Production of low-calorie cake by partial replacement of flaxseed mucilage and flaxseed flour and investigation of its physicochemical, textural and sensory characteristics

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Abstract

Cake is one of the most important baking products, which is widely produced due to its ease of storage and consumption. However, considering the high caloric value of grain products, the aim of this research was to produce low-calorie cake, so the mixture design, in D-optimal format was used to investigate the effect of replacing flaxseed mucilage with animal butter and flaxseed flour with cake flour on the physicochemical, textural and sensory properties of the cake were evaluated. The results of the rheological properties of two types of flax mucilage prepared from 1 to 15 and 1 to 20 ratios of flax seeds to water and butter showed Newtonian behavior in flax mucilage and pseudoplastic behavior in butter. According to the results of the frequency scanning test, with an increase in frequency at constant strain of 1%, the loss modulus (G') of all samples increased. Storage modulus (G″) increased in the flax mucilage sample (1:15) and was almost constant in flax mucilage (1:20) and butter. The results showed that the moisture content and water activity of the samples increased with the increase in the substitution of mucilage and flax seed flour. Also, with the increase of flax mucilage replacement, the antioxidant capacity, tissue cohesion and resilience increased and the specific volume, elasticity and hardness of the shell decreased (P < 0.05). Flax seed mucilage had a significant effect on reducing the height and increasing the stiffness of the samples. The overall acceptance score decreased with the replacement of mucilage and flaxseed flour, but all samples had an acceptable overall acceptance score (p < 0.05). According to the numerical optimization results, the cake formulation with 60% flaxseed mucilage + 28% flaxseed flour was identified as the optimal sample with textural, sensory and high nutritional value.

1. Introduction

Cake is an energizing food with high caloric value. In addition, this food has the advantages of having an attractive appearance, a pleasant taste and aroma, and a very pleasant texture. As a caloric source, the cake is in the middle of bread and biscuits. All kinds of vegetable and animal oils can be used in the cake formula. Fats are a source of energy, and excessive use of them in the cake structure increases health risks. Also, fats are the main factor in improving the taste of cakes (Ramachandran et al., 2007; Dhaka et al., 2011). Getting a lot of fat causes an increase in all types of cancer, and getting saturated fat causes an increase in blood cholesterol and coronary artery disease. Also, consumption of food rich in fat has been identified as a risk factor for receiving more energy and spreading obesity. In order to achieve better health, it is recommended to increase the consumption of fruits, vegetables, legumes and modify the type and amount of fat consumed (Kim and Giovannucci, 2021). Therefore, with the increase in people's demand to reduce fat in the diet, food product manufacturers started producing new substitutes to replace most of the fats in foods. Some alternative fats in foods can be replaced by formulating. These substitute fats can be based on fat, protein, carbohydrates, which can be used alone. Today, fat substitutes are used in many types of food products such as salad dressings, frozen desserts, etc. as thickeners and stabilizers (Patel et al., 2020; Rios et al., 2014). Absorbable carbohydrates such as modified starch and dextrin provide 4 kcal/g of energy, but indigestible complex carbohydrates provide less calories. Many carbohydrates act as thickening agents or gelling agents. Mucilages, gums, starch, pectin, cellulose and other carbohydrate substances provide many functions of fat in food by bonding with water and create a favorable texture and mouthfeel in food (Pirsa and Hafezi, 2022; Mohtarami et al., 2022; Pirsa et al., 2018a; Pirsa et al., 2018b). Carbohydrate-based fat substitutes have a creamy state of fat that stabilizes food by absorbing water and gives it volume and consistency. One of the most important substitutes for fat in grain products is mucilage, gum and flax seed flour. This oilseed is a good source of lignan, dietary fiber, protein, minerals and vitamins (Puligundla and Lim, 2022). Flax seeds contain 24 to 44% oil, of which 50 to 55% contains alpha-linolenic acid. Alpha-linolenic
acid is included in the group of $3\omega$ fatty acids and is actually an essential fatty acid for humans. Because there is no synthesizing enzyme in the human body. Flaxseed is the best source of $\omega 3$, especially for people who do not consume fish (El-Zenary et al., 2022; Edel et al., 2016). Linoleic acid also makes up about 16% of the total fatty acids of flax. This causes the ratio of $\omega 3$ to $\omega 6$ in flaxseed oil to be 1 to 0.3. Meanwhile, in most edible oils, the amount of $\omega 6$ is more than $\omega 3$. This type of fatty acid distribution in flaxseed oil makes it more valuable from a nutritional point of view (Sharil et al., 2022).

Considering the things mentioned above and the importance of replacing fat in grain products such as cakes with mucilages and gums, in this research, low-calorie cakes with the partial replacement of flax mucilage and flaxseed flour was provided and the physicochemical, textural and sensory characteristics were investigated. According to the results, flaxseed mucilage could be used as a fat substitute in cakes, adding flaxseed mucilage can lead to improvement of the physicochemical and rheological characteristics of the cake, and replacing flaxseed powder with cake flour improves the sensorial and textural characteristics of the cake. Flaxseed mucilage and flax powder in sponge cake formulation increased the nutritional value of the product.

2. Materials And Methods

2.1. Chemicals and devices

Flax seeds were obtained from a vegetable store in Urmia (Iran). Flax seeds were used to prepare flax powder and mucilage. 2,2-diphenyl-1-picrylhydrazyl (DPPH), methanol, rapeseed, hydrochloric acid, petroleum ether, sulfuric acid, copper sulfate, selenium dioxide, boric acid, sodium sulfate, chloroform and other compounds needed to perform cake quality tests were prepared from Merck (Germany).

