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ORIGINAL PAPER

Investigating the effect of whole oat flour, maltodextrin and isomalt on textural and sensory characteristics of biscuits using response surface methodology

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Abstract The objective of this study was to develop biscuit that contains whole oat flour (5–15%) maltodextrin (1–3%) and isomalt (10–20%) using Response Surface Methodology (RSM) as the optimization technique. For this purpose, the biscuit samples were analyzed. The analysis was based on hardness of the biscuit, fracturability, penetration force value and overall acceptability scores. The results showed that increasing the amount of whole oat flour and isomalt in biscuit decreased the hardness and penetration force value, whereas, fracturability increased. Overall acceptability scores increased up to the level at which whole oat flour was 10% after which it decreased. An increase in the amount of maltodextrin was followed by an increase penetration force value, while hardness decreased. Optimization suggested biscuit containing 11.39% whole oat flour, 16.73% isomalt and 2.2% maltodextrin as the best proportion of these components. Optimized biscuit had improved protein (15.43%), ash (2.76%), carbohydrate (58.08%) and specially fibre (4.07%) in addition to acceptable textural characteristics.

Keywords Biscuit · Whole oat flour · Maltodextrin · Isomalt · Optimization · Overall acceptability

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Introduction

Biscuits are a popular foodstuff, consumed by a wide range of populations, due to their high nutritive value, ready-to-eat nature, and easy availability in different shapes and sizes at an affordable cost [1, 2]. Biscuits and other sweet baked items are rich in sugar (mainly sucrose) and fat are usually avoided by calorie-conscious consumers [3]. Because of competition in the market and increased demand for healthy, natural and functional products, attempts are being made to improve biscuits' nutritive value and functionality by modifying their nutritive composition [1]. Functional properties of biscuits can be increased by improving or modifying the major ingredients, namely, flour, sugar, and fat along with supplementation of health promoting ingredients like whey protein concentrate, skimmed milk powder, dietary fiber, etc. Such modification can be achieved by replacing whole or part of the flour with whole multigrain flour, use of artificial sweeteners and fat replacers [2].

Incorporation of whole grains increases the nutritional profile of the products as they are a rich source of dietary fiber, trace minerals, antioxidants, and phenolic compounds, which play a significant role in protecting against cancer, diabetes, obesity, and cardiovascular diseases [4]. Several workers had studied the effect of partial replacement of wheat flour for biscuit production with defatted soy flour [5], oat, wheat, rice and barley bran [6], coconut residue [7], untreated, roasted, and germinated black gram [8].

Sweetener plays an important role in providing flavor, appearance, color, taste, and dimension to the finished product. It is well known that excessive consumption of sugar amounts increases the energy intake which, in turn, can lead to diseases like diabetes and obesity [9]. The use of artificial sweeteners, polyols and other bulk sweeteners as a sucrose substitutes for the development of low-calorie products has been the focus of R&D in the recent past. Several workers had studied the effect of replacement of sugar on cookies with natural and artificial sweeteners like sorbitol, mannitol, lactitol, maltitol, fructose and xylitol [3], stevia [5], sucralose and maltodextrin [10], and inulin and erythritol [11].

The optimal proportions among different ingredients can beachieved by changing one ingredient at a time; however this approach is very laborious, often fails to guarantee the determination of optimum conditions, and does not depict the combined effect of all the factors involved. One option to overcome this problem is the use of response surface methodology (RSM). RSM is the most popular optimization method used in recent years for the development of new products and processes, the enhancement of existing products and processes, the optimization of quality and performance of a product, the optimization of an existing manufacturing procedure, and the minimization of production cost. It can be used to define the relationship between the response and the independent variables, and it is a very useful tool in food industries [12].

The aim of the present investigation was to formulate a biscuit using whole oat flour by replacing 5–15% of the wheat flour. In order to reduce the calorie content of the above formulated biscuit, two types of sweeteners (maltodextrin and isomalt) were tried to replace all of the sucrose. RSM was used to minimize the number of baking trials while gathering all information relating to ingredient interactions and quality characteristics.

