation, its long-term consumption results in obesity and health problems (3; 4). Therefore, due to the consumers' awareness of this problem, there is a significant demand for low-sugar, low-calorie, and natural-sugar foods. In this regard, many kinds of research have been conducted on the use of natural sweeteners such as grape syrup (5) and date syrup (6) in sponge cake, powder and liquid honey (7), stevia, inulin (8), and Jaggery (9) in the muffin, chicory syrup (10) in sweets, Chicory syrup and date syrup (11) in Kesari (traditional Indian dessert).

The forests of the western and northwestern parts of Iran are the primary source of acorn trees (*QuercusPersica*) which occupy more than 49% of the total forests of the country. The dominant tree species in the forests of Kohkiluyeh and Boyer-Ahmad, Kermanshah, and Lorestan provinces are only acorn. Acorn fruit is chemically similar to many kinds of cereals and contains carbohydrates, oil, fiber, minerals, and vitamins (12). This fruit is also a good source of bioactive compounds with antioxidant properties (gallic acid and ellagic acid) and tannin, which makes it more functional and useful (13; 14; *15*). Acorn, with useful and valuable properties, is abundant and available in a wide range of forests in the northwest and west of Iran. Large quantities of this fruit are wasted under trees, and its usage is limited to livestock food, in the production of syrup and flour for local products such as bread. Incorporating acorn syrup and flour in food formulation can increase the nutritional value of the resulting products and prevent wasting a large amount of this fruit under trees. This study aimed to investigate the effect of flour and syrup of acorn as substitutes for cake flour (wheat flour) and sugar (sucrose) on the physical, textural, and sensory characteristics of the sponge cake.

2.Materials and methods

2.1 Materials

The used acorn fruits were collected from Ilam forests (Ilam, Iran). Wheat flour, corn oil, sugar, eggs, vanilla, and baking powder, were obtained from the local market of Urmia, Iran. All the chemicals and reagents (analytical grade) were purchased from Merck, Darmstadt, Germany.

2.2 Preparation of acorn flour

The acorns collected were dried at room temperature for 72 h after the separation of the hard outer layers and second layers (pairs). After milling with a commercial mixer grinder, the dried acorn fruits were sieved with a 60 mesh (250 µm) sieve. The flour prepared(SupplementalFigure1 (A)) was stored in a glass container in a refrigerator at 4 °C (16).

2.3 Preparation of acorn syrup

Acorn syrup (Supplemental Figure 1 (B)) was extracted from tree leaves and acorn fruit caps. Initially, acorn fruit with the leaves and cap was boiled for one hour to extract the syrup. The syrup was filtered to remove the cap, leaf, and suspended

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substances and then boiled to obtain the desired concentration (Brix = 60-65).

2.4 Preparation of sponge cake samples

The formulation of the control cake is given in Supplemental Table 1. First, the oil, eggs, water, sugar, and vanilla were mixed using an electric mixer for one minute. Then, the wheat flour, baking powder, and milk powder were added and mixed for 2 min to obtain a uniform dough. According to the experimental design (Supplemental Table 2), the acorn flour (AF) and acorn syrup (AS) were replaced with wheat flour (WF) and sugar (Su) in sponge cake formulation at levels of 0-30% and 0-100%, respectively. Considering the constant water content of the formulation, in the samples containing acorn syrup, the amount of water required was obtained by mass equilibrium considering the AS Brix (65) and subtraction of the water content of the AS from the control formulation water. 50 g of the dough was poured into paper molds (50 mm in diameter and 40 mm in height), and baked in an industrial rotating oven at 250 °C for 20 min (Supplemental Figure 2). The samples were cooled to room temperature after baking and then stored in polyethylene bags.

2.5 Chemical analysis of acorn flour

Ash, moisture, protein, fat, and crude fiber of prepared acorn flour were measured according to the international standard(AACC 2000).

2.6 Density of sponge cake dough

The dough density was obtained by calculating the ratio of the dough weight to its volume (determined by the rapeseed method) (17) and the following equation calculated the percentage of baking loss:

$$Baking\ loss\ (\%) = \frac{M_C}{M_d} \times 100 \text{ (Eq. 1)}$$

Where M_d is dough weight and M_C is cake weight.

