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Optimization of composite flour-based sugar-free muffins

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Abstract

Muffins are among high sucrose-containing bakery products enjoyed globally for their soft texture and great taste. Its excess consumption results in high-calorie intake, leading to many health problems such as diabetes, obesity, cardiovascular disorders, etc. Replacement of sucrose from muffins helps in the preparation of low-calorie bakery products. The objective of the current study was the preparation of sugar-free muffins and examining their effect on the height and textural attributes. Refined flour was replaced with millet-legume-based composite flour selected from our previous work. Statistical analysis was done using the central composite design of Design Expert, v.11. Polydextrose and guar-gum were the variables, and height, hardness, fracturability, springiness, adhesiveness, cohesiveness, and resilience were the responses in the experimental design. The ANOVA, R^2, and R^2 adjusted values for all the responses except cohesiveness and resilience showed a significant effect of polydextrose and guar-gum on the height and textural quality of sugar-free muffin. Replacement of sucrose resulted in muffins with lower height ($p < 0.01$), more hardness, more fracturability, lesser springiness, adhesiveness ($p < 0.05$), and no significant effect on cohesiveness and resilience. Incorporating composite flour containing high fiber and protein in the muffin formulation may be another reason for the present findings. However, adding polydextrose and guar-gum to sugar-free muffins has helped to prepare low-calorie products with accepted quality attributes. The best solution from optimization with a design expert was polydextrose (12.627%) and guar-gum (0.707%) with a desirability value of 0.791. These sugar-free muffins will help the bakery industry achieve the new goal of preparing less energy-containing functional foods. In the future, this research will help food technologists and bakery experts to prepare sugar-free muffins with desirable quality.

Keywords bakery product, composite flour, design expert, guar-gum, polydextrose, sugar-free Muffin

Introduction

Recently consumers have been interested in knowing the food ingredients used in the products. This increasing consciousness makes them aware of the adverse effects of certain ingredients like sugar, fat, oils, etc., on their health. Sucrose is a crucial ingredient in the bakery industry. It has so many properties necessary for a baked product. A lot of sucrose is used in preparing bakery products like muffins, cakes, cupcakes, etc. Muffins are the common sweet snack in the bakery industry. It is accepted around the globe among children and adults due to its soft texture and taste. Muffin batter is an emulsion of egg, sucrose, fat in a continuous aeration process. The air-bubbles during aeration give the muffin the desirable volume and porous structure. However, muffins are higher in sugar, fat, and calories-containing bakery product [1]. Excessive sucrose consumption may lead to global obesity, Type 2 diabetes, cardiovascular diseases, and hypertension [2-3]. Now, this creates a demand in the market for functional food. Therefore, the bakery industry is exploring different ingredients or combinations of other ingredients to prepare functional foods or foods without sugar, less fat, or even adding fiber to impart some therapeutic properties.

The solution may be limiting the use of sucrose or completely replacing it with artificial sweeteners. Artificial sweeteners impart a sweet taste without adding extra calories to the product. Still, the removal of sugar creates a missing bulk in the batter because of its high weight and volume [4]. Therefore, replacing sucrose from muffins and achieving good quality attributes is challenging, and there may be a slight deviation in the final product texture. Polydextrose and guar-gum are carbohydrate-based fat replacers that are helpful in the formulation of sugar-free products. Polydextrose is a non-digestible, functional fibre with an energy value of only 1 kcal/g [5]. US Food and Drug Administration approved polydextrose as a food additive. It is widely used as a low-calorie bulking agent in various foods and a partial replacement for fat and sugar [6]. Guar-gum is a plant-based natural non-ionic, water-soluble polysaccharide. It is one of the cheapest hydrocolloids available in the food industry and a non-caloric source for dietary fiber [7] and enhancing the dough yield [8].

The aim of this study was the formulation of composite flour-based sugar-free muffins. Different combinations of polydextrose and guar-gum were used. Their effect on height and textural attributes of muffins were examined to find out the best combination for the preparation of sugar-free muffins.

