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Abstract

The effect of heat treatment (roasting and steaming) of flaxseed on physicochemical properties of mucilage and its potential to use as fat replacer in cake formulation were investigated. Flaxseeds were roasted at 100, 130, 160 °C for 5, 10, 15 min, and steamed for 5, 10, 15 min before mucilage extraction. The highest water-holding capacity (22.6%) and oil-holding capacity (4.2%) were observed in mucilage extracted from flaxseed steamed for 15 min, and roasted for 15 min at 160 °C, respectively. However, heat treatment decreased the foam capacity of the mucilage. The highest emulsion capacity (45.5%) was observed in mucilage from flaxseed roasted at 100 °C for 15 min. Mucilage was used in cake formulation at 50% replacement with fat. Heat-treated flaxseed mucilage significantly increased the cake's specific volume, with the highest (2.52 cm^3/g) was determined in the cake supplemented by 15 min steamed flaxseed mucilage. Steamed flaxseed mucilage resulted in a softer cake texture. Moreover, mucilage from steamed flaxseed generally resulted in lower color differences in cake samples compared to that from roasted flaxseed. The addition of mucilage increased total dietary fiber content of cake samples and decreased their glycemic index values. Steamed flaxseed mucilage resulted in the lowest glycemic index values. Overall, heat-treatment of flaxseed, especially steam treatment, before mucilage extraction results in mucilage with improved functional properties without resulting any adverse effects at 50% replacement with shortening in low-fat cake quality.

Keywords: Mucilage, flaxseed, heat treatment, fat replacer, cake

INTRODUCTION

The increasing prevalence of chronic diseases, including obesity, cardiovascular diseases, cancer, hypertension, and diabetes, has led to a surge in consumer interest in healthier foods, including low-calorie, low-sugar, and reduced-fat products [1]. Although health professionals recommend limiting fat intake per day to no more than 30% of the total caloric intake, in the USA and most of Europe, the fat consumption represents about 40% of the daily caloric intake [2]. This has increased the focus on research into reducing the fat content in baked goods including cookies and cakes, which are often high in fat. However, replacing fat in a food system is complex due to its crucial role in sensory attributes of foods like color, flavor, aroma, and texture [3]. Reducing fat content often leads to undesirable changes in food quality, including reduced volume, a denser crumb, increased firmness, and flavor loss. Fat replacers are employed to mitigate or prevent these adverse effects in reduced-fat products [4, 5].

Flaxseed is considered one of the most significant oilseed crops globally, values for its high-quality protein, dietary fiber, alpha-linolenic acid, lignans, and phenolic compounds. Additionally, flaxseed is unique among oilseeds for its mucilage content, which is located in the outer seed layers of the seed. Mucilage, a hydrocolloid extracted from flaxseed, has been associated with beneficial effects on gastrointestinal function, blood sugar regulation, and cholesterol levels. In the food industry, flaxseed mucilage is commonly utilized as a thickening agent, stabilizer and emulsifier. Additionally, its potential as a fat replacer in various foods, including cakes, mayonnaise and cheese, has been recognized [6].

This study aimed to investigate the effects of heat treatment on flaxseed mucilage extraction, the physicochemical properties of the extracted mucilage, and its use as a fat replacer in cake formulation. To this end, the physicochemical properties of mucilage, including water-holding capacity, oil-holding capacity, foaming capacity and emulsion capacity were determined. Additionally, the sensory, textural and nutritional characteristics of cake samples containing the mucilage were evaluated. Specifically, total dietary fi ber content, and *in vitro* glycemic index value of cake samples were also determined.

MATERIALS AND METHODS

Flaxseed, wheat flour, and other constituents used in cake formulation were obtained from a local market.

Heat Treatment

Flaxseed samples underwent two different pre-treatments: roasting and steaming. A part of the flaxseed samples was roasted in a drying oven at varying temperatures (100, 130, and 160 °C) and times (5, 10, and 15 minutes). After roasting, samples were allowed to cool to room temperature before being stored in sealed bags at 4 °C. The rest of flaxseed was steamed at a steamer (Raks steam cooker) for different times (5, 10, and 15 minutes). Following steam treatment, samples were dried overnight at 40 °C in an air-oven (Simsek Laborteknik, Türkiye), and stored at 4 °C in sealed bags.