2.7 Physical properties of sponge cake

The volume of cakes was determined by the rapeseed replacement method (18) and then a specific volume was calculated. The water activity (*aw*) was determined using a MS1 water activity meter (Novasina, Lahen, Switzerland) after calibration with standard relative humidity salts. The temperature was maintained at 25 °C during the measurement.

2.8 Textural properties of cake

The textural characteristics of the cakes were measured using a texture analyzer (TA-XT plus, Stable Micro System Ltd, Surrey, UK). For this purpose, samples of the central part of the cake (2×2×2 cm) were subjected to a two-consecutive compression test using a 25 mm flat aluminum probe. Selected settings included a test speed of 5 mm/s and 50% compression and a 5-s time interval between the two cycles. The calculated texture parameters include firmness (maximum force required for compression of the sample in the first cycle, Kg), cohesiveness(ratio of the area of the time-force curve during the second compression to the first compression), springiness(time ratio of the second compression to the first compression), chewiness (multiplication of firmness, cohesiveness, and springiness, kg) and gumminess (multiplication of firmness and cohesiveness) (19).

2.9 Color properties of cakes

The color of the crust and crumb of the cakes were determined based on lightness-darkness (L*), red-green (a*), and yellow-blue (b*) indices. To determine these parameters, a 2×2×2 cm slice was cut from the cake samples, and crust and crumb were imaged using a scanner (HP Scanjet G3010) with a resolution of 300 pixels. The images were then opened with

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Photoshop software. The above indices were calculated by activating the LAB space (20).

2.10 Sensory evaluation

The sensory evaluation of cake samples was performed using the linear scoring method (15 cm linear scale) by 20 evaluators (21). Scores were determined by each evaluator according to color, taste, porosity, texture, and overall acceptance. The results of this evaluation (0–1) were reported by measuring the curve length from the source to the marked point divided by the total axis length.

2.11 Statistical analysis

Experiments were designed and implemented using a mixture-mixture design by Design-Expert-version 7.0.0 Software (Stat-Ease Inc., Minneapolis, MN, USA) in 13 treatments (Supplemental Table 2). In this design, the first mixture consists of AS and sugar (with a substitution ratio of 0-100%), and the second mixture contains AF and WF (0-30% replacement of WF with AF). The results were analyzed by analysis of variance at a 95% confidence level in terms of the significance of factors. If models fitted to the experimental data were significant ($p < 0.05$), had high R^2 and adj-R^2, and insignificant lack of fit, they could be used as more reliable models for predicting the effect of factors on the physical and sensory properties of the samples.

3. Results and discussion

The results of the analysis of predictive models fitted with the dough and cake properties have been presented in Tables (1 and 2). According to the results, most of the models, which predict the physical properties of dough and physical, textural, and sensory properties of cake samples (except specific volume, springiness, and moisture content), were significant with relatively high R^2 and adj-R^2 and insignificant lack of fit. So, they can be used to predict the effect of replacing different levels of AF and AS in the sponge cake formulation.

3.1 Properties of acorn flour

The acorn flour contained 9.62% moisture, 1.2% ash, 5.13% protein, 9.33% fat, 8.3% fiber, and 57% carbohydrate. Similar results were reported by Molavi et al. (2015)(22) and Parsaei et al. (2018)(16).

3.2 Density of cake dough

According to the results, the effect of AF and AS was significant on the dough density of the samples ($p < 0.05$). With the increase of AF and AS, the dough density of the samples increased and decreased, respectively (Fig. 1(A)). An increase in dough density by the addition AF is probably due to the high fiber content as well as the type of protein present in AF and its hydrocolloid compounds, which increased its bonding with water in dough compounds and increased dough density (23). Another reason can be the weakening of the gluten structure caused by the substitution of AF, which results in less gas retention in the dough texture, and so increases the viscosity and density of the dough (24). Similar results have been presented by Salehi and Ekhlas (2018)(25) by adding gum *salvia macrosiphon* to cake dough

3.3 Physical properties of cake

During the baking process, produced gas and the vapor pressure have increased due to the expansion of water vapor when heat penetrates the cake dough. Loss of gas causes damage and weight loss. Weight loss led to a change in cake structure and reduces product shelf life. However, reducing weight loss improves the texture and quality of bakery products (26). The percentage of weight

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loss in cake refers to the amount of water evaporated during baking that is dependent on the concentration of insoluble material (21). Substitution of AF and AS significantly affected the baking loss of the samples (p <0.05) (Table 1). The baking loss of cakes increased and decreased with the substitution of AF and AS, respectively (Fig.1(B)). Increasing water absorption by AS compounds may reduce water evaporation during baking; thereby reducing the baking loss. Gluten-free flours also have less water absorption capacity than WF (27). Therefore, AF loses more water during baking. Goswami *et al.* (2015)(27) have also reported an increase in weight loss by adding millet flour to muffin formulation.