Methodology

Source of materials

Millet-legume-based composite flour for muffin preparation was obtained from our previous work [9]. Urban Platter guar-gum powder was purchased from Amazon. Litesse 2 (polydextrose) was received as a sample from Danisco India Pvt. Ltd. Sugar-free Natura and Delicious cholesterol-free butter were purchased from the local market. Baking powder, baking soda, skim milk powder, and cinnamon powder was used from the bakery production laboratory (Assocom institute of bakery technology & management AIBTM, New Delhi, India).

Experimental design

The center composite design of response surface methodology (RSM) (Design Expert 11 version) was used to analyze the effect of replacing sucrose on muffin height and textural attributes using polydextrose (A) (10-15%) and guar-gum (B) (0-1%) at different levels (Table 1) of its weight percentage. The design consists of 13 different treatments of sugar-free muffins (Table 2). The range of the independent variables was based on previous literature [1, 10-12] and preliminary trials. The dependent variables include the height and texture of muffins, i.e., hardness, fracturability, adhesiveness, springiness, cohesiveness, and resilience.

Table 1. Experimental design using optimal mixture model of RSM for sugar-free muffins

S. No.	Independent variables	Symbol	Minimum (%)	Maximum (%)
1.	Polydextrose	A	10	15
2.	Guar-gum	B	0	1

Muffin preparation

Control muffins were prepared using refined flour (100%), butter (100%), sugar (100%), egg (100%), custard powder (5%), milk powder (3%), baking powder (1%), cinnamon (1%), essence (0.5%) (Table 3). KitchenAid stand mixer was used for the preparation of muffin; first of all, creaming was done (mixing butter and sugar) at a medium speed, followed by gradually adding egg into the cream such that the mixture

Table 2. Effect of independent variables on experimental muffins physical and textural attributes

T	A	B	Height	Hardness	Fracturability	Adhesiveness	Springiness	Cohesiveness	Resilience
	%	%	mm	G	g	g sec			
1	10	0	45.2	3137.62	2314.473	-413.79	0.702	0.2521	0.06125
2	15	0	45.13	2773.86	2109.776	-409.27	0.8199	0.2433	0.05425
3	10	1	45.33	3074.086	2470.11	-449.56	0.809	0.2455	0.06175
4	15	1	45.9	2598.8	1959.372	-440.28	0.775	0.2215	0.05175
5	10	0.5	44.37	2337.468	2177.44	-266.91	0.722	0.22425	0.0525
6	15	0.5	40.95	3127.28	2407.932	-291.22	0.852	0.266	0.065667
7	12.5	0	44	2531.2	2025.061	-242.79	0.7814	0.24225	0.059
8	12.5	1	39.88	2112.19	1308.22	-418.89	0.712	0.3066	0.05575
9	12.5	0.5	34.98	2129.88	1601.12	-318.99	0.798	0.2572	0.0575
10	12.5	0.5	35.16	2142.89	1459.76	-290.76	0.768	0.2498	0.0572
11	12.5	0.5	35	2102.79	1497.15	-242.34	0.7963	0.2567	0.0569
12	12.5	0.5	37.38	2100.17	1547.76	-296.16	0.8147	0.2542	0.057
13	12.5	0.5	35.78	1729.72	1229.82	-296.47	0.7742	0.2322	0.0572
C	0	0	53	1528.12	1179.37	-201	0.905	0.4001	0.07

T: Treatment; C: Control; A: polydextrose; B: guar-gum

became fluffy and at last all the dry ingredients were mixed for the formulation of muffin batter. The batter of 60 gm was transferred to muffin trays. Muffins were placed on an oven tray and baked at 180 ºC for 20-25 minutes. For the experimental muffins (sugar-free muffins) preparation, refined flour was replaced by composite flour comprising millets, legumes, and wheat (100%), sugar-free (10%), butter (100%), egg (100%), milk (70%), cinnamon (1.5%) (Table 3)

Table 3. Muffin formulation

S. no.	Ingredients	Control (%)	SFM (%)
1.	Refined flour	100	-
2.	Composite flour	-	100
3.	Butter	100	100
4.	Egg	100	100
5.	Milk	-	70
6.	Sugar	100	-
7.	Sugar-free	-	10
8.	SMP	5	5
9.	Custard powder	5	-
10.	Baking powder	3	3
11.	Cinnamon powder	1.5	1.5

SMP: skim milk powder; SFM: sugar-free muffins

standardized through trials and polydextrose and guar-gum were mixed in the required proportion as per the response surface design (Table 2). Baking powder, milk powder, essence, and cinnamon were kept fixed. Experimental muffins were baked at 180 ºC for 22-24 minutes. After baking, both the muffins were cooled, packed, and stored for further analysis. The experimental muffins (sugar-free) are shown in Figure 1.