Mucilage Extraction

Flaxseed mucilage was extracted following the method described by Emadzadeh et al. [7]. Briefly, flaxseed was mixed with distilled water at a 1:20 (w/v) ratio, incubated at 80 °C for 2 h, and filtered through a 300 µm cheesecloth. The mucilage was dried overnight at 50 °C in an air-oven, and then ground for further analysis.

The extraction yield was determined by calculating the ratio of the mucilage weight obtained to the initial weight of sample used (Eq.1)

$$\text{Yield } (\%) = \frac{\text{Weight of dried mucilage}}{\text{Flaxseed sample}} \times 100 \quad (1)$$

Physicochemical Analysis

The water holding capacity and oil holding capacity of mucilage samples were measured following the method described by Alfredo et al. [8]. Briefly, sample was mixed with distilled water at a 1:100 ratio (w/v) using a vortex mixer for 30 seconds, and then rested for 30 min at room temperature. Mixture was centrifuged at 2200 *xg* for 20 min, supernatant was carefully separated, and remaining wet sample was weighed. For oil holding capacity, the sample was mixed with sunflower oil instead of distilled water. Foaming capacity was determined following the method of Emadzadeh et al. [7]. Briefly, sample was mixed with distilled water and mixed using a Turrax homogenizer at 12500 rpm for 2 min. Foam volume was measured. Emulsion capacity was determined by Boutemak et al. [9]. Briefly, sample (1 g) was mixed with distilled water (50 ml), and then sunflower oil (25 ml) was added. After homogenization at 10000 rpm for 1 min, mixture was centrifuged (1800 *xg*, 5 min) and emulsion volume was measured.

Cake Making Procedure

Cake formulation was prepared by replacing shortening with mucilage at a 50% substitution level, and a control cake (Table 1) was formulated without the addition of flaxseed mucilage. First, sugar powder, egg white powder, non-fat dry milk, shortening, and 40% of water were mixed with a laboratory mixer/blender (Kitchenaid, USA) for 1 min at low speed. Then, all other dry ingredients and the rest of the water were added and mixed for 1 minute at low speed, 1 minute at medium speed, and 2 additional minutes at low speed. Baking was performed using a conventional kitchen oven (Arcelik ARMF 4 Plus, Türkiye). Cakes were baked at 180 °C for 30 min. In each baking trial, three cakes were prepared using 70 g batter per cake. Cakes were removed from the pans after cooling for 30 min at room temperature.

Table 1 Cake composition

Ingredients(%)	Control	Mucilage
Wheat flour	100	100
Powdered sugar	100	100
Dried egg white	9	9
Shortening	40	20
Mucilage	0	20
Non-fat dry milk	12	12
Baking powder	5	5
Salt	1	1
Water	100	100

Physical Characteristics of Cakes

Specific volume of the cake samples was measured using the rapeseed displacement method 2 h after baking. Weight loss (%) was calculated by the difference between the initial batter weight and the cake weight immediately after baking. The color of cake crust was determined 24 h after baking using Minolta Spectrophotometer (CM-3600d, Japan). CIE L*, a*, b* values were measured and the color change (ΔE) was calculated using the equation shown in Eq.(2):

$$\Delta \mathrm{E} = \sqrt{(L_2{*}-L_1{*})^2 + (a_2{*}-a_1{*})^2 + (b_2{*}-b_1{*})^2} \qquad (2)$$

The firmness of cake samples was measured 24 h after baking according to AIB (American Institute of Baking) by using a texture analyzer (Stable Micro Systems, England) using an aluminum cylindrical probe with diameter of 36 mm. Three pieces (20 mm width, 30 mm length, and 15 mm height) were cut from each cake sample and compressed by 25% of their initial height using a load cell applying a 50 N force. The average firmness of three pieces was recorded as the overall firmness value for each sample.

Proximate Composition and Estimated *in vitro* Glycemic Index Analysis

Moisture, ash, and protein contents of wheat flour and flaxseed were analyzed following AACCI standard methods [10]. Total dietary fiber (TDF) content of the cake samples was determined using an enzymatic-gravimetric method with a total dietary fiber assay kit (Megazyme Int., Ireland) [10].