According to the results, the substitution of AF and AS had no significant effect on moisture content and thespecific volume of cake samples (p> 0.05). The addition of AF and AS had a significant effect on the *aw* of cake samples (p <0.05). As can be seen in Fig.1(C), the replacement of AF at high levels of AS had no significant effect on *aw*, but when the As level was less than 70%, the aw factor significantly increased. In general, the highest *aw* was obtained in the samples containing the highest amount of AF and Su. According to the results, According to these results, with the increase in the AF level, the moisture content did not change, in contrast, the aw increased. This indicates the poor ability of water for binding with AF compared to WF, which increases the partial pressure of water and consequently increases the *aw*. Similar results were obtained by Raei et al. (2016)(28)by adding date syrup to sponge cake.

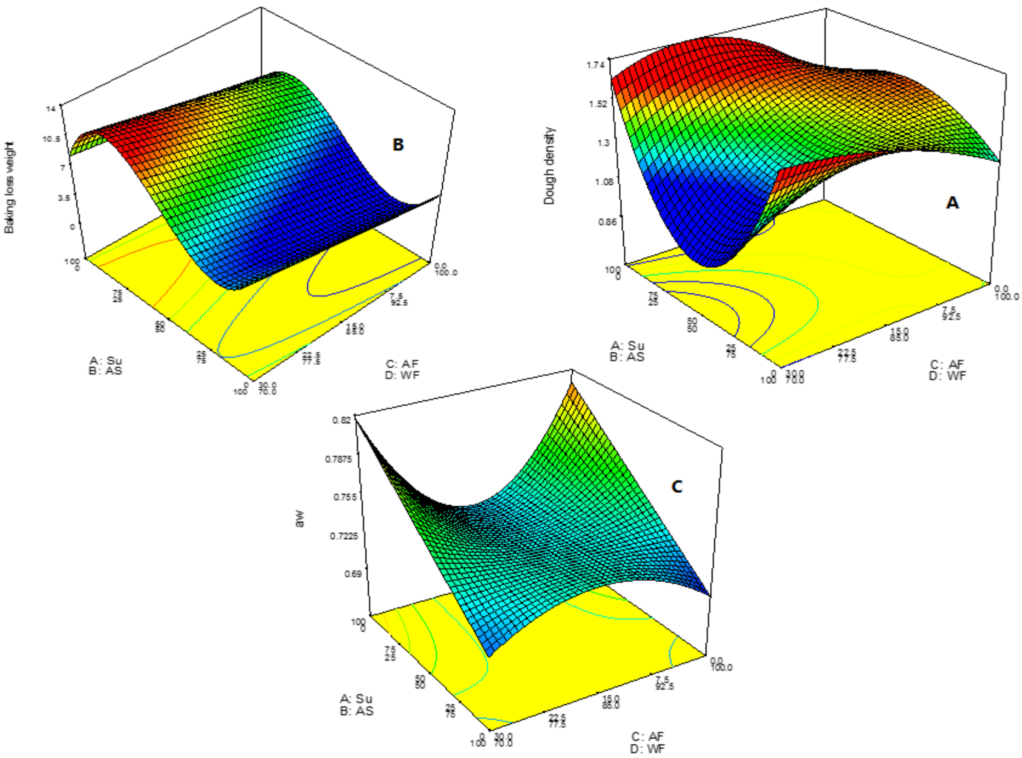

Figure 1. Three-dimensional diagram of the effect of replacing acorn flour and acorn syrup on the dough density (A); baking loss (B), and water activity of cake samples (C), (AF: acorn flour; WF: wheat flour; Su: sucrose; AS: acorn syrup).