Muffin height

The muffin was taken out from the paper baking case, and the height was measured with a vernier caliper from the highest point of the muffin to the bottom of the muffin [13].

Texture analysis

Texture Analyzer (TA) HD Plus (Stable Micro Systems, Surrey, England) was used for the texture analysis of formulated muffins; six replicates were taken from each treatment batch. Hardness, fracturability, adhesiveness, springiness, cohesiveness, and resilience were calculated using an automatic trigger type force of 5 g. The mode of the test was compression, and the analyser was set to 'return to start' cycle with the following test conditions: pre-test speed of 1.00 mm/sec, test speed of 3.00 mm/sec, post-test speed of 3 mm/sec, and hold time of 5 seconds, a distance of probe was maintained at 50%, and method settings were maintained by adjusting data acquisition rate at 200 pps.

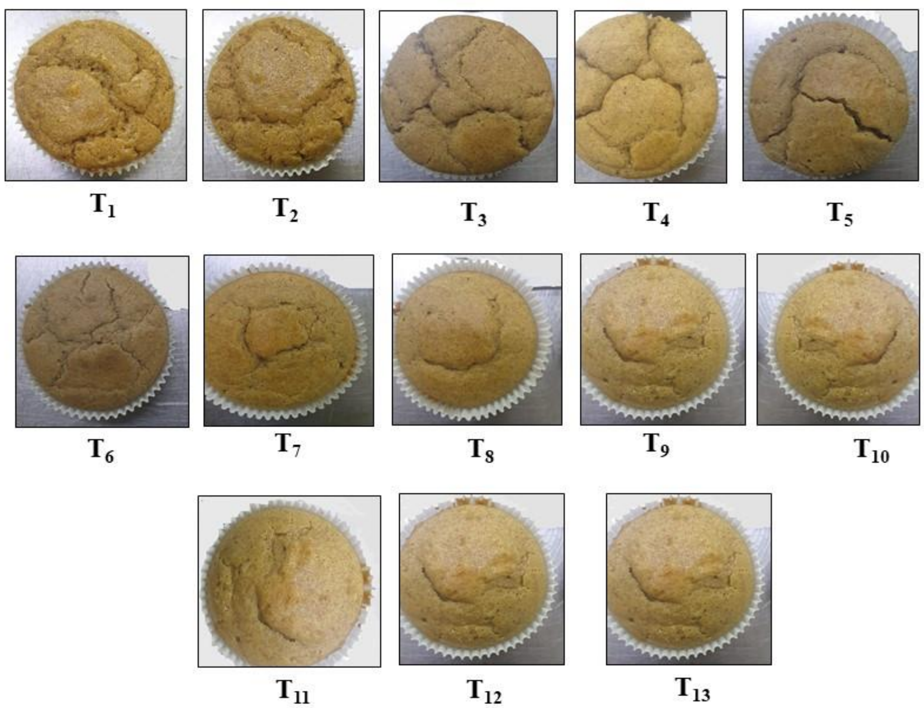

Figure 1. Experimental muffins formed using different levels of polydextrose and guar-gum

Statistical analysis

Response Surface Methodology (Design-Expert software version 11, Stat-Ease Inc. Minneapolis, U.S.A) analysis of variance (ANOVA) and regression models were used to study the effect of polydextrose (A) and guar-gum (B) on the height and textural characteristics of the formulated muffins. The experimental data obtained from the design was analyzed using a second-order polynomial equation. The statistical significance of the model was evaluated using model analysis, lack of fit F- value and model F- value and coefficient of determination (R^2) [14]. The linear, quadratic, and interactive effect of variables on the response was described at 1% and 5% levels of confidence.