To estimate the *in vitro* glycemic index (GI), defatted samples were digested following the method described by Englyst et al. [11]. Briefly, 100 mg of each sample was placed into 50 ml tubes containing 10 glass beads (5 mm diameter). Then, 2 ml of 0.05 M hydrochloric acid and 10 mg of pepsin (Sigma, P7000) were added. The tubes were incubated at 37 °C for 30 min in a shaking water bath. After incubation, sodium acetate buffer (4 ml, 0.5 M, pH 5.2) was added, followed by 1 ml of an enzyme solution containing 0.104 g pancreatin (Sigma-Aldrich, P7545) and 14.45 U amyloglucosidase (3300 U/ml, Megazyme Int., Ireland). The tubes were incubated again in a shaking water bat hat 37 °C and 100 µL of aliquots were collected at 0, 10, 20, 30, 60, 90, 120, and 180 min, and then mixed with 1 ml of absolute ethanol. After centrifugation at 800 g for 10 min, the glucose content of the supernatant was measured using glucose oxidase-peroxidase reagent (GOPOD, Megazyme Int., Ireland). Absorbance was measured at 510 nm using a spectrophotometer (Scilogex, China). D-Glucose was used as the reference carbohydrate. A graph was plotted of D-glucose against time. The hydrolysis index was calculated by dividing the area under the curve (AUC) for the sample by that for the reference D-glucose. Hydrolysis index (HI) represents rate of starch digestion of sample relative to that of a reference material, white bread. HI was calculated using the following Eq. (3);

$$\mathrm{HI} = \frac{\text{Area under the curve of the sample}}{\text{Area under the curve of white bread}} \qquad (3)$$

The *in vitro* GI was calculated using the Eq.(4) derived by Goñi et al. [12];

$$\mathrm{GI}_{\text{in vitro}} = 39.71 + 0.549\,\mathrm{HI} \qquad (4)$$

Statistical Analysis

All treatments were performed in duplicate, and each sample was analyzed at least in duplicate. The experimental data were statistically evaluated using one-way analysis of variance (ANOVA) in SPSS software (IBM SPSS Statistics, version 22). When significant differences were observed among samples, Duncan test was applied to identify differences between the means.

RESULTS AND DISCUSSION

Wheat flour used in cake production was found to have 9.6% protein, 0.4% ash, and 14% moisture, and flaxseed had a protein content of 19%. Mucilage was extracted from flaxseed before and after heat treatments. Mucilage yield of untreated flaxseed was 7.5%, which is well in line with literature reporting mucilage extraction yield varying between 3.5 and 10.0% [13]. Heat treatment of flaxseed resulted in an extraction yields ranging from 7.5 to 8.0%.

Physicochemical properties of mucilage were evaluated by measuring its water-holding capacity, oil-holding capacity, emulsion capacity, and foaming capacity (Table 2). Water-holding capacity (WHC) of untreated flaxseed mucilage was 16.2%, while those of heat-treated flaxseed mucilage ranged from 15.5 to 22.6%. Heat treatment significantly increased WHC, except for roasting at 100 °C for 10 and 15 min. Increasing temperature during 5-minute roasting significantly decreased WHC. However, roasting for 10 and 15 min, increasing temperature increased WHC, except that of increase from 130 to 160 °C for 15 min roasting. Steam treatment for 15 min resulted in the highest WHC (22.6%), which could be due to structural changes in components leading to the absorption of more water and improving the hydration property. An increase in WHC of flaxseed after heat treatment is reported in literature [14, 15]. Flaxseed mucilage has been reported to possess strong water-binding properties and is the primary component contributing to the high water-holding capacity of flaxseed [16].