3.4 Texture properties of cakes

The results showed that the linear effect of the first mixture (AS-Su) and the quadratic effect of the second mixture

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(AF-WF) were significant on the firmness of the cake samples ($p < 0.05$). According to Figure 2 (A), the replacement of AF and AS orderly had the most significant effect on increasing the firmness of the cake samples. So, the highest firmness was obtained in the samples containing the highest percentage of AF and AS. This phenomenon may be because of the greater effect of AF in reducing gluten content and the direct relation of firmness with the dough density and its indirect relation with the volume (29). This is consistent with the results of the increase in density resulting from the addition of AF. The gluten content of cake dough decreased when AF increased causing the poor dough structure and low gas retention capacity of dough which increases the firmness of the cake texture. Increased firmness with reduced sugar content is likely due to the effect of sugar on the mechanism of inhibition of starch gelatinization that makes them soft (5). These results are in agreement with the results of sugar substitution with black currant and Aronia (19) grape syrup (Mohtarami 2018) in cake samples and replacement of Quinoa flour (30) in bread, acorn flour (Molavi*et al.* 2015)(22), Chennyuncho flour (24) and black rice flour (31) in cakes.

As shown in Figure 2 (B), increasing the levels of AF decreased the cohesiveness of cake samples, while AS replacement had no significant effect on the cohesiveness ($p > 0.05$). The reason for the decrease in cohesiveness with increasing the percentage of AF can be attributed to the presence of non-gluten proteins in it (22). The results were in agreement with the findings of Korus *et al.* (2015)(32) who suggested a reduction in the cohesiveness by replacing WF with AF in bread. The elasticity of the samples is calculated by determining the degree of recovery between the first and second compression by the springiness. The studied factors had no significant effect on the springiness ($p > 0.05$).

The chewiness is dependent on the firmness degree and usually shows similar behavior. According to the results, the linear effect of AS and the quadratic effect of AF on chewiness were significant ($p<0.05$). Substitution of AF and AS increased cake chewiness. The highest chewiness was obtained at high ratios of AF and AS replacement, which was in agreement with the results of the sample's firmness (Fig.2(C)). Similar results have been reported for the chewability of cakes enriched with waxy rice flour (8), black rice flour (31), and Chennyuncho flour (24). In general, the firmness and chewiness of the cake increased with the increase of AF and AS. Replacing AF had a negative effect on the cohesiveness of the cake.