Optimization

The numerical method of Design-Expert software (version 11, Stat-Ease Inc. Minneapolis, U.S.A) was used for the optimization process. The optimization aimed to find the best combination of polydextrose and guar-gum to prepare sugar-free muffins. In the optimization process, the independent variables, namely polydextrose and guar-gum, were kept in range. On the other hand, within the response hardness, fracturability was minimized, and the remaining height, adhesiveness, springiness, cohesiveness, resilience was kept in range. After adjusting all the above parameters, the highest desirability solution was selected. The desirability function is a method used in the optimization process; its value ranges from 0 (lowest) to 1 (highest) [15]. The 3D response surface graphs were obtained showing the effect of polydextrose and guar-gum on the different responses. Experiment muffins were prepared with optimal conditions of polydextrose and guar-gum, and their height and textural attributes were analysed. The experimental results were comprehended with predicted values from the fitted model. The model's accuracy was established with a two-tailed, one-sample T-test using SPSS Statistics version 22 (IBM).

Results

Muffin height

The height of the control muffin was 53 nm. Experimental muffins height ranges from 34.98 mm to 45.90 mm (Table 2). Maximum height is for treatment 4 (PX15, GG 1) and minimum for treatment 9 (PX 12.5, GG 0.5). The ANOVA shows that the model (quadratic) and model terms (A, B, AB, A_2, B_2) are significant ($p<0.05$) (Table 4). This shows that both factors significantly affect the height of muffins. The 3D plot showing the effect of polydextrose and guar-gum on the height of the sugar-free muffins is shown in Figure 2(a). The R- squared and adjusted R squared values are 0.9008 and 0.8299 (Table 4), respectively.

Table 4. Coefficient of analysis and ANOVA model

Factor	Height	Hardness	Fracturability	Adhesiveness	Springiness	Cohesiveness	Resilience
Intersept	36.15	2057.21	1505.57	-274.15	0.7788	0.2501	0.0575
A	-0.4867	-8.21	-80.82	-1.75	0.0356		
B	-0.5367	-109.6	-118.6	-40.48	-0.0012		
AB	0.16	-27.88	-76.51	1.19	-0.038		
A2	5.29	634.86	690.98	-41.9			
B2	4.57	224.18	64.94	-93.68			
Model							
Type	quadratic	quadratic	quadratic	quadratic	2FI	mean	mean
F-value	12.71	4.08	6	4.11	3.92	5.87	408.8
p-value	0.0021**	0.0471*	0.018*	0.0462*	0.0484*	0.0525	<0.0001
Lack of fit	ns	ns	ns	ns	ns	ns	s
R2	0.9008	0.7443	0.8108	0.746	0.5663	0	0

ns: non-significant; s: significant, * significant at 5% ($p<0.05$); ** significant at 1% ($p<0.01$)

Textural attributes

The hardness of the control muffin was 1528.12 g. The hardness of the experimental muffin ranges from 3137.62 g to 2100.17g. Hardness is maximum for treatment 1 (PX 10 GG 0) and minimum for treatment 12 (PX 12.5, GG 0.5) (Table 2). The ANOVA shows that the model (quadratic) and model terms (A, B, AB, A_2, B_2) are significant ($p<0.05$) (Table 4). This shows that both factors significantly affect the hardness of muffins. The 3D plots showing the effect of polydextrose and guar-gum on the hardness of sugar-free muffins are shown in Figure 2(b). The R- squared and adjusted R squared values are 0.7443 and 0.5617 (Table 4), respectively. Fracturability of the control muffin was 1179.37 g. The Fracturability of experimental muffins ranges from 2470.11 g to 1229.82 g (Table 2). Fracturability is maximum for treatment 3 (PX 10 GG 1) and minimum for treatment 13 (PX 12.5 GG 0.5). The ANOVA shows that the model (quadratic) and model terms (A, B, AB, A_2, B_2) are significant (p<0.05) (Table 4). This shows changing both factors affect the fracturability of muffins. The 3D plots showing the effect of polydextrose and guar-gum on the fracturability of sugar-free muffins are shown in Figure 2(c). The R- squared and adjusted R squared values are 0.8108 and 0.6757 (Table 4), respectively.