The devices used included the following: an oven made by Teyf Azma Teb Company (Iran), a digital scale with an accuracy of 0.0001 made by Taraz Aria Weighing Company (Iran), an electric furnace (Oxaiton Company of Iran), a centrifuge made by Behdad Company (Iran), Spectrophotometer made by Nano Mabna (Iran), desiccator (made in China), HunterLab KONICA CR-400 (Japan), water activity measuring device Novasina-ms1-aw (England) and histometer TA-XT Plus, Stable Micro System Ltd, Surrey (England).

2.2. Preparation of flax seed mucilage and flax seed powder

In the preliminary investigation for the preparation of flax seed mucilage as an oil substitute, different ratios of flax seed mucilage to water were prepared and a ratio that has the same consistency as oil was used as an oil substitute in the cake formulation. In order to prepare mucilage, different proportions of flaxseed and water (1:40, 1:30, 1:25, 1:20, and 1:15) were mixed together and stirred at 50°C for 2 hours. It was heated. The resulting mixture was passed through a mesh cloth in two steps to separate the insoluble components of the seed from the mucilage part (Fig. 1-A).

To prepare flaxseed powder, after cleaning, the flax seeds were roasted on a gentle heat and after cooling, they were powdered by a mill. The resulting powder was sieved to separate the coarse shell components (Fig. 1-A).

2.3. Preparation of sponge cake

Control cake formulation was provided by mixing wheat flour (confectionery flour) (200 g), eggs (120 g), animal butter (98 g), sugar (140 g), milk (165 g), baking powder (4 g), vanilla (2.5 g). Then, 50 g of the mix was poured into muffin paper molds and baked in the oven at 190°C for 19 minutes. After cooling for one hour, they were
packed in polythene bags and kept at room temperature until the test. In the cake samples that mucilage and flaxseed flour used in the formulation, the flaxseed mucilage (mucilage to water ratio, 1:20) at levels of 0 to 60% and flaxseed powder at levels of 0 to 30% replaced oil and cake flour (According to Table 1), respectively (Fig. 1-B).

Figure 1

2.4. Determination of rheological characteristics

Rheological tests were carried out by MCR301 rheometer made by Anton Paar, Austria, using two parallel plates at a temperature of 20°C. These tests included static rheological test (flow behavior test) and oscillation test (frequency scan).

2.4.1. Flow behavior test

In this test, the distance between the pages was 1 mm and the range of cutting rate was 0.05–1250 s. This test was done to draw flow charts and identify the changes in apparent viscosity. Also, in order to detect the time-dependent behavior, the cutting speed until reaching the value of 250 s⁻¹, then it remained constant for 100 seconds and decreased again to the initial value. In order to determine the appropriate model to describe the flow behavior, the power law model and Herschel's model were compared. The following equations show the relationship between power law and Herschel's exact model:

\[ \tau = k \gamma^n \] (1)

\[ \sigma = \sigma_H + K_H \gamma^n \] (2)

In this regard, \( \tau \) is the shear stress (Pa), \( \gamma \) is the yield strength (S⁻¹), \( K \) is the consistency coefficient (Pa×sⁿ), \( \sigma_H \) is the yield stress and \( n \) is the flow behavior index (without dimension). The consistency coefficient, the viscosity of the fluid and the flow behavior index show how close the fluid behavior is to the Newtonian fluid.

2.4.2. Swing tests

The frequency scanning test was performed in the frequency range of 0.1–100 Hz and by applying a constant strain of 1%. The curves obtained from the frequency scanning test were drawn according to the frequency (in Hz unit). The three important parameters that result from this test are complex modulus, storage modulus or shear modulus (\( G' \)) and viscous modulus or effacement modulus (\( G'' \)). The storage modulus shows the amount of elastic behavior and the amount of energy recovered in a unit volume and in each full cycle of the strain wave. The drop modulus or viscous modulus (\( G'' \)) indicates the amount of flow behavior and the amount of wasted energy per unit volume and in each complete cycle of the strain wave. In the frequency scan test, if \( (G'') < (G') \), the sample has solid viscoelastic behavior and if \( (G'') > (G') \), the sample shows the liquid viscoelastic behavior (Dadkhah et al., 2017).

2.5. Chemical tests

2.5.1. Moisture measurement

In order to measure the moisture content of the cake samples, first the sample container was heated for 30 minutes in an oven at 100°C and then cooled in a desiccator using tongs. The sample container was placed in the scale with the help of tongs, weighed, and 2 g of the crushed sample was weighed in it. The container containing
the sample was heated in an oven at 110°C for 5 hours, and after cooling in a desiccator, it was placed on a scale with tongs and weighed, and the moisture content was calculated by the following equation (Emerald et al., 2021).

\[
\text{Moisture (\%)} = \frac{M_1 - M_2}{\text{Sample weight}} \times 100
\]

M1 is plate weight before drying and M2 is plate weight after drying

### 2.5.2. Ash measurement

3 g of the crushed cake sample was weighed in a cup. The sample was burned slowly on the flame under the hood until the smoke disappeared. The container containing the sample was heated for 6 hours in an electric furnace at 550 to 600°C to form a light ash. The ash container was placed in a desiccator to cool and then weighed (Richardson et al., 2021).

\[
\text{Ash (\%)} = \frac{M_1 - M_2}{\text{Sample weight}} \times 100
\]