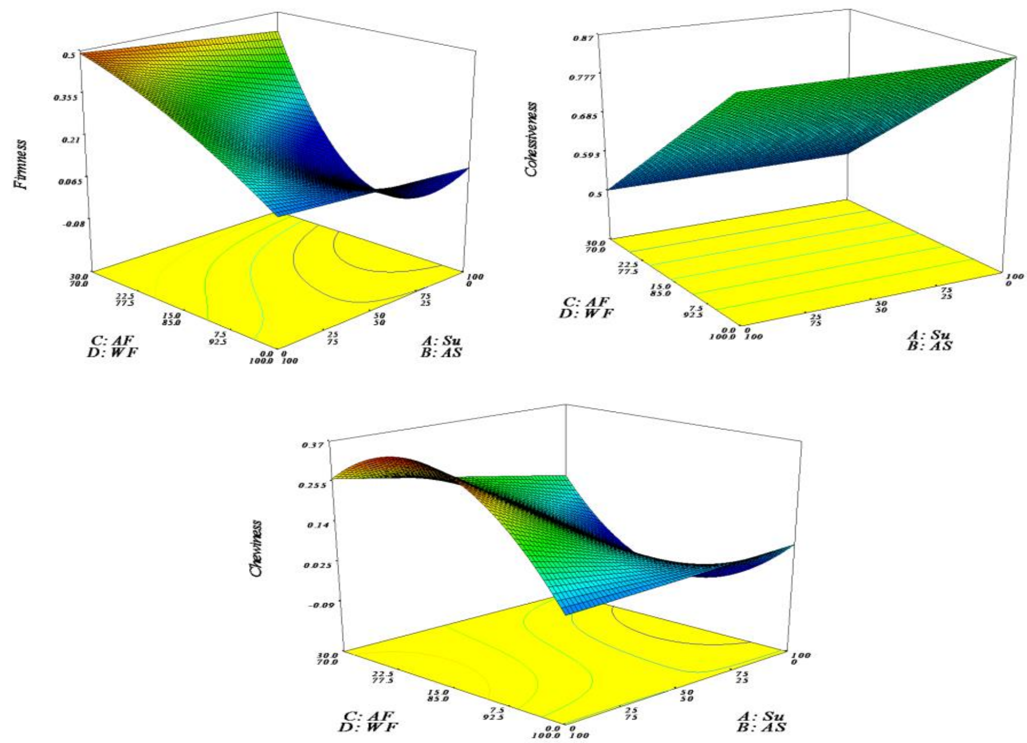

Figure 2.Three-dimensional diagram of the effect of replacing acorn flour and acorn syrup on the textural properties (firmness (A), cohesiveness (B), and chewiness (C))of sponge cake samples (AF: acorn flour; WF: wheat flour; Su: sucrose; AS: acorn syrup).

3.5 Color properties of cakes

The color of the products significantly affects their Customer-Friendly. As shown in Figure 3, the replacement of WF with AF decreased L* and b* of crumb and crustas well as a* of crust (p<0.05). Substitution of sugar with AS had no significant effect on the L* and a* of crust. However, it decreased L* and increased a* of crumb. AF and AS had a synergistic effect on cake redness. So that AF in samples containing low levels of AS caused a slight increase in a*, but the highest