The adhesiveness of the control muffins was -201 g sec. The adhesiveness of the experimental muffins ranges from -449.56 g sec to -242.34 g sec (Table 2). Adhesiveness is maximum for treatment 3 (PX 10 GG 1) and minimum for treatment 11 (PX 12.5 GG 0.5). The ANOVA shows that the model (quadratic) and model terms (A, B, AB, A_2, B_2) are significant (p<0.05) (Table 4). This shows both factors have a positive effect on the adhesiveness of muffins. The 3D plots showing the effect of polydextrose and guar-gum on the adhesiveness of muffins are shown in Figure 2(d). The R- squared and adjusted R squared values are 0.7460 and 0.5645 (Table 4), respectively.

The springiness of the control muffin was 0.905. The springiness of the experimental muffins ranges from 0.852 to 0.702 (Table 2). Springiness is maximum for treatment 6 (PX 15 GG 0.5) and minimum for treatment 1 (PX 10 GG 0). The ANOVA shows that the model (2FI) and model terms (A, B, AB) are significant (p<0.05) (Table 4). This indicates that both factors have a linear effect on the springiness of muffins. The 3D plots showing the effect of polydextrose and guar-gum on the springiness of muffins are shown in Figure 2(e). The R- squared and adjusted R squared values are 0.5663 and 0.4217 (Table 4), respectively.

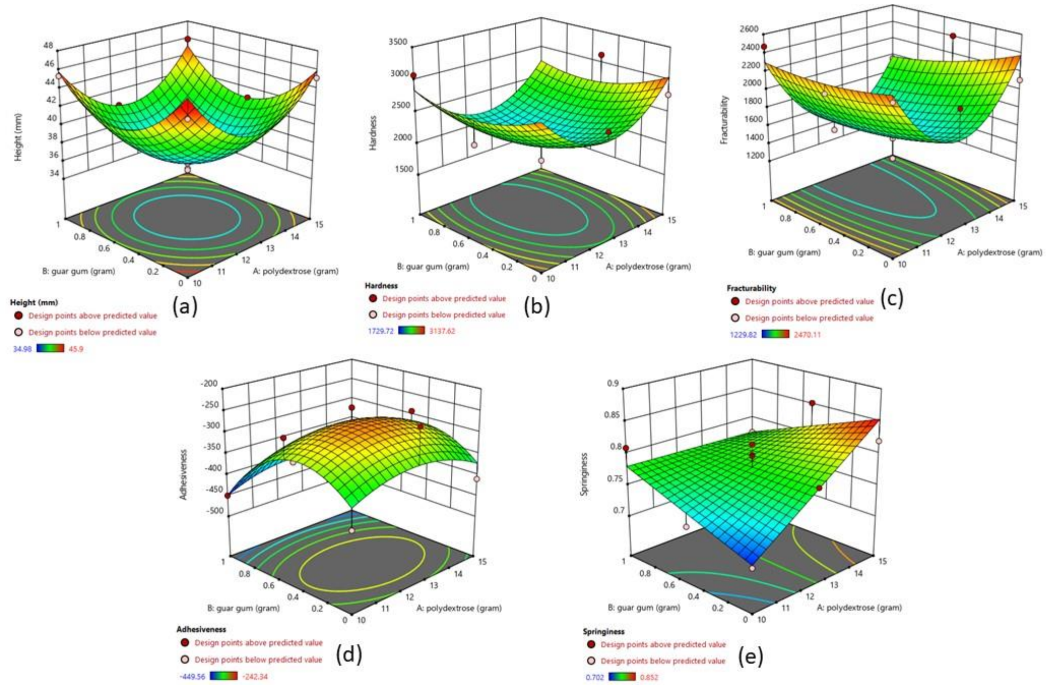

Figure 2. 3 D response surface graphs showing the effect of polydextrose and guar-gum on (a) height (b) hardness (c) fracturability (d) adhesiveness (e) springiness experimental muffin

The cohesiveness and resilience of the control muffin were 0.4001 and 0.07. Cohesiveness and resilience of the experimental muffin values range from 0.3066 to 0.2215 and 0.0656 to 0.05175 (Table 2), respectively. The ANOVA shows that the model (mean) is insignificant for both responses. This indicates no significant effect of polydextrose and guar-gum on the cohesiveness and resilience of formulated muffins.