Materials and methods

Materials

The various ingredients used for biscuit formulation were obtained from different sources. These include (1) Wheat flour suitable for biscuit preparation (Var. Alvand, Atlas group, Iran) (composition data provided by the supplier: 11.5% protein, 2.02% fat, 0.63% minerals, and 14.1% moisture), (2) Whole oat flour (Var. Shosh, Pakanbazr, Iran)(composition data provided by the supplier: 18.27% protein, 7.98% fat, 2.06% minerals, and 9.3% moisture), (3) Bakery shortening (Ladan, Iran), (4) Isomalt (Cargill, Germanyl), (5) Maltodextrin (Foodchem International Corporation, China), (6) Soya lecithin (Behpak, Iran), (7) Ammonium bicarbonate and Sodium bicarbonate (SRL, India), (8) Spray dried skimmed milk powder (Zarinshad, Iran), (9) Spray dried egg powder (Golestan powder, Iran), (11) Vanilla flavor (kurtgeorgy, Germany).

Experimental design

RSM which involves design of experiments, selection of levels of variables in experimental runs, fitting mathematical models and finally selecting variable levels by optimizing the response was used in the study. A central composite rotatable design (CCRD) was used to design the experiments comprising of three independent variables (Table 1). Twenty experiments were performed taking into account three factors, viz., whole oat flour, maltodextrin and isomalt. There were six experiments at centre point to determine the experimental error and reproducibility of the data [13]. This was based on the textural and sensory characteristics of the biscuit viz., hardness of biscuit, biscuit fracturability, biscuit penetration force value and overall acceptability scores.

Biscuit preparation

Control biscuits were prepared using the creaming method adopted by Raju et al. [14] with slight modification. Bakery shortening (16%) was creamed using Hobart Mixer at high speed (240 rpm) until its volume doubled. Ground sugar (18%) was then mixed to the foamed cream along with the lecithin (2%), skimmed milk powder (6%), spray dried egg powder (4.5%), sodium bicarbonate (0.5%), ammonium bicarbonate (0.5%), vanilla aroma (0.5%) and water (12%) for 10 min at low speed (55 rpm). Then, the flour (40%) was added and mixed in for 2 min at 55 rpm. The dough was then fed in to the cookie drop machine (Padovani SRL, Italy) and biscuits with a thickness of 5 mm were collected on baking tray and baked (Polin Industry, Italy) at 210 °C for 20 min followed by cooling at room temperature for 20 min. Biscuits were packed in LDPE pouches (0.2 mm thick) and stored at 25 °C for further analysis. For experimental biscuit, whole oat flour replaced the wheat flour, and maltodextrin and isomalt also replaced the sucrose and were mixed in the required proportion as per the RSM (Table 1).

Texture analysis

The hardness of the biscuits was studied using a three-point bend test performed on a TAXT2 texture analyzer (Stable Micro Systems, UK), equipped with the three-point bending rig (HDP/3 PB). Texture analyzer settings were pre-test speed at 0.5 mm/s, test speed at 3.0 mm/s, post-test speed at 10.0 mm/s, and distance at 5 mm. The load cell used was 5 kg. The maximum force at break (g) and the mean distance at break (mm) were recorded. Penetration tests were conducted with the upper Volodkevich Bite Jaw (VB), penetrating the sample (whole biscuit) to 5 mm; a trigger force

Table 1 Experimental design for manufacturing of biscuit and response values for textural and sensory quality of biscuits