a* was observed in samples containing the highest AS. Crumb b* was not affected by the AS replacement, but the b* of the crust decreased. The difference in the color parameters of the cakes can be due to the natural pigments and the darker color of the AF and AS compared to the WF and Su as well as the caramelization reactions and non-enzymatic browning occur because of the addition of AS (containing reducing sugars). The results were in agreement with the findings of Korus *et al.* (2015)(32), who reported that with increasing AF, the lightness and redness of the samples decreased and increased, respectively. In addition, Karp*et al.*(2017)(21) reported similar results with the addition of date syrup to Kesari.

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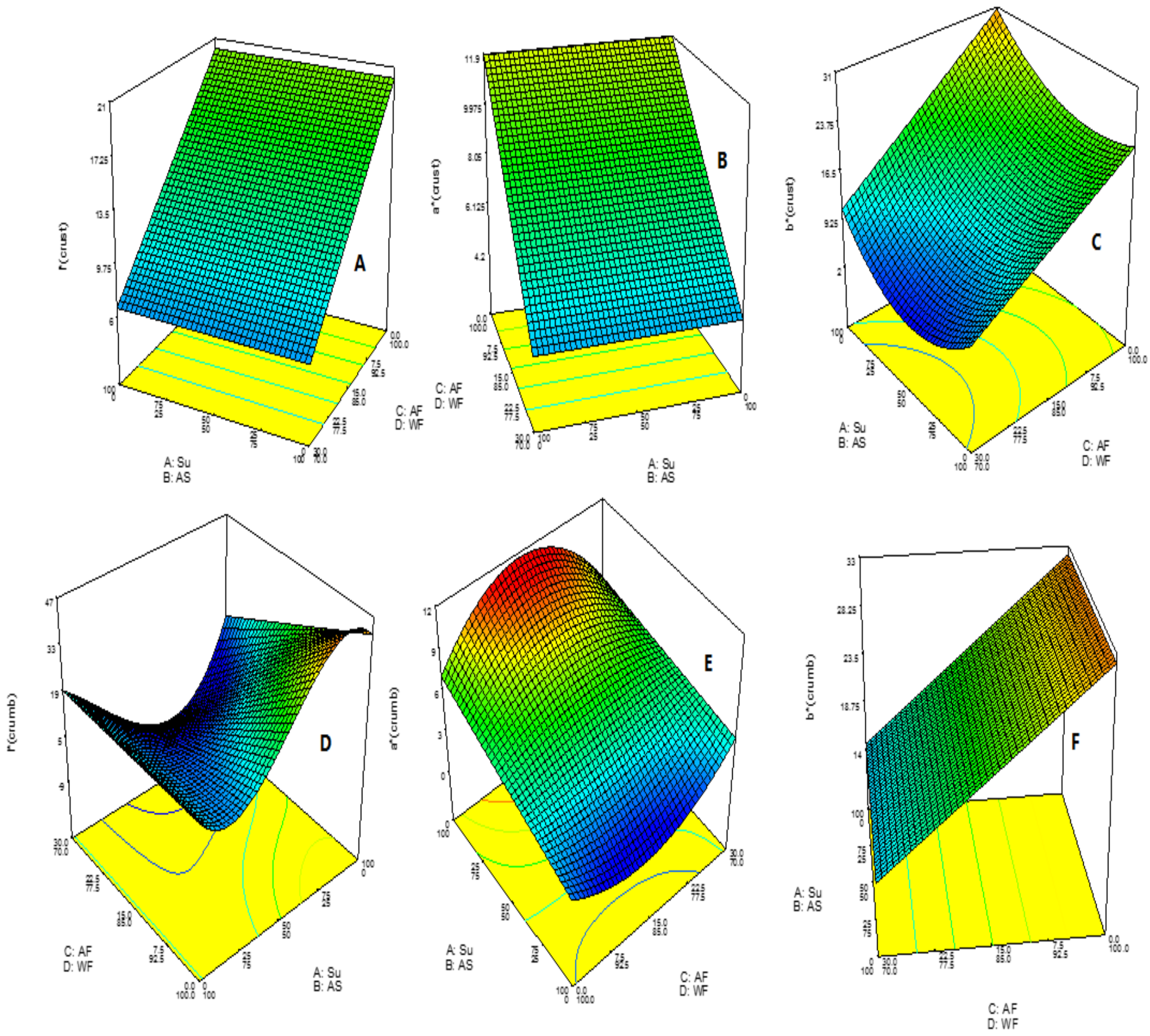