Discussions

Effect of sugar replacement on muffin height

Muffin height is mainly responsible for its density. A greater height means less density of muffins [4]. The control muffin prepared using sucrose had a greater height than the experimental muffins (Table 2). During baking, sugar delays starch gelatinization and contributes aeration to the batter. This helps in the formation of structure and improves the muffin's texture [16]. Control muffins with full sucrose content had many air bubbles achieved at the time of beating the batter, which expands carbon dioxide and water vapor pressure generated during baking. This results in creating air channels, which influence the texture of the finished muffin product. Less air incorporation may be responsible for the lower expansion of sugar-free muffins during baking. Lesser air channels are result of sugar replacement associated with reduced air holding capacity during baking [1, 17]. Results from the design showed a variation in the height of sugar-free muffins. At lower and higher levels of polydextrose and guar-gum greater height is observed while at intermediate levels of both the factors muffins have a lower height (Table 2). Similar results of lower muffin height on sucrose replacement were reported [4, 13]. The coefficient of estimation shows the individual effect of polydextrose ad guar-gum is negative on height which means increasing levels of both the factors height decreases and vice-versa while the interactive effect is positive. Figure 2 (a) shows the effect of polydextrose and guar-gum on muffin height. It explains at the starting and end of the graph muffin has higher heights which means at lower and higher levels of each factor muffin expands and attains a satisfying height. But as the graph grows and reaches in the middle muffins have a lesser height which means an intermediate level of each factor; muffins are not expanding well due to lesser air bubbles.

Effect of sugar replacement on Textural attributes

Hardness is defined as the maximum applied force at the first bite. Reducing or replacing sucrose in muffin batter affects the product texture. The hardness of the control muffins was greater than the sugar-free muffins (Table 2). The reason may be the property of sucrose to delay protein denaturation and starch gelatinization. Karp et al., [18] suggested the more water evaporates from the batter during baking the more desirable crumb structure of muffin will be formed. Due to the hygroscopic nature of sucrose, starch, gluten there is a competition of sucrose for water [4]. Replacement of sucrose changes gelatinization temperature, gluten hydration and affects water migration which can be a reason for the high hardness of the sugar-free muffins. The results from the design (Table 2) showed that hardness increases significantly on the higher and lower level of both the factors while decreasing at an intermediate level. Sucrose replacement in muffins results in an increased hardness [13, 17, 19-20]. Coefficients of estimates show a negative effect of both factors on the hardness of the muffins. This means on the increasing level of both the factors hardness decreases significantly. The 3D plot of Figure 2 (b) shows the effect of polydextrose and guar-gum on the hardness of the muffins. It illustrates hardness increases at the starting and end of the graph when both the factors were lower and higher levels. The hardness of the sugar-free muffins decreases when both the factors were at intermediate levels.

Fracturability is the force at the first peak. Not all products fracture, but when they do fracture the fracturability point occurs where the plot has its first significant peak (where the force falls off) during the probe's first compression of the product. Fracturability of the control muffin was less than the sugar-free muffins (Table 2). Fracturability is maximum at the minimum and maximum

levels of factor A and factor B but minimum at intermediate level (Table 2). The coefficient of estimates interprets a negative effect of both factors on the fracturability of muffins. This means increasing or decreasing the level of both the factors has an antagonist effect on fracturability. Figure 2 (c) displays the effect of polydextrose and guar-gum on the fracturability of muffins. The response graph shows a rise at the graph's starting when both factors were at lower levels. The graph further falls significantly at the intermediate level and again rises at the end when both the factors were at maximum level. The Texture profile analysis sequence involves contacting a product, compressing that product, withdrawing to the original contact point, then repeating the entire cycle a second time. Adhesion is measured as the negative work between the two cycles. According to the result on adhesiveness tests shown in table 2, increasing the level of both factors increases adhesiveness. The adhesiveness of the control muffin was less than the sugar-free muffins (Table 2). The coefficient of estimates showed the antagonist effect of both the factors on adhesiveness, whereas the interactive impact of both the factors was positive. Figure 2 (d) shows the impact of polydextrose and guar-gum on adhesiveness on muffins. It explains that at the initial levels of each factor adhesiveness was higher which gradually lowers at the intermediate level and again reclaim the maximum value at the end of the graph when both the factors were at the highest level.