M1 is ash containing crucible weight and M2 is crucible weight

### 2.5.3. Antioxidant activity

DPPH free radical scavenging method was used to determine the antioxidant activity of cake samples. At first, 1 g of cake sample was mixed with 10 ml of methanol and kept at room temperature and away from light for 24 hours. Then the supernatant was separated from the settled part and centrifuged for 10 minutes at high speed. 1 ml of the clear upper part (sample extract) was mixed with 4 ml of 90% methanol and 1 ml of DPPH methanol solution (0.004%) and placed in a dark place for half an hour. To determine the absorbance of the solution, the spectrophotometer was first calibrated at a wavelength of 517 nm with methanol, and then the absorbance of the samples was measured at the same wavelength (Szydłowska-Czerniak et al., 2021).

\[
\text{Antioxidant activity (\%)} = \frac{A_c - A_s}{A_c} \times 100
\]

Where, \(A_s\) is the absorption rate of the sample and \(A_c\) is the absorption rate of the control

### 2.5.4. Measurement of peroxide number

To measure the peroxide of the cake samples, first, 2 g of the fat of the cake samples was extracted and poured into a 250 ml flask. Then 30 ml of acetic acid and chloroform solution (2:3 volume ratio of acetic acid to chloroform) was added. Also, 0.5 ml of potassium iodide saturated solution was included in the solution and kept in a dark place for 1 minute. Then, 30 ml of distilled water was added to the solution. At this stage, the obtained solution has a yellow color, and the titration should be continued until it becomes colorless. For this purpose, a few drops of starch glue reagent were added to the solution. The prepared sample, which had a dark color, was titrated
with 0.01 sodium thiosulfate until it became colorless. The amount of peroxide was calculated according to the following equation (Sahraee et al., 2020).

\[ P(\text{meqO}_2/\text{kg}) = \frac{N \times V \times 100}{W} \]

Where, \( N \) is sodium thiosulfate normality, \( V \) is volume of sodium thiosulfate for titration, and \( W \) is weight of fat

### 2.5.5. Protein measurement

Kjeldahl’s method was used to measure protein. First, 1 g of cake sample was poured into Kjeldahl digestion balloons and after adding 20 ml of concentrated sulfuric acid, one catalyst tablet (containing 96% sodium sulfate, 3.5% copper sulfate and 0.5% selenium dioxide) was added. A balloon without sample also containing acid and catalyst was used as a control sample. The digestion process continued for 60 minutes until the digestion solution became clear, which is a sign of the complete breakdown of all organic compounds. After cooling down and removing the acid vapors, the distillation step was performed. For this purpose, 50 ml of 32% soda and 250 ml of water were added to the digested solution. An Erlenmeyer flask containing 50 ml of boric acid and a few drops of methyl red reagent was placed at the end of the distillation apparatus in such a way that the end of the distillation apparatus was completely immersed in the acid, and the distillation was carried out until the volume reached 250 ml. At the end, in the titration stage, the resulting solution was obtained by using 0.1 normal sulfuric acid until the pink titer color was reached and the percentage of total nitrogen was obtained from the following equation (AOAC, 2005).

\[ \text{Nitrogen} (\%) = \frac{N \times 1.4 \times (V_2 - V_1)}{m} \]

Where, \( N \) is the normality of sulfuric acid, \( V_2 \) is ml of acid used in the sample, \( V_1 \) ml of acid used in the control acid, and \( m \) is the weight of the sample in g. In order to obtain the protein percentage of the samples, the amount of nitrogen was multiplied by the protein factor of 6.25 and the amount of protein was expressed in terms of dry matter.

### 2.5.6. Fat measurement

The fat content of the samples was measured by Soxhlet method. First, the balloons for Soxhlet were washed and dried in the oven. Then it was cooled in a desiccator and the weight of the balloons was recorded. 1 g of each cake sample was weighed and enclosed by filter paper and placed inside the cartridge and then placed in the extracting part of the Soxhlet machine. After connecting the balloon to the device, two-thirds of its volume was filled with petroleum ether and the temperature of the device was set to 60°C. Fat extraction was done for 6 hours. Then the balloons were placed in an oven at 100°C for 1 hour. The difference between the initial weight and the final weight of the balloon shows the amount of fat extracted from the samples. Fat percentage was calculated from the following equation.

\[ \text{Fat} (\%) = \frac{(W_2 - W_1)}{m} \times 100 \]
In this regard, $W_1$ and $W_2$ are the primary and secondary weight of the balloon and $m$ is the weight of the sample in grams.

2.5.7. Carbohydrate

Carbohydrate content was obtained by deducting the total moisture, fat, ash and protein content of the samples from 100.

2.5.8 Calorie evaluation

For this purpose, the percentage of fat, protein and carbohydrate was multiplied by their energy-generating values and the total calories of the samples were calculated according to the following equation.

\[
\text{Calories (\%)} = (\text{fat} \times 9) + (\text{protein} \times 4) + (\text{carbohydrate} \times 4) \quad (9)
\]

2.6. Physical tests

2.6.1. The specific volume of the cake

Canola seed displacement method was used to measure the volume of cake samples. For this purpose, the graduated cylinder was filled with canola seeds up to a volume of 20 ml, and then the contents of the cylinder were poured into the empty beaker so that only 5 ml of canola seeds remained, and then a cube of the sample with dimensions of 1 cm was placed. It was previously weighed and its weight was recorded, it was placed inside the cylinder containing the canola and the cylinder was filled with the canola that had been transferred to the beaker to a volume of 20 ml. In the next step, the remaining canola seeds inside the beaker were transferred to a smaller cylinder and its volume was recorded. By dividing the obtained volume by the weight of the sample, the specific volume of the cake was obtained.

\[
v = \frac{V}{m} \quad (10)
\]

2.6.2. Determination of water activity

In order to evaluate the water activity of the samples, a water activity measuring device (Decagon Devices, Pullman, WA) was used. The water activity measuring device for each food item has special standards that are included in the device itself. The desired samples were completely homogeneous powdered and placed in the corresponding sample chamber. The amount of water activity of the samples was analyzed and read by the device (Van der Sman et al., 2020).