Run	Factor 1 Whole oat flour (%) (kg)	Factor 2 Malto-dextrin (%)	Factor 3 Isomalt (%)	Response 1 Biscuit hardness (g)	Response 2 Biscuit fracturability (mm)	Response 3 Penetration force value (g)	Response 4 Overall acceptability score
1	7.02	1.40	12.02	1341.30	0.87	556.60	4.19
2	7.02	2.40	12.02	1480.60	1.01	468.61	4.21
3	12.02	1.40	12.02	1518.60	0.41	1074.32	3.97
4	12.02	2.40	12.02	1269.80	0.81	635.50	3.89
5	7.02	1.40	17.02	709.00	0.57	527.02	3.97
6	7.02	2.40	17.02	994.10	0.72	681.19	4.02
7	12.02	1.40	17.02	989.00	0.61	431.30	4.11
8	12.02	2.40	17.02	1661.50	1.55	869.13	4.09
9	10.00	1	15.00	973.00	0.46	801.41	4.11
10	10.00	3	15.00	1238.30	0.70	821.00	4.38
11	5.00	2	15.00	1421.00	0.66	728.80	4.12
12	15.00	2	15.00	1206.50	0.74	891.10	4.13
13	10.00	2	10.00	1348.80	0.73	795.10	4.23
14	10.00	2	20.00	1071.55	0.67	633.8	3.83
15	10.00	2	15.00	1420.63	0.90	596.00	4.50
16	10.00	2	15.00	1478.00	0.91	658.20	4.51
17	10.00	2	15.00	1383.10	0.92	654.10	4.50
18	10.00	2	15.00	1469.26	0.92	652.00	4.49
19	10.00	2	15.00	1470.11	0.91	653.02	4.48
20	10.00	2	15.00	1475.01	0.93	654.00	4.49

of 5 kg was set. The maximum force at penetration (g) was measured.

Sensory evaluation

The freshly baked biscuits were presented to twenty members to evaluate overall quality. The overall quality score was taken as the combined score of five quality attributes (sweetness, flavor, after taste, color, and texture). Ask each person to taste each sample in turn and tick a box, from (1—dislike extremely, 2—dislike moderately, 3—neither like nor dislike, 4—like moderately and 5—like extremely) to indicate their preference. Analyze the results to determine which sample received the greatest/lowest scores and present details on sensory evaluation and panel formed.

Chemical analysis

Moisture, ash, crude fat and protein were determined using AOAC (1997) methods [15]. For the estimation of total dietary fibre, the defatted residue of biscuits obtained during the analysis for crude fat was finally powdered using a blender to pass through a sieve of 100 mesh. This fine powder of each sample was utilized for the estimation of total dietary fibre content following the method of Asp et al. [16]. All Experiments were conducted in triplicate.

Data analysis

Analysis of data generated during the present investigation was carried out using RSM by employing CCRD. Optimization was done for textural and sensory properties of biscuit. Fitting of mathematical models and finally selecting variable levels by optimizing the response was employed as per the method given by Khuri and Cornell [17]. The statistical significance of the model term was examined with the help of regression analysis and analysis of variance (ANOVA).

Results and discussion

It was observed that the lack-of-fit test (F values) for all the models were insignificant (Fcal < Ftab), implying that the models were accurate enough to predict the responses.

Biscuit hardness

The quadratic equation obtained of the RSM of the data showing the effect of whole oat flour (W), maltodextrin (M) and isomalt (I) on biscuit hardness resulted in the following equation: 'by the response …….. showing the' …… with 'of'