Figure 3. Three-dimensional diagram of the effect of replacing acorn flour and acorn syrup on the crust and crumb color of cake samples (AF: acorn flour; WF: wheat flour; Su: sucrose; AS: acorn syrup).

3.6 Sensory evaluation

The texture score of the cake samples decreased with increasing AF and AS, but the porosity was not affected by this substitution (Fig.4(A)). Overall, the samples with higher levels of sugar had more overall acceptance scores, but replacing WF with AF did not affect the overall acceptance score, significantly ((Fig.4(B)). However, the overall acceptance for all samples was acceptable (above 0.7). Panelists found that by increasing the ratio of AF, the taste score improved, whereas replacing high levels of AS had a negative effect on acceptance of the cake taste ((Fig.4(C)). The results of the sensory evaluation were in agreement with the reported results for the replacement of grape syrup (5), with sugar in cakes, as well as the replacement of millet flour with wheat flour in amuffin (27).

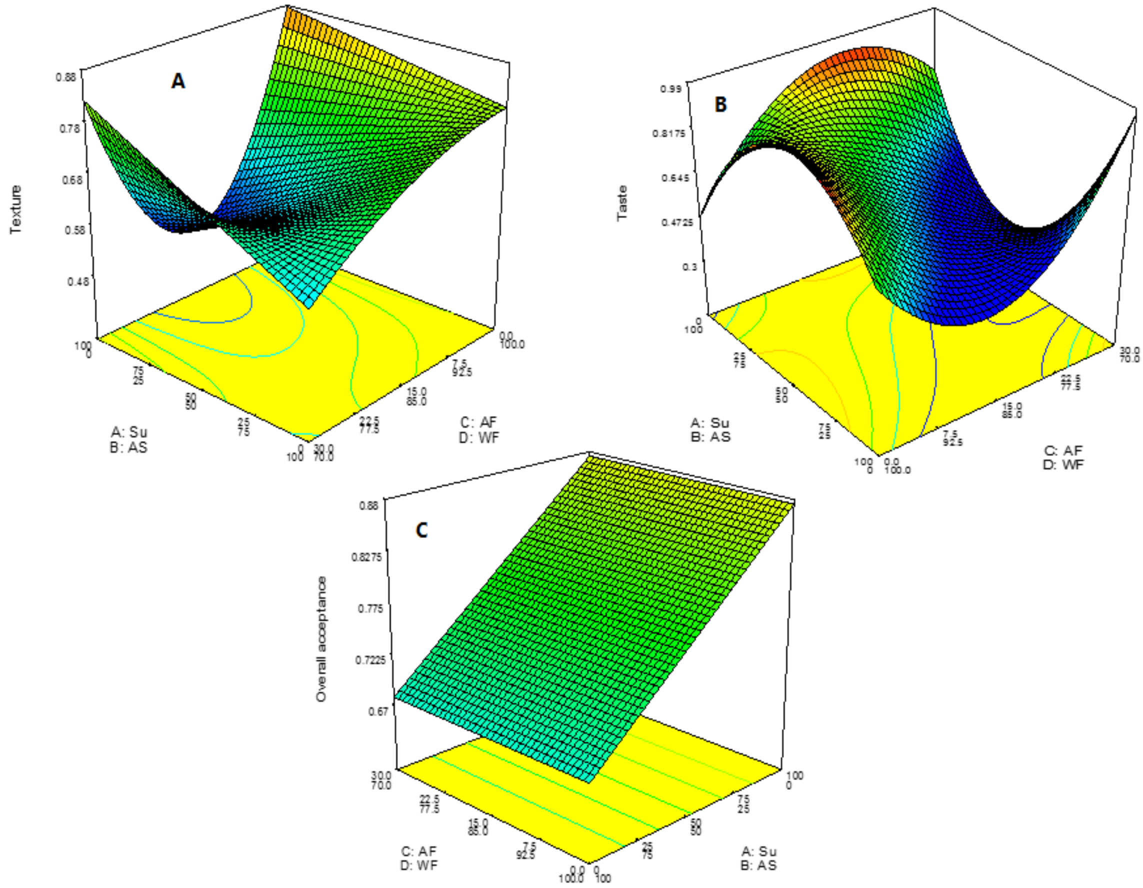

Figure4.Three-dimensional graphs of the effect of substitution of acorn flour and syrup on sensory evaluation of samples by panelists for texture (A), taste (B), and overall acceptance (C).

Table 1. Analysis of variance of models of fitting physical properties of dough and cake samples and sensory assessment of samples

Factor	Model	F	F>P	Lack of fit	R^2	adj-R^2
Backing loss %	Cubic×Linear	12.16	0.0147	0.075	0.95	0.87
Dough density	Quadratic×Quadratic	8.21	0.029	0.09	0.93	0.82
aw	Linear×Quadratic	27.51	0.0005	0.57	0.95	0.92
Specific volume	Mean ×Linear	2.98	0.11	0.86	0.23	0.15
moisture	Linear×Linear	0.12	0.94	0.6	0.04	-0.31
hardness	Linear×Quadratic	16.66	0.0018	0.67	0.93	0.87
cohesiveness	Mean ×Linear	7.30	0.02	0.84	0.42	0.36

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chewiness	Linear×Quadratic	5.94	0.02	0.75	0.83	0.69
Springiness	Linear×Quadratic	1.24	0.39	0.98	0.5	0.09
L*(Crumb)	Cubic×Linear	381.54	0.0001	0.06	0.99	0.99
a* (Crumb)	Linear×Quadratic	9.77	0.0076	0.74	0.89	0.79
b* (Crumb)	Mean×Linear	33.21	0.0002	1.70	0.76	0.74
L*(crust)	Mean×Linear	13.21	0.0046	0.89	0.56	0.52
a*(crust)	Mean×Linear	8.74	0.0144	0.21	0.46	0.41
b*(crust)	Quadratic×Linear	6.09	0.024	0.145	0.83	0.69
Porosity	Quadratic×Quadrat	2.27	0.22	0.03	0.79	0.44
Taste	Quadratic×Quadratic	12.03	0.01	0.081	0.95	0.87
Texture	Linear×Quadratic	11.01	0.005	0.601	0.90	0.81
Overall acceptance	Linear×Mean	15.96	0.0025	1.54	0.61	0.57

3.7 Numerical optimization

A numerical optimization method was used to perform the optimization. To this end, the optimization objectives (taking into account the highest replacement of AF and AS, the least firmness, and the highest cohesiveness and overall acceptance score) and their degree of importance were determined. The results showed that the samples containing 25 or 45% acorn syrup with 11% AF had the highest desirability, and they were suggested as the optimum samples with desirable physical-sensory properties.