2.6.3. Weight loss measurement

To measure the weight loss of cake dough after baking, the coded samples of cake dough were weighed before and after baking, and then the weight loss is calculated according to the difference in the weight of the samples before and after baking (Belorio et al., 2021).
2.6.4. Sensory evaluation

To evaluate the sensory characteristics of the cake samples, the 5-point hedonic method was used to test the cake samples on the first day of baking by a number of trained and expert people in terms of color, taste, texture, smell and overall acceptance of the item. In this test, the level of people's satisfaction with the sensory characteristics of cake samples was collected and evaluated in the form of scores (1 = very poor, 2 = poor, 3 = moderate, 4 = good, 5 = very good) (Noshad et al., 2020).

2.7. Texture analysis

A histometer (TA-XT Plus, Stable Micro System Ltd, Surrey, UK) was used to perform a tissue profile test (TPA). The samples required for the test were prepared from the central part of the cake with dimensions of 2x2x2 cm after separating the cake shell. The method of fabric testing was double compression with a time interval of 10 seconds between two cycles and with the help of a flat aluminum probe with a diameter of 75 mm. In order to perform the test, the device was set at a test speed of 0.8 mm/s and a pressure of 50%. The textural parameters reported included firmness, elasticity, cohesion, resilience, and chew ability. Texture analysis was done on the first day after baking for each sample. The crust hardness measurement of the prepared cake samples was used after the first and seventh days after the baking time. For this purpose, a 2 mm probe was used with a test speed of 1 mm/s. The maximum pressure force applied to the sample at the end of the test was reported as a stiffness index (Quiles et al., 2018).

2.8. Statistical analysis

In this research, the effect of relative replacement of flax flour on the surface (0–30%) with cake flour and flaxseed mucilage on the surface (0–60%) with oil as an experimental design of the response surface method based on D-optimal (Table 1) in the formulation Sponge cake was studied. The single effect and the interaction of these two factors were evaluated at the α = 5% level on the characteristics of the cake. Design Expert-10 software was used to draw contour plots and obtain mathematical models.
Table 1
Experimental design of based on D-optimal design

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3. Results And Discussion

3.1. Rheological properties

In this study, rheological properties were investigated as the most important functional properties of hydrocolloids. Figure 2 shows the apparent viscosity of flaxseed mucilage (1 to 15 water ratio), flaxseed mucilage (1 to 20 water ratio) and animal butter. Apparent viscosity was almost constant with increasing shear rate in flaxseed mucilage and butter samples. Also, according to the results of the flow behavior index, it can be seen that both mucilages have Newtonian behavior and are part of Newtonian fluids. In the animal butter sample, the viscosity decreased with the increase in shear speed, but overall it had a higher viscosity than the flax seed mucilage samples. The decrease in viscosity with the increase in shear rate indicates the pseudoplastic behavior of butter. The reduction of apparent viscosity in animal butter has a higher intensity at the beginning of the increase in shear speed, but then the intensity of the decrease in apparent viscosity decreased and reached a constant value. The reason for the sharp decrease in apparent viscosity is due to the loss of intermolecular bonds. This is despite the fact that the link between the molecules is broken and as a result the apparent viscosity decreases slowly or becomes stable (Kim et al., 2018). Similar results regarding Newtonian behavior have been expressed by Jin et al. (2017) who investigated the rheological behavior of a variety of compounds including corn fiber gum, modified corn starch, gum Arabic and soluble soybean polysaccharides. Their results showed that the apparent viscosity of modified starch and corn fiber gum solutions was almost constant due to highly branched structures and was independent of the shear rate, and no obvious pseudoplastic behavior was observed. Cuomo et al. (2020) also investigated the
behavior of chia seed mucilage combined with lemon essential oil and stated that the use of essential oil leads to
the stability of the Newtonian behavior of chia mucilage.

The frequency sweep test is the most common oscillatory test. In this test, the amplitude of the input voltage or
strain is kept constant, while the frequency is increased. The frequency scan test is used to investigate the effect
of different additives (for example, hydrocolloids) and the effect of different processes (for example, stirring and
heating) on changing the viscoelastic behavior of materials. In this test, if the elastic component (G') is larger than
the viscous component (G''), it indicates a gel-like structure, and if the viscous component (G'') is larger, the
material in this area shows liquid characteristics. According to Fig. 2, with increasing frequency (0.1-1 Hz) and at a
constant strain of 1%, the loss modulus (G'') of all samples increased. In the sample of flaxseed mucilage with a
ratio of 1:15, the drop and storage modulus is increasing, which indicates the behavior of dilute and semi-dilute
solutions, and there is no big difference between both modules, and both are frequency-dependent. Also, the
distance between both modules has been maintained during different frequencies. In the mucilage sample with a
ratio of 1:20, first the storage modulus is greater than the loss modulus, and then from a certain frequency
onwards, the storage modulus decreases and the loss modulus is increasing. In the mucilage sample with a ratio
of 1:20, the G'' numbers are in a larger range than the G' numbers of the mucilage sample with 1:15, which is due
to the increase in the concentration of the sample and as a result, the increase in the interaction of polymers,
which causes an increase in the consistency of the sample.