Springiness is associated with fresh, aerated, and elastic products [21]. It gives information about the after-stress recovery capacity after the delay between compressions [22]. Well-aerated and elastic muffins, with high springiness values, are perceived as fresh and of high quality [21]. As the size of the gas cell increases, the product has a softer crumb structure. Muffins with high springiness are preferred as it shows that the texture is smooth and acceptable. The experimental muffins had a lower value than control muffins (Table 2). The lower springiness value of the experimental muffins may be due to inhomogeneity of the composite flour, fewer air cells incorporation during creaming, and replacement of sugar in the formulation. Similar results of lower springiness were observed in legume-based muffins [20-23]. The coefficient of estimates shows the negative interactive effect of both factors on springiness. The linear effect of polydextrose was positive, and guar-gum was negative. This means as the level of polydextrose increases, springiness also increases, while as guar-gum level increases, springiness decreases significantly. The response graph of springiness shows the linear effect of polydextrose and guar-gum in Figure 2 (e). At the starting of the graph, springiness increases linearly and declines at the end. No significant difference in cohesiveness and resilience was found among experimental muffins. This means polydextrose and guar-gum have no significant effect on these textural attributes of muffins.

Optimization of sugar-free muffins

Optimization of sugar-free muffins resulted in a desirability value of 0.791. This desirability value corresponds to the conditions: polydextrose 12.627% and Guar-gum 0.707% with predicted value by the design for height 36.701mm, hardness 2050.860, fracturability 1463.704, adhesiveness -307.080, springiness 0.779, cohesiveness 0.250, and resilience 0.058 (Table 5). Desirability value > 0.7 is considered to be excellent [24]. The experiment is carried out with the optimal conditions of muffins. The physical and textural attributes were evaluated and compared with the predicted values to validate the model obtained. There was no significant difference between the values predicted by the model and the real values obtained in the validation (Table 5). Therefore, the model used in each response resonates with the optimal level of polydextrose and guar-gum to formulate composite flour-based sugar-free muffins.

Table 5. Comparison of observed and predicted values of optimized sugar-free biscuits

Response	Predicted value	Actual value ± SD
Height	36.7008^a	36.60 ± 0.19^a
Hardness	2050.86^a	2050.16 ± 1.04^a
Fracturability	1463.7^a	1462.33 ± 1.53^a
Adhesiveness	-307.08^a	-305.11 ± 1.04^a
Springiness	0.779^a	0.772 ± 0.004^a
Cohesiveness	0.250^a	0.223 ± 0.026^a
Resilience	0.057^a	0.048 ± 0.007^a

Means ± standard deviation; means followed by the same superscript in each row are not significantly different (p > 0.05)

Conclusion

The texture of muffins is the primary criterion determining their quality. In the bakery industry products were earlier rejected for not having desirable shape and texture. Sucrose is an essential compound of the bakery industry. It imparts sweetness to the product and has many essential properties necessary for bakery products. Reducing or replacing sucrose has a dramatic effect on the texture of the products. The current health aspects and consumer awareness about the adverse effect of sucrose and fat have forced the industry to prepare functional bakery products. The sugar-free muffins prepared in this research have accepted quality attributes. The combination of polydextrose and guar-gum used in the study significantly affects each attribute except cohesiveness and gumminess. The result shows a lower height of sugar-free muffins than control muffins due to less air incorporation. This could be improved by taking care of the creaming process during batter preparation. The use of composite flour enhances the protein and fiber content of the muffins as legumes and millets are rich in them. Today consumer demands product with less fat, no sugar, high fiber and somehow accepts the fact on achieving these parameters there will be a slight deviation from earlier textural attributes of the product. These functional muffins can be an alternative to unhealthy bakery products and may help in health management.

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