$$Y_1 = 61.68 + 7.30M - 7.134W - 7.74M^2 - 5.26W^2 + 5.17MW + 5.54IW \quad (1)$$

Model F value of 26.93 (Table 2) implied that model was significant. Biscuit hardness was in the range of 709–1661 g. The coefficient of determination (R^2) was 0.96. The coefficeint of estimation of biscuit hardness showed that as the level of whole oat flour and isomalt was increasing, hardness of the biscuits was decreasing (Fig. 1a). Pomeranz et al. [18] also reported that addition of oat flour lowered the hardness of biscuit. This is probably due to the higher levels of fat from oats compared with wheat. Fats have softening properties and act as a lubricant in biscuit [19]. Furthermore, oat β-glucan played an important role in increasing water absorption and biscuit moisture. In general, dietary fibre increases water absorption and mixing tolerance. Rosell et al. [20] expected such a result due to the hydroxyl groups of the fibre structure which allows more water interaction through hydrogen bonding. Oat starch has higher water absorption than other cereals. It could also be observed from Fig. 1b that with the increase in the level of maltodextrin till the range of 1.4–1.9% there was increase in the biscut hardness after which it decreases. Maltodextrin forms gels in the presence of water, it would immobilize a part of the water, markedly reducing the water available for gluten to hydrate and develop hardnesss [10].

Biscuit fracturability

The quadratic equation obtained of the RSM of the data showing the effect of whole oat flour (W), maltodextrin (M) and isomalt (I) resulted in the following equation:

$$Y_2 = 23.63 + 3.41M + 2.38I - 2.29W^2 + 3.47IW \tag{2}$$

Model F value of 20.92 (Table 2) implied that model was significant. Biscuit fracturability was in the range of 0.41–1.55 mm. The coefficient of determination (R^2) was 0.89. The coefficeint of estimation of biscuit fracturability showed that as the level of isomalt was increasing, fracturability of the biscuits was increasing. The fracturability of the biscuit decreased until the level of whole oat flour ranges from 10%, after which it increases (Fig. 1c). It was an expected result because the addition of isomalt increased the moisture content of the reduced sucrose products. This was because isomalt generally absorbed more water [21]. Also, oat β-glucan and the hydroxyl groups of the fibre structure of hole oat flour which allows more water interaction through hydrogen bonding played important role in increasing water absorption and biscuit moisture [22]. Results of the effect of water content on textural properties of sample showed that the biscuit samples with higher initial water content are statistically significantly different in biscuit textural properties and lowers fracturability [23, 24].

Biscuit penetration force value

The quadratic equation obtained of the RSM of the data showing the effect of whole oat flour (W), maltodextrin (M) and isomalt (I) on biscuit penetration force value resulted in the following equation:

$$Y_3 = 31.84 + 3.90M + 2.83I - 5.04M^2 - 2.73W^2 + 2.52MI + 3.66MW \tag{3}$$

Model F value of 28.74 (Table 2) implied that model was significant. Penetration force value was in the range of 431–1074 g. The coefficient of determination (R^2) was 0.86. The coefficeint of estimation of penetration force value showed that as the level of whole oat flour and isomalt was increasing, penetration force value of the biscuits was decreasing. These results are probably due to the effects of gluten dilution, water retention and higher levels of fat. However, as the level of maltodextrin was increasing, the penetration force value of the biscuit was increasing (Fig. 1e).

Table 2 ANOVA and model statistics for biscuit

Term	Responses			
	Biscuit hardness (g)	Biscuit fracturability (mm)	Penetration force value (g)	Overall acceptability score
Model	Quadratic	Quadratic	Quadratic	Quadratic
F value	26.93	20.92	28.74	51.23
P > F	<0.0001	<0.0001	<0.0001	<0.0001
Mean	1295.95	0.80	689.11	4.21
SD	238.74	0.24	152.88	0.22
R^2	0.96	0.89	0.86	0.94
Adjusted R^2	0.92	0.79	0.82	0.90
Predicted R^2	0.69	0.71	0.75	0.61
Lack of fit	0.51	0.23	0.17	0.41