In the butter sample, the storage modulus is almost constant and has little dependence on the frequency, and the
drop modulus has increased significantly from a certain frequency onwards. So that at higher frequencies, the
distance between G' and G'' increases and the value of G'' is greater than G', which shows that the fluid-like
behavior is increasing. In terms of units, the values of G' and G'' in the butter sample are between 10 and 1000
Pa and in mucilage samples between 10\(^{-4}\) to 10 Pa. While the loss and storage modulus values in the butter
sample (10–10\(^3\) Pa) are higher than the mucilage samples. Another parameter investigated in the frequency test
is the complex modulus, which is obtained from the ratio of the maximum stress to the maximum strain in the
oscillation test. The complex modulus shows the overall stiffness, which includes elastic stiffness and viscous
stiffness. The complex viscosity is obtained from the ratio of the modulus of the complex to the frequency, and it
is a measure of the overall stiffness of the desired material (Yilmaz et al., 2011). The viscosity of the complex in
the mucilage samples first decreased and then increased; While in the animal butter sample, the complex viscosity
was decreasing. Also, the flow behavior index for butter is less than one, which indicates pseudoplastic and non-
Newtonian behavior in animal butter. Finally, according to all the graphs and the obtained results, flax mucilage
(1:20) formed a stronger gel than flax mucilage (1:15) and maintained its structure more during the tests.

**Figure 2**

### 3.2. Chemical properties (moisture and antioxidant capacity)

Figure 3 shows the contour plot of the effect of replacing flaxseed mucilage and flaxseed flour on the moisture
content of the low-calorie cake on days 1, 7, and 10 after baking, as well as the antioxidant capacity of the cake
samples. As shown in Fig. 3, with the increase of flax mucilage substitution, the moisture content of the samples
increased. Flax seed flour had no significant effect on moisture at low percentages of mucilage replacement, but
at high levels of flax mucilage replacement, with the increase of flax flour, the moisture content of the samples
increased significantly. On the tenth day after cooking, flax flour had no significant effect on moisture content, but
with the increase of flax mucilage, the moisture content increased significantly (P ≤ 0.05). Mucilages have the

ability to form a continuous gel-like texture, and with this ability, they can successfully maintain moisture during the shelf life. Also, the compounds that have the ability to form a gel by forming a series of transverse links that connect the polymer chains, produce a three-dimensional network and trap water in their cracks, thus increase the moisture content of the product. On the other hand, the oil in food can prevent their evaporation by surrounding water molecules, especially during the cooking process, and act as a barrier to the exit of moisture. The power of flaxseed mucilage in retaining water is more than that of oil, which increased the moisture content of cake samples by reducing the amount of oil in the formulation. Also, the reason for the increase in moisture in cake samples containing flax flour can be attributed to minerals (1.54%) and fiber (1.80%), which is more than wheat flour (0.62% minerals and 1.1% raw fiber) related that fiber absorbs more water and thus increases moisture (Belghith Fendri et al., 2016). Similar results have been reported with the addition of flax mucilage in cookies (Kaur et al., 2015) and in bread (Fernandes and Mercedes Salas-Mellado, 2017) regarding the increase in moisture with the addition of mucilage. The predictive regression model for moisture was a significant model with high $R^2$ and Adj-$R^2$, non-significant mismatch ($P > 0.05$) and low coefficient of variation, which indicates the effectiveness of the presented model. The presented model for moisture on days 1, 6 and 10 after baking is as follows:

\[
\text{Moisture (1th day)} = 21.61 + 1.10 \times A + 6.13 \times B + 3.43 \times AB + 3.66 \times A^2 + 3.57 \times B^2
\]

\[
\text{Moisture (6th day)} = 26.58 + 2.48 \times A + 4.84 \times B + 34.96 \times C + 2.76 \times AB
\]

\[
\text{Moisture (10th day)} = 29.54 + 0.03 \times A + 5.25 \times B
\]

By examining the contour plot of the antioxidant capacity, it was determined that the antioxidant capacity of the samples increased with the single replacement of flax mucilage and flax seed flour, and the highest amount of antioxidant capacity was observed in cakes with the maximum amount of mucilage and flax seed flour replacement. The increase in antioxidant capacity in samples containing flax is due to the presence of antioxidant substances such as phenolic compounds and lignans. Flax is a rich source of secoisolariciresinol diglucoside (SDG) lignans and small amounts of matricinol lignan. SDG and matricinol can be converted into enterodiol and enterolactone lignans by colon bacteria (Han et al., 2018). Meral and Dogan (2013). In a research aimed at investigating the effect of flaxseed on the quality of bread preparation and the antioxidant properties of bread, it was found that total phenols and flavonoids increased significantly with increasing the level of enrichment with flaxseed, and the highest values were found in bread containing 8% of flaxseed. Sanmartin et al. (2020). Also, similar results were reported by Valerga, et al. (2020), with the addition of eggplant flour in wheat bread. The predicted model (15) for this feature is a significant model with $R^2$ and Adj-$R^2$ of 0.98 and 0.96, respectively, with a non-significant discrepancy ($P > 0.05$) and a low coefficient of variation, which shows the effectiveness of the model.

\[
\text{Antioxidant capacity} = 30.27 + 3.60 \times A + 3.75 \times B - 0.59 \times AB + 3.38 \times A^2 - 0.73 \times B^2
\]
3.3. Physical properties (water activity, weight loss, specific volume and height)

Figure 4 shows the contour plot of the effect of replacing flaxseed mucilage and flaxseed flour on the water activity of low-calorie cake on days 1, 7, and 10 after baking, weight loss, specific volume, and height of cake samples.