Oil-holding capacity (OHC) of untreated flaxseed mucilage was 2.8%. Mucilage from heat-treated flaxseed had oil-holding capacity varying between 2.8 and 4.2%, with the highest OHC observed in mucilage from flaxseed roasted at 160°C for 15 min. Increasing time at a constant temperature had no significant effect on OHC ($p>0.05$), while increasing temperature from 130 to 160 °C at a constant time significantly increased OHC ($p<0.05$). The short intervals between the treatment times may have limited the observable effect of time on OHC of mucilage samples. Although steam treatment slightly increased OHC compared to roasting at 100 °C, this increase was not statistically significant ($p>0.05$). Both roasting at 160 °C for 5, 10 and 15 min, and steaming for 15 min resulted in higher OHC than that of untreated sample ($p<0.05$). Shaikh et al. [15] and Hussain et al. [17] reported increased fat retention capacities in heat treated flaxseeds. On the contrary, Khan and Saini [14] observed a decrease in fat retention capacity after heat treatment at 180 °C for 10 min. Fats in foods contribute to flavor and mouthfeel, making fat retention capacity a critical quality attribute for fat-containing foods. Heat treatments lead to protein denaturation and dissociation, exposing hydrophobic groups that bind to the hydrocarbon chains of fats, thereby increasing the fat retention capacity [18]. The observed increase in the oil-holding capacity of heat treated flaxseed mucilage in this study can be attributed to this phenomenon. Foam capacity (FC) of untreated mucilage was 20%, while heat-treated flaxseed mucilage exhibited FC values ranging from 5.8 to 16.7%. Both roasting and steaming significantly reduced FC ($p<0.05$). Among heat-treated flaxseed mucilage samples, the lowest FC (5.8%) was observed after roasting at 100 °C for 5 min, and the highest (16.7%) after roasting at 130 °C for 15 min. Steaming resulted in a slightly higher FC compared to roasting at 100 °C. Similar results were reported by Hussain et al. [17] and Khan and Saini [14]. Foam formation and stability are largely influenced by the interfacial film created by proteins, which stabilize air bubbles and retard their coalescence. Additionally, foaming properties are affected by other constituents, including carbohydrates [19]. A high foaming capacity indicates a greater amount of soluble protein in the sample. The reduction in foaming capacity of mucilage samples following heat treatment can be attributed to denaturation of proteins and formation of insoluble protein aggregates. Emulsion capacity (EC) of untreated sample was 34.5%. EC for mucilage from heat-treated flaxseed ranged

Table 2 Extraction yield, water holding capacity, oil holding capacity, foaming capacity and emulsion capacity of mucilage

Sample	Temperature (°C)	Time (°C)	Extraction yield (%)	WHC (%)	OHC (%)	FC (%)	EC (%)
Untreated	-	-	7.5	16.2^{h}	2.8^{d}	20.0^{a}	34.5^{de}
	100	5	7.5	20.5^{b}	2.8^{d}	5.8^{f}	38.2^{c}
		10	7.5	15.8^{h}	2.9^{d}	6.7^{ef}	38.2^{c}
		15	7.6	15.7^{h}	3.1^{cd}	7.5^{de}	45.5^{a}
	130	5	7.7	17.2^{fg}	2.8^{d}	7.5^{de}	34.5^{de}
Roasting		10	7.7	17.3^{ef}	3.0^{d}	10.8^{c}	33.6^{ef}
		15	7.7	17.8^{de}	3.1^{cd}	16.7^{b}	44.5^{a}
	160	5	8.0	16.7^{g}	4.0^{ab}	8.3^{d}	27.3^{h}
		10	8.0	18.0^{d}	4.1^{a}	7.5^{de}	26.4^{h}
		15	8.0	17.5^{def}	4.2^{a}	6.7^{ef}	41.8^{b}
	100	5	7.5	19.2^{c}	3.2^{cd}	8.3^{d}	30.0^{g}
Steaming		10	7.5	19.3^{c}	3.2^{cd}	10.0^{c}	32.7^{f}
		15	7.5	22.6^{a}	3.6^{bc}	8.3^{d}	35.5^{d}

WHC: Water holding capacity, OHC: Oil holding capacity, FC: foaming capacity, EC: emulsion capacity from 26.4 to 45.5%. Roasting for 15 min significantly increased EC at all temperatures compared to untreated sample. Significantly lower EC values were observed in the samples roasted at 160 °C for 5 and 10 min, and steamed for 5 and 10 min. EC values of mucilage from steamed flaxseed were significantly lower compared to those of roasted flaxseed at 100 °C, which could be due to the increase in protein aggregation and decrease in surface hydrophobicity after steam treatment.