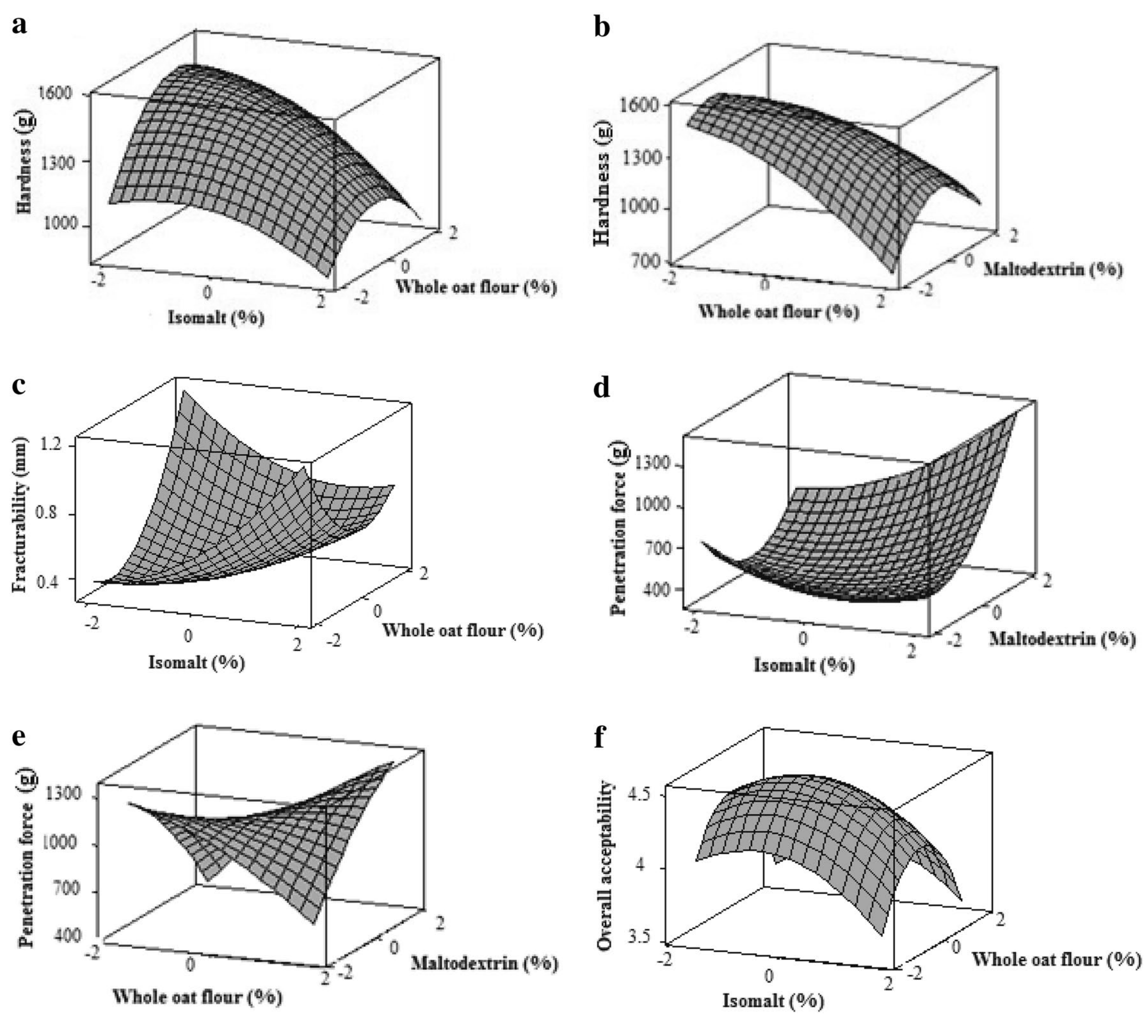

Fig. 1 Response surface plots showing the effect of whole oat flour, isomalt and maltodextrin on the quality of biscuits