Water activity is one of the most important characteristics of food, which is extremely important in terms of maintaining the health of food, storage time, taste, nutritional value and economic aspects, and is affected by temperature and pH. As it is clear from the contour plot, with the increase of flax mucilage, the water activity of the samples increased, but flax seed flour had no significant effect on this parameter. The results of water activity (WA) evaluation on the sixth and tenth day after cooking showed that with the replacement of mucilage, the water activity increased significantly, but the effect of flaxseed flour on the water activity factor was not statistically significant ($P < 0.05$). In general, replacing oil with wet mucilage increased water activity, which is consistent with the results of increasing moisture. The use of mucilage in food due to its hydrophilic properties leads to the creation of water-soluble molecules and controls the moisture content of the food through the formation of a structure that is permeable to water. The results of this research were in agreement with the results of Fernandes and Salas (2018). Regression model for water activity, a significant model with high $R^2$ and Adj-$R^2$, non-significant mismatch ($P < 0.05$). And the coefficient of change was low, which indicates the efficiency of the presented model. The presented model for water activity in 1, 6 and 10 days after baking is as follows:

$$WA (1\text{th\ day}) = 0.82 - 0.001 \times A + 0.03 \times B$$

$$WA (6\text{th\ day}) = 0.77 + 0.0008 \times A + 0.02 \times B + 0.005 \times AB + 0.04 \times A^2 + 0.01 \times B^2$$

$$WA (10\text{th\ day}) = 0.8 - 0.003 \times A + 0.01 \times B$$

According to the weight loss contour plots, it was found that with the increase in the percentage of mucilage and flax flour replacement, the weight loss percentage of the samples decreased, but this decrease was not statistically significant ($P < 0.05$).

By examining the contour plots of the specific volume, it was observed that, with the increase in the percentage of flaxseed flour replacement, the specific volume decreased slightly. The reduction in volume with the increase of flax flour is due to the reduction of wheat flour and the reduction of gluten, which leads to the weakening of the flour and the reduction of the ability of the dough to retain air. Also, the decrease in the specific volume of bread with the increase in the substitution of flaxseed mucilage can be attributed to the disruption of gas retention by fiber, the decrease in gas storage capacity, and the decrease in the amount of dough expansion during baking. On the other hand, there is a possibility that the high levels of flaxseed mucilage by producing more gel have strengthened the wall of the air bubbles entering the cake dough so that these bubbles have lost the ability to
expand and increase in volume during the baking process and thus lead to a decrease in the specific volume of the samples. The regression model for specific volume was a significant with a non-significant discrepancy (P < 0.05) and a low coefficient of variation, which indicates the efficiency of the presented model. The model presented for the special volume is presented as follows:

\[
\text{Specific volume} = 2.84 - 0.29A - 0.18B - 0.25AB
\]

The height contour plot showed that the height of the samples decreased with the increase in the substitution of flaxseed mucilage and flax seed flour, and the lowest height was observed in the samples with the maximum substitution of flaxseed mucilage. The decrease in the height of the samples is due to the weak texture strength of the low-calorie cake samples produced due to the addition of mucilage at high levels (Lee and Puligundla, 2016). The results of the present research were consistent with the results of Vasantha Rupasinghe et al. (2008) who reported that the addition of apple peel powder led to a decrease in the height of the muffin samples. Regression model for height, a significant model with non-significant mismatch (P < 0.05). The coefficient of variation was low, which shows the high efficiency of the presented model. The presented model is as follows:

\[
\text{Height} = 3.88 - 0.10A - 0.57B
\]

Figure 4

3.4. Hardness, cohesion, elasticity, chewability, resilience, crust hardness and overall acceptance

Figure 5 shows the contour plot of the effect of replacing flaxseed mucilage and flaxseed flour on hardness, cohesiveness, elasticity, chewability, resilience, shell firmness and overall acceptance of cake samples. Examining the contour plot curve of cake core hardness showed that the addition of flaxseed mucilage caused the cake samples to be hard. While flaxseed flour did not change the texture of the samples. The increase in hardness at high levels of mucilage is due to the increase in cake dough viscosity. Also, adding the fiber in the mucilage to the baked products increases the hardness of the samples and there is an indirect relationship between the volume and the hardness, and the results of the hardness correspond to the results of the specific volume. The predicted model for this feature is a significant model with a non-significant discrepancy (P < 0.05) and a low coefficient of variation, which shows the effectiveness of the presented model (21).

\[
\text{Hardness} = 0.57 - 0.22A + 0.26B - 0.19AB
\]

Cohesiveness as the internal resistance of the structure of the food, determines the adhesion between the internal components. According to the contour plot related to cohesiveness, with the increase in the levels of flour and mucilage of flaxseed, the cohesiveness of the samples increased. So that the samples containing the highest levels of flour and mucilage showed the highest degree of cohesion. The addition of flour and flax seed mucilage improved the structure of the cake and its reversibility to its initial state was strongly affected. Therefore, adding flour and mucilage of flax seed increased the cohesiveness in low calorie cake samples. Similar results were reported by Avila et al. (2017) who stated that replacing the mixture of millet, quinoa, chickpea, flaxseed and
chickpea flours increased the cohesiveness of the cake samples. The predicted model for this feature is a significant model with a non-significant discrepancy (P < 0.05) and a low coefficient of variation, which shows the effectiveness of the presented model (22).

\[
\text{Cohesiveness} = 0.55 + 0.03 \times A + 0.07 \times B
\]

22

The results of the elasticity contour plot showed that the elasticity of the samples decreased with the addition of flour and mucilage, and the samples containing the highest percentage of flour and mucilage replacement had the lowest elasticity. This behavior is probably related to the larger size of flaxseed flour granules compared to wheat flour. In addition, flaxseed flour contains high amounts of fiber, fat, and protein, which interact with gluten and starch and affect the formation of the gluten network and eventually cause a decrease in the elasticity of the samples. The results of the present research were in agreement with the findings of Mau et al. (2015) regarding the reduction of elasticity by adding tea powder to the cake. The results obtained were in agreement with the findings of Fendri et al. (2016) who stated that by adding chickpea fiber to bread samples, a decrease in elasticity was observed. The predicted model for this feature is a significant model with a non-significant discrepancy (P < 0.05) and a low coefficient of variation as follows:

\[
\text{Springiness} = 0.64 - 0.10 \times A - 0.14 \times B
\]

22

According to the results of the statistical analysis and contour plot related to chewing ability, with the increase in the replacement percentage of the studied factors, the changes in the chewing ability of the samples were not statistically significant (P < 0.05).