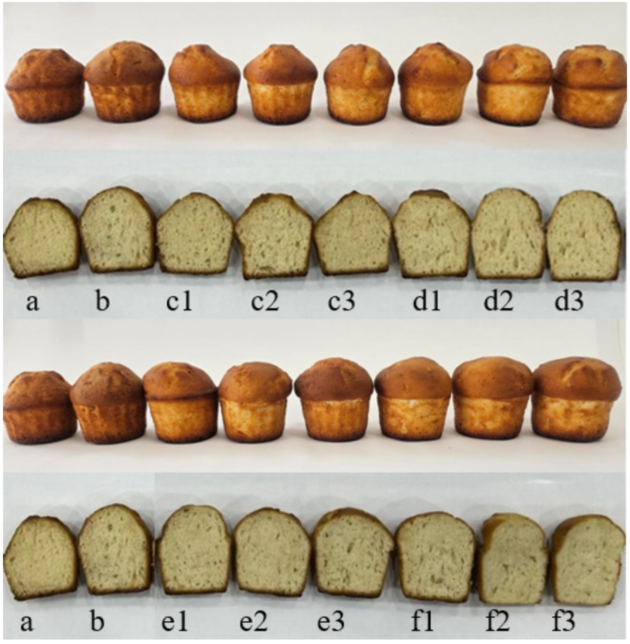

Figure 1 Physical appearance and cross-section views of cake samples

a: control cake produced without mucilage addition, b: cake produced with untreated flaxseed mucilage, c, d and e represent cakes with mucilage from flaxseed at 100, 130 and 160 °C heat treatments, f represents cake samples with steamed flaxseed mucilage. 1, 2 and 3 represent heat treatment times of 5, 10 and 15 min, respectively.

Physical appearance and cross-section views of cakes are presented in Fig.1. Cake samples were analyzed for their quality properties, including specific volume, color, texture, total dietary fiber, and *in vitro* glycemic index values. Specific volume, weight loss, and texture properties (firmness) of cake samples are presented in Table 3. Volume is a crucial physical attribute that influence cake quality and consumer preference [20]. Specific volume indicates the amount of air retained in the cake. The control sample (baked without mucilage addition) had a specific volume of 1.85 cm^3/g. Specific volume of cake samples significantly increased by mucilage addition ($p<0.05$). The highest specific volume (2.52 cm^3/g) was observed in the sample containing mucilage extracted from flaxseed steam-treated for 15 min. Additionally, cake samples produced by the addition of mucilage extracted from steam-treated flaxseed had significantly higher specific volumes than that of made with mucilage from flaxseed roasted at 100 °C. A higher specific volume value indicates an airy cake texture [21]. Since the type and amount of fat directly affect cake volume, the potential volume reduction due to reduced fat content was compensated by the addition of mucilage [5, 22]. Gomez et al. [23] determined that the cake volume increased when hydrocolloid was added. This results in agreement with the present study.

Weight loss is directly related to water loss during cake baking. Control cake exhibited a weight loss of 12.90% which slightly increased with addition of untreated flaxseed mucilage ($p>0.05$). Mucilage from flaxseed roasted at 100 °C had a higher weight loss. However, mucilage from flaxseed roasted for 5 min at 130 °C, for 5 and 15 min at 160 °C, and steamed for 5 and 15 min significantly decreased weight loss ($p<0.05$). Texture is an important quality attribute in cakes, significantly influencing consumer preferences [24]. Volume expansion, enzymatic activities, protein coagulation, and partial starch gelatinization in the batter affect textural properties of final product [20]. Firmness of control cake was found as 1647.04 g through texture analysis. Addition of mucilage from untreated flaxseed and the flaxseed roasted at 100 and 130 °C for all treatment times, and 160 °C for 5 min, significantly increased firmness up to 1879.38 g ($p<0.05$). Increases in firmness observed in the cake samples are likely due to higher bake loss. Mucilage from flaxseed roasted at 160 °C for 15 min and from steamed flaxseed significantly reduced cake firmness ($p<0.05$). The lowest firmness value (1270.97 g) was observed in cake sample containing mucilage from flaxseed steamed for 15 min. This is likely due to the significantly higher specific volume of these cake samples. Mucilage from flaxseed roasted at 100 and 130 °C did not influence cake firmness. However, increasing the roasting time at 160 °C significantly decreased firmness compared to cake with mucilage from untreated flaxseed. An increase in cake firmness observed by mucilage addition could be attributed to the increased batter viscosity [25]. Higher temperatures during heat treatment can enhance water permeability into flaxseed during extraction, reducing mucilage viscosity [26]. This may explain the observed lower cake firmness.