Overall acceptability score

The second degree polynomial equation obtained of the RSM of the data showing the effect of whole oat flour (W), maltodextrin (M) and isomalt (I) on overall acceptability resulted in the following equation:

$$Y_4 = 159.26 - 4.70W - 8.07M^2 - 5.16I^2 - 9.43W^2 + 2.40IW \quad (4)$$

The quadratic model was significant ($P < 0.05$) and overall acceptability varied from 3.83 to 4.51. The 007Acoefficient of determination (R^2) was 0.94. The coefficeint of estimation of overall acceptability score showed that as the level of isomalt was increased, overall acceptability score decreased. It could also be observed from Fig. 1g that with the increase in the level of whole oat flour till the range of 10% there was significant increase in the overall acceptability score after which it decreases. Biscuits with more than 10% whole oat flour were not preferred because of their bitter taste. Wholegrain oats have the greatest percentage of fat among the major cereals with a good balance of the essential fatty acids, which are primarily unsaturated. The high content of oleic and linoleic acid, results in a favorable polyunsaturated to saturated fatty acid ratio of 2:2 [25, 26] Lipase, the major enzyme in oats, causes the rapid release of free fatty acids in damaged or milled oats which can result in off flavours. Oat flour has been shown to be a complex collection of volatile flavour components. Nitrogen heterocycles, formed from Maillard reactions and lipid oxidation products are the key compositional types of flavour volatiles. Heat induced reactions of precursors native to the oat groat are primarily responsible for the development of oat flavour during its normal processing into commercial food products. Oat product flavor stability is dependent upon lipid composition and resistance to oxidation. The flavor instability of oats correlates directly with the appearance of low molecular weight

Table 3 Constraints and criteria for optimization for biscuit

Constraints	Goal	Lower limit	Upper limit
Whole oat flour	Maximize	5	15
Maltodextrin	Is in range	1	3
Isomalt	Is in range	10	20
Biscuit hardness	Is in range	709.00	1661.50
Biscuit fracturability	Is in range	0.41	1.55
Biscuit penetration force value	Is in range	431.30	1072.32
Overall acceptability score	Maximize	3.85	4.51

Table 4 Chemical composition of biscuit

Parameters	Control biscuit composition (%)	Optimized biscuit composition (%)
Moisture	2.39	3.26
Fat	16.52	18.11
Protein	13.46	15.43
Ash	1.53	2.76
Carbohydrate	55.31	58.08
Fibre	1.21	4.07

lipid oxidation products and specifically with pentanal, hexanal, 2, 4 decadien-1-als, and 3,5-octadien-2-ones [27–29].

Optimization

The numerical optimization technique of the Design-Expert software was used for simultaneous optimization of the multiple responses. The constraints have been listed in Table 3. The desired goals for each factor and response were chosen. Responses obtained after each trial were analyzed to visualize the interactive effect of various parameters on textural properties and sensory attributes of biscuits. Optimized solutions obtained from the Design-Expert software for the biscuit hardness, biscuit fracturability, biscuit penetration force value and overall acceptability score were determined as whole wheat flour (11.39%), maltodextrin (2.2%) and isomalt (16.73%).

Chemical composition

The proximate composition of the optimized biscuit compared with average composition of control biscuits was determined and the results are presented in Table 4. It can be seen that the optimized biscuits had high level of dietary fibres (4.07%), fat content (18.11%), protein content (15.43%), carbohydrate (58.08%) and ash content (2.76%) as compared to the average composition of the control samples.

Conclusion

Biscuit is the most popular bakery product worldwide. They are high in carbohydrates and fat but low in fiber, vitamin, and mineral which make it unhealthy for daily use. Because of its acceptability in all age group, better taste and its position as snacks it is consider as a good product for nutritional improvement. This research intended to explore the possibility of fortifying the oat flour and natural sweeteners (isomalt and maltodextrin) to formulate the functional biscuit which has the ability to improve the quality of food products due to various functional properties. In this manner, RSM was applied for statistical designing of operating conditions in order to optimize the level of isomalt, maltodextrin and oat flour for production of sugar free biscuits. Optimization for the processing of sugar-free biscuits was predicted based on score of textural characteristics, and sensory quality. The formulation with 11.39% whole oat flour, 2.2% maltodextrin and isomalt of 16.73% was considered to be the most appropriate for producing free sugar biscuit. The developed biscuit had 4.07% total dietary fibre and can be considered as functional health benefits of sugar- free biscuits.

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