Resilience is one of the extracted parameters of texture analysis, which is considered as elasticity. Resilience also shows the capacity of a material to store energy. The evaluation of the resilience results indicated an increase in resilience with the increase in substitution of the studied factors (flax seed flour and mucilage). The control sample had the lowest resilience compared to other samples.

As mentioned in the cohesion and elasticity factor section; Due to its high fiber content and its interaction with gluten and starch, flaxseed mucilage and flour have an effect on the formation of the gluten network of the cake and ultimately led to an increase in the resilience of the samples. The predicted model for this feature is a significant model with a non-significant mismatch (P < 0.05). The low coefficient of variation is given below, which shows the efficiency of the presented model.

\[
\text{Resilience} = 0.21 + 0.04 \times A + 0.08 \times B + 0.01 \times AB
\]

23

The firmness of the crust was checked on the first day and the 7th day after baking, and the corresponding contour plot curves show that the individual effect of flour and flax seed mucilage on the firmness of the cake samples on the first day after baking was significant (P < 0.05). While the studied factors had no significant effect on the stiffness of the 7th day after cooking (P < 0.05). On the first day after cooking, the hardness of the samples decreased with the addition of flour and mucilage, and the samples containing the highest levels of flour and mucilage had the lowest firmness. This behavior may be related to the high moisture of the enriched samples as
well as the gum state and the amount of fat in the flax seeds. The results obtained were in agreement with the findings of Marpalle et al. (2014), who stated that the addition of flaxseed flour to bread decreased the firmness of the samples. The predicted model for this feature is a significant model with a non-significant mismatch (P < 0.05) and the low coefficient of variation that shows the efficiency of the presented model.

\[
\text{Firmness (1th day-crust)} = 0.04 - 0.006 \times A - 0.004 \times B
\]

24

The contour plot of overall acceptance shows that the overall acceptance of the samples decreased with the increase in the replacement percentage of flax mucilage and flax seed flour. The highest overall acceptance score was related to samples with a low percentage of flax mucilage and flax seed flour, as well as samples with a high replacement percentage of mucilage and low levels of flax flour, which according to the results obtained from physical tests (specific volume, density, height and colorimetric) and histometry, this result is not far from expected.

Ganorkar and Jain (2014) cited the darkening of the color, the creation of a dry surface, the reduction of crispness, and the creation of a rougher mouthfeel as the reasons for the decrease in the overall acceptance score with the increase in the amount of flax flour. The predicted model for this feature is a significant model with \( R^2 \) and \( \text{Adj-}R^2 \) of 0.80 and 0.67, respectively, with a non-significant discrepancy (P < 0.05). The low coefficient of variation that shows the efficiency of the presented model.

\[
\text{Overall acceptance} = 3.46 - 0.08 \times A - 0.09 \times B + 0.004 \times AB + 0.21 \times A^2 + 0.57 \times B^2
\]

25

Figure 5

3.5. Optimizing the formulation

To determine the optimal processing conditions, the resulting models were numerically optimized for different responses. For this purpose, the desirability function is an effective method in multi-response optimization. Figure 6 shows the optimization diagram based on the desirability function. Based on this graph and the desirability function in the conditions of the maximum desirability function (0.76), taking into account the maximum consistency and overall acceptance and the lowest hardness of the shell and core, cake samples with 60% flax mucilage and 28% flax seed flour were chosen as the optimum formulation. In the following, some physicochemical characteristics were analyzed for the control sample and the optimal sample and their results were reported in Table 2. By examining the fat measurement results of the optimal and control cakes in Table 2, it was found that the fat content of the optimal and control samples has a statistically significant difference (P ≤ 0.05) and the addition of flaxseed flour (28%) and Flax mucilage (60%) has reduced the amount of fat so that the highest fat content was observed in the control sample. The reason for fat reduction can be explained due to the high level of unsaturated fatty acids and the low level of saturated fatty acids of flax mucilage and flax seed flour compared to the animal butter. On the other hand, the high moisture content of flaxseed mucilage causes the interaction of water and kneaded macromolecules, which ultimately leads to the reduction of fat in the samples. In this regard, Liu et al. (2020) used flaxseed flour as a relative substitute for wheat flour in the formulation of Chinese steamed bread, which ultimately led to a decrease in the fat content of the final product. According to the results of the chemical tests of the optimally produced cake samples, the protein content of the samples
increased, as expected, there was a significant difference between optimal sample and control sample. The reason for this can be attributed to the high amount of protein in flaxseed mucilage (10.38%) and flaxseed flour (27.46%), which leads to the production of cakes with high protein quality (Romankiewicz et al., 2017). The results were consistent with the results of Codina et al. (2019), who stated that the addition of flax in wheat-flax composite flour led to an increase in flour protein.