Table 3 The specific volume, weight loss and firmness values of cake samples

Sample	Temperature (°C)	Time (°C)	Specific volume (cm^3/g)	Weight loss (%)	Firmness (g)
Control[(1)]			1.85^{e}	12,90^{cd}	1647.04 ^{b}
Untreated	-	-	2.32^{d}	13,85^{c}	1826.72 ^{a}
	100	5	2.31^{d}	14,93^{a}	1890.94 ^{a}
		10	2.35^{cd}	14.93^{a}	1846.13 ^{a}
		15	2.39^{c}	14.71^{a}	1816.02 ^{a}
	130	5	2.34^{cd}	11,43^{e}	1888.27 ^{a}
Roasting		10	2.39^{c}	14,29^{b}	1867.15 ^{a}
		15	2.39^{c}	13,04^{c}	1836.38 ^{a}
	160	5	2.41^{c}	11,43^{e}	1879.38 ^{a}
		10	2.47^{b}	14,29^{b}	1523.62 ^{bc}
		15	2.47^{b}	12,86^{d}	1445.37 ^{c}
	100	5	2.45^{b}	11,43^{e}	1545.57 ^{bc}
Steaming		10	2.49^{b}	12,86^{d}	1357.07 ^{de}
		15	2.52^{a}	11,43^{e}	1270.97 ^{e}

(1) Cake produced without mucilage addition

Color is a critical sensory attribute that directly influences consumer preference for food product, including cakes [27]. Crust color of cake samples are shown in Table 4. Control cake has L*, a*, and b* values of 45.95, 18.54, and 30.36, respectively. Mucilage addition decreased L* values (lightness) of the crust ($p<0.05$), and the lowest was observed in the cake with mucilage from flaxseed roasted at 160 °C. Mucilage from steamed flaxseed resulted in a lighter crust color than that of sample roasted at 100 °C. The a* values (redness) of cake crust were not affected by mucilage addition, except for mucilage from flaxseed roasted at 160 °C, which caused a significant increase ($p<0.05$). The yellowness (b* values) of cake crust significantly decreased with mucilage addition. Absolute color difference (ΔE) was used to analyze the results and a higher ΔE value indicates a greater color difference between two samples. ΔE values of cake with mucilage varied between 3.38 and 5.66, indicating that all color differences observed between the control cake and cakes with mucilage were detectable by human eye. The lowest color difference was observed in the cake with mucilage from untreated flaxseed, while the highest was observed in cake with mucilage from flaxseed treated at high temperature for a long time. Mucilage from roasted flaxseed generally resulted in higher differences compared to that from steamed flaxseed. Heat treatment of flaxseed can lead to mucilage exhibiting a darker color, attributed to the formation of Maillard reaction products [28, 29], which explains darker crust color of cake. Additionally, leaching of impurities such as natural pigments, tannins, coat, tegument, and germ into the aqueous extract may also contribute to color change [28].

Table 4 Color properties of cake samples produced with mucilage from untreated and heat-treated flaxseed