Table2. Predicated models for responses

Dough Density = -5.12AC+1.31AD-0.09BC+1.27BD-12.21ABC-0.92ABD+10.71ACD+3.51BCD
Baking Loss= 14.62AC+5.66AD+17.74BC+4.31BD+26.52ABC-3.38ABD+65.87ABC(A-B)+34.85ABD(A-B)
Water Activity= 3.67AC+0.80AD-0.30BC+0.69BD-0.04ACD+1.48BCD
Firmness=11.21AC+0.10AD+0.21BC+0.15BD-14.31ACD+1.51BCD
Cohesiveness= -0.35C+0.86D
Chewiness= 6.47AC+0.07AD-5.20BC+0.5BD-8.80ACD+8.52BCD
L* (crust) = -24.89C+20.22D
a* (crust) = -13.20+11.88D
L* (crumb) = -47.21AC+42AD+18.388BC+20.65BD-298.42ABC-8.472ABD-407.58ABC(A-B)+101.33ABD(A-B)

a* (crumb) = 97.30AC+2.92AD-144.96BC+7.20BD-126.02ACD+214.01BCD

b* (crumb) = -26.41+32.20D

Texture = 12.09 AC + 0.87 AD -1.12 BC +0.79 BD -16.26ACD + 1.79 BCD

Taste=14.1 AC+0.7AD-8.07BC+0.47BD-10.80ABC+1.51ABD-17.29ACD+13.49BCD

Overall acceptance= 0.87 A+ 0.67 B

Where A, B, C and D represent sugar, acorn syrup, acorn flour and wheat flour, respectively.

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4. Conclusion

Adding AF and AS in cake formulation increases its nutritional value due to the desired properties of acorn fruit as an herbal source with medicinal and health properties. The replacement of AF increased the density of the dough and the baking loss. Replacement of AS resulted in a decrease in the density of the dough and the baking loss. By replacing AF and AS, the firmness and chewiness of cake samples increased and their cohesiveness decreased. Also, this substitute increased the *aw* of samples compared with the control. The replacement of AF and AS had no significant effect on the specific volume and moisture content. Adding AF caused darkness and redness of crust and crumb. According to the results of the sensory assessment, samples with low AS substitution had higher desirability and AF had no significant effect on the overall acceptance, but generally overall acceptance of all samples was acceptable. Based on optimization, considering the highest cohesiveness, springiness, and overall acceptability score and the least firmness, the samples containing 11% acorn flour with 25 or 45% acorn syrup were suggested.

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6. Disclosure statement

No potential conflict of interest was reported by the author(s).

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بهینه‌سازی فرمولاسیون کیک اسفنجی جدید جهت بررسی اثر جایگزینی آرد بلوط و شیره بلوط با آرد گندم و شکر

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چکیده

هدف از مطالعه‌ی حاضر بررسی جایگزینی آرد بلوط با آرد گندم (آرد کیک) و شیره‌ی بلوط با شکر بر مبنای طرح ترکیبی بر ویژگی‌های کیک اسفنجی می‌باشد. با توجه به نتایج حاصله، جایگزینی آرد بلوط با آرد گندم باعث افزایش دانسیته‌ی خمیر و درصد اتلاف پخت و کاهش پیوستگی، شاخص روشنایی و قرمزی نمونه‌ها گردید. رنگ پوسته‌ی کیک با افزودن شیره‌ی بلوط تیره شد. محتوای رطوبتی و حجم مخصوص تحت تاثیر جایگزینی آرد بلوط و شیره‌ی بلوط قرار نگرفت. همچنین با افزودن آرد بلوط و شیره‌ی بلوط فعالیت آبی، سفتی و قابلیت جویدن افزایش یافته در حالی که ارتجاعیت نمونه‌ها کاهش یافت. نتایج ارزیابی حسی نشان داد که با جایگزینی شیره‌ی بلوط از امتیاز پذیرش کلی نمونه‌ها کاسته شد در حالی که آرد بلوط اثر معناداری بر آن نداشت. با توجه به نتایج بهینه‌سازی، فرمولاسیون کیک اسفنجی با ۱۱ درصد جایگزینی آرد بلوط همراه با ۲۵٪ و ۴۵٪ شیره‌ی بلوط به عنوان نمونه‌ی بهینه با ارزش تغذیه‌ای بالا و ویژگی‌های بافتی و حسی مطلوب پیشنهاد می‌گردد.

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