By examining the ash results of the optimal and control cakes in, it was found that the amount of ash of the optimal and control samples has a significant difference (P ≤ 0.05) and the addition of flour and flaxseed mucilage increased the amount of ash. This increase is due to the higher amount of ash and the presence of high amounts of mineral salts such as calcium, magnesium, phosphorus and iron in flax seed flour (3.96%) and flax mucilage (6.57%) compared to animal butter.

By examining the moisture results of the optimal and control cakes, it was found that the moisture content of the optimal and control samples has a statistically significant difference (P ≤ 0.05) and the addition of flax with moisture (4.69%) and mucilage with moisture (97.3%) has increased the moisture content. This effect is due to the more minerals and fiber of flax flour compared to wheat flour, which fiber absorbs more water and thus increases the moisture. Also, mucilages have the ability to form a continuous gel-like texture, and with this ability, they can lead to an increase in the moisture of the samples.

By examining the peroxide value results, it was found that the amount of peroxide of the optimal and control samples has a statistically significant difference (P ≤ 0.05). The addition of mucilage and flax seed flour decreases the amount of peroxide. The reduction of peroxide can be explained due to the reduction of fat in the formulation as a result of the substitution and the presence of hydroxyl groups in the mucilages, which have free radical trapping properties and thus prevent oxidation or reduce the rate of oxidation. The results obtained are in agreement with the results of Goyat et al. (2019).

Figure 6

<table>
<thead>
<tr>
<th>Factor</th>
<th>Protein</th>
<th>Fat</th>
<th>Ash</th>
<th>Moisture</th>
<th>PV (1)</th>
<th>PV (8)</th>
<th>PV (16)</th>
<th>Carbohydrate</th>
<th>Calorie(Kcal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.85 ± 0.001a</td>
<td>22.87 ± 0.01b</td>
<td>0.55 ± 0.03a</td>
<td>22.1 ± 0.001a</td>
<td>1.72 ± 0.01b</td>
<td>1.84 ± 0.001b</td>
<td>2.1 ± 0.001a</td>
<td>47.78 ± 0.01</td>
<td>424.15 ± 0.001b</td>
</tr>
<tr>
<td>28FF+ 60FM</td>
<td>7.88 ± 0.002b</td>
<td>17.7 ± 0.03a</td>
<td>0.82 ± 0.03b</td>
<td>41.3 ± 0.001b</td>
<td>1.56 ± 0.01a</td>
<td>1.68 ± 0.001a</td>
<td>2.55 ± 0.001b</td>
<td>32.3 ± 0.01</td>
<td>320.02 ± 0.001a</td>
</tr>
</tbody>
</table>

Dissimilar letters in a column indicate a significant difference (p ≤ 0.05).

FM: Flax mucilage FF: Flax seed flour

4. Conclusion

The obtained results indicate that mucilage and flaxseed flour can be used well in optimizing the physicochemical, textural and sensory characteristics of low-calorie cake. The results of rheological properties indicate Newtonian
behavior in flax mucilages (1:15 and 1:20) and pseudoplastic behavior in animal butter. The results of cake data analysis showed that by increasing the replacement of mucilage and flax seed flour on the first day after baking, the moisture content and water activity of the samples increased, and after 6 and 10 days after baking, with the replacement of flax mucilage, the moisture content increased and aquatic water increased. With increasing replacement of the studied factors, the antioxidant capacity, tissue cohesion and resilience increased and the specific volume, elasticity and hardness of the shell decreased (P < 0.05). Overall acceptance decreased with the replacement of mucilage and flax seed flour, but all samples had an acceptable acceptance score. Taking into consideration the maximum consistency of the texture and the overall acceptance score and the least hardness of the shell and core, the cake samples with the formulation of 60% flax mucilage and 28% flaxseed flour were identified as the optimal samples with acceptable textural and sensory quality. The comparison between the optimized sample and the control showed that the amount of protein, ash and moisture of the optimized cakes was higher than the control sample. The reduction of fat, carbohydrates, calories and peroxide in the optimized samples compared to the control sample, was observed. In general, according to the results, it is possible to replace animal butter with flax seed mucilage and flax seed flour in the cake formulation, and it is possible to reduce the amount of fat without significantly reducing the quality of the product.

Declarations

Conflict of Interest Statement

There is not any Conflict of interest between authors. The authors whose names are listed in the manuscript certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers’ bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Author’s contribution

Forogh Mohtarami conceived of the presented idea. Fariba Ahmadiania developed the theory and performed the computations. Mohsen Esmaili verified the analytical methods. Forogh Mohtarami and Sajad Pirsa discussed the results and contributed to the final manuscript. Fariba Ahmadiania out the experiment. Sajad Pirsa wrote the manuscript and revised it.

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Data Availability Statement

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.
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Figure 1

Flaxseed, flaxseed powder and mucilage (A) and low-calorie cake sample (B)
Figure 2

Viscosity diagram (A), frequency scan of $G'$, $G''$ and $\eta$ (B) in the flax seed mucilage (1 to 15 water ratio) (X), Flax seed mucilage sample (1:20 water ratio) (Y) and animal butter sample (Z)
Figure 3

Contour plot of the effect of replacing flaxseed mucilage and flaxseed flour on the moisture content of the low-calorie cake on days 1, 7, and 10 after baking and the antioxidant capacity of the cake.
Figure 4

Contour plot of the effect of replacing flaxseed mucilage and flaxseed flour on the water activity of low-calorie cake on days 1, 6, and 10 after baking, weight loss, specific volume, and height of cake samples.
Figure 5

Contour plot of the effect of replacing flaxseed mucilage and flaxseed flour on the hardness, cohesiveness, springiness, chewability, resilience, firmness and overall acceptance of cake samples
Figure 6

Optimization diagram and desirability function