Sample Treatment	Temperature (°C)	Time (°C)	Crust color(2) L*	a*	b*	ΔE
Control(1)			45.95 ^{a}	18.54 ^{b}	30.36 ^{a}	
Untreated	-	-	44.32 ^{b}	18.41 ^{b}	27.40 ^{b}	3.38
Roasting	100	5	43.36 ^{bc}	18.38 ^{b}	26.19 ^{b}	4.91
		10	43.26 ^{bc}	18.42 ^{b}	26.25 ^{b}	4.91
		15	43.18 ^{bc}	18.58 ^{b}	26.39 ^{b}	4.84
	130	5	43.17 ^{bc}	18.43 ^{b}	26.38 ^{b}	4,86
		10	43.03 ^{bc}	18.75 ^{b}	26.41 ^{b}	4.92
		15	43.01 ^{bc}	18.89 ^{b}	26.55 ^{b}	4.83
	160	5	42.98 ^{c}	19.23 ^{a}	26.01 ^{b}	5.31
		10	42.67 ^{c}	19.34 ^{a}	26.17 ^{b}	5.38
		15	42.19 ^{c}	19.68 ^{a}	26.28 ^{b}	5.66
Steaming	100	5	44.52 ^{b}	18.41 ^{b}	26.59 ^{b}	4.04
		10	44.46 ^{b}	18.51 ^{b}	26.78 ^{b}	3.88
		15	44.29 ^{b}	18.61 ^{b}	26.91 ^{b}	3.83

(1) Cake produced without mucilage addition
(2) L*: lightness, a*: redness, b*: yellowness, ΔE: color difference.

Table 5 presents the total dietary fiber (TDF) and *in vitro* glycemic index (GI) of cake samples. TDF content and *in vitro* GI values of control cake were 2.6% and 69.3, respectively. Mucilage addition significantly increased TDF content of cakes, which ranged from 3.1 to 3.5%. Although mucilage from heat-treated flaxseed slightly increased TDF content of cake samples compared to mucilage from untreated flaxseed, these increases were not statistically significant ($p>0.05$). Similar increases have been reported with the incorporation of heat-treated flaxseed in bread [30]. *In vitro* GI value of cake with untreated flaxseed mucilage was 69.3, which significantly decreased down to 55.1 with mucilage addition. Cakes containing mucilage from steamed flaxseed exhibited significantly lower GI values compared to those made with mucilage from untreated and roasted flaxseed. This could be attributed to the higher formation of resistant starch induced by steaming compared to roasting. Flaxseed mucilage has been shown to possess functional properties that can reduce glycemic response [31]. An *in vivo* study found that using flaxseed mucilage as a fiber source in white bread lowered postprandial blood glucose levels [32]. It has been suggested that fiber and protein may act as barriers by coating swollen starch granules, potentially protecting them from enzymatic degradation and thereby influencing glycemic index values [33].

Table 5 Total dietary fiber content and in vitro glycemic index values of cake samples produced with mucilage from untreated and heat-treated flaxseed

Sample Treatment	Temperature (°C)	Time (°C)	TDF (%)(2)	*In vitro GI(3)*
Control(1)			2.6^{b}	69.3^{a}
Untreated	-	-	3.1^{a}	59.2^{b}
Roasting	100	5	3.2^{a}	59.1^{b}
		10	3.3^{a}	59.1^{b}
		15	3.2^{a}	59.2^{b}
	130	5	3.3^{a}	59.7^{b}
		10	3.4^{a}	59.9^{b}
		15	3.4^{a}	60.1^{b}
	160	5	3.4^{a}	60.1^{b}
		10	3.4^{a}	60.5^{b}
		15	3.5^{a}	60.8^{b}
Steaming	100	5	3.4^{a}	56.1^{c}
		10	3.4^{a}	55.4^{c}
		15	3.4^{a}	55.1^{c}

(1) Cake produced without mucilage addition
(2) TDF: total dietary fiber
(3) GI: glycemic index

CONCLUSION

Flaxseed was heat-treated under various conditions, and extracted mucilage was used in cake formulation as partial replacement with shortening. Heat treatment generally increased water-holding capacity and oil-holding capacity of mucilage. Incorporating extracted mucilage at a 50% replacement level increased the specific volume of cake samples. Mucilage addition generally increased firmness values, depending on the treatment conditions. Notably, mucilage from steamed flaxseed resulted in softer cake samples. Crust color was darkened with mucilage addition. The cakes with mucilage had higher fibre content and a lower glycemic index. Despite consumers' negative assessment of color change, observed increases in specific volume and fiber content, along with lower glycemic index, have potential to compensate. In conclusion, mucilage from heat-treated flaxseed offers a promising approach for use in low-fat cake formulations with good baking quality.

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