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Research Article

Effect of Chia Seed as Egg Replacer on Quality, Nutritional Value, and Sensory Acceptability of Sponge Cake

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This study aimed to make a cake by incorporating chia seed flour (CSF) at 0, 3, 5, and 7% with egg replacement at 0, 25, 50, and 100%, respectively. The addition of CSF increased the total proteins, fats, and mineral contents. However, cake volume, uniformity, and symmetry were lowered significantly ($p > 0.05$) at an elevated level (5% and 7%) of CSF. Similarly, the cake depicted relatively higher textural hardness, springiness, cohesiveness, and chewiness upon addition of CSF. The higher substitution of CSF resulted in darker crust and crumb with lower sensory acceptability by the panelists, though the 3% CSF addition did not compromise the cake acceptance. Nonetheless, there were a significant rise in total phenolics and better antioxidant activity with CSF, measured as free radical scavenging activity. Most importantly, a massive rise in unsaturated fatty acids (ω-3, ω-6) and the simultaneous decline in total cholesterol were detected with increasing substitution of CSF.

1. Introduction

The ever-growing population and many diet-related ailments are challenging the food industry to focus on more healthy food products. Cardiovascular diseases, diabetes, obesity, and colon cancer are among the prevalent diet-related diseases, in conjunction with the sedentary lifestyle. There is valid epidemiological evidence that the diet rich in healthy fats (ω-3) and dietary fibers but with low levels of cholesterol, saturated fats, and transfats could significantly promote human health and vitality [1, 2]. Moreover, the higher intake of whole grains, seeds, fruits, and vegetables with a good number of prebiotics leads to harnessing the low-density lipoproteins in blood and lessening the prevalence of cardiovascular issues [3]. Thus, concerning the foods with special features that enhance vigor and immunity, there has been a growing interest in developing so-called "functional foods" [4]. A functional food, upon consumption, other than satisfying the basic body nutrients needs, either imparts physiological advantages or minimizes the chances of chronic ailments [2, 4].

Bakery products such as bread, cake, cracker, and cookies are delightful, ready-to-eat staples and snacks in many parts of the globe. The cake is one of the most deliciously relished bakery products because of the diverse recipes and cultural preferences. Technically, the cake is a semidry foam food developed by the air bubbles entrapped in the protein and starch matrix. The foam structure and tenderness are majorly contributed by the added egg proteins and fats [5]. Fats could be as high as 15 to 20 g per 100 g of cake, such as in pound cake. The added fat and emulsifiers impart tenderness, higher volume, and fluffy texture to the cake, while the egg proteins hold fine gas bubbles during baking and originate a softer and finer crumb [6].

Additionally, the delayed retrogradation of starch by amylose-lipids complexation further enhances the tenderness, moistness, and flavor, extending the cake's shelf life [7].

However, the consumer preference for a vegan diet and the risk of egg consumption, such as allergy and high cholesterol content, urges egg replacement in foods [8]. The increased amount of cholesterol (~1.08 g/100 g) in egg yolk has vastly been correlated with the amplified occurrence of cardiovascular diseases [8]. Similarly, the lecithin (~250 mg) in the yolk, which metabolizes to trimethylamine by the intestinal flora and is further oxidized by the liver, is considered a proatherosclerotic factor [9]. Although the limits of dietary cholesterol intake have been removed in Dietary Guidelines in the USA, cholesterol consumption is not recommended to people with a history of cardiovascular ailments [10]. Thus, egg substitution with plant or animal proteins and replacement of fats with healthy fats (rich in ω-3) have been preferred [4].

Salvia hispanica L. (chia) seed is one of the nutritionally rich grains blessed with a substantial amount of polyunsaturated fats and essential amino acids. The seed oil contains almost 65% α-linolenic acid (18 : 3, ω-3) and 22% linoleic acid (18 : 2, ω-6) with a very low percentage of saturated fatty acids [11]. The lower ω-6 to ω-3 ratio in chia seed oil helps in attaining the crucial ratio between 9 : 1 and 5 : 1 to control the metabolic and chronic diseases [12], as recommended by the European Food Safety Authority (EFSA) and by the World Health Organization/Food and Agriculture Organization (WHO/FAO) expert panel [13, 14]. Similarly, based on the cultivar and growth conditions, chia seed may reach up to 27% of proteins, roughly 2 to 5 times higher than the conventional staples, such as rice (6%) and wheat (9.5%). Contrary to the regular staples deficient in lysine, the chia seed proteins possess a complete profile of essential amino acids, including valine, leucine, isoleucine, and lysine, imparting a nutritionally better score [15]. Besides, the seed has a high amount of soluble fibers covering the chia seed coat and ranging from 20 to 40%, higher than many legumes and cereals [16, 17]. The chia mucilage possesses functional impacts, such as lowering cholesterol delaying starch's digestion, thus preventing postprandial glycemia [18]. In baked products, the chia mucilage hinders the starch gelatinization depressing the starch hydrolysis by amylases, consequently lowering the glycemic index [18, 19]. Moreover, phenolic-rich fractions (quercetin and kaempferol) and minor percentages of chlorogenic acid and caffeic acid impart antioxidative and antihypertensive properties to chia seed [20, 21]. Furthermore, some minerals like iron, zinc, and calcium are also found in the seed to satisfy the daily recommended intakes upon consumption [15].

Chia seed has widely been accepted for different food applications, including breakfast cereals, bread, cookies, snacks, bars, fruit juices, and yogurt [22, 23]. Previously, as a soluble gel, the chia mucilage was incorporated in the pound cake, and almost 25% fat reduction was made without any major change in the cake quality [5]. The addition of chia flour in bread, as a wheat replacement up to 6%, was better accepted by the consumers and depicted enhanced shelf stability by inhibiting the starch retrogradation under storage [24]. Similarly, nutrients' concentration improved when raw chia flour was composited in wheat bread. Additionally, a significant increase in linoleic acid was found in bread with a relatively lower glycemic index than the control [25].

Thus, the objective of the current study was to replace egg by whole chia seed flour (CSF) in cake to augment the nutritional and functional properties of the final product. The textural and sensory studies were made to rank the cake acceptability by the consumers. Moreover, the fatty acid profile and cholesterol contents were also estimated to evaluate the relative improvement in essential fatty acids of cake.

2. Material and Methods

2.1. Material. The chia seed and other ingredients of the cake formulation were procured from a local supermarket (Riyadh, Saudi Arabia). The chia seed flour (CSF) was obtained by grinding in a kitchen coffee grinder and deposited in an airtight glass container at 4°C for further use.

2.2. Methods

2.2.1. Cake Preparation. Table 1 presents the formulation of cake. Chia seed flour (CSF) was introduced into the formulation as 3, 5, and 7% based on wheat flour by replacing 25, 50, and 100% of egg proportion, respectively. Ingredients other than flour and water were blended in a cake mixer (KitchenAid, General Electric, USA) for 2 min at speed #6 corresponding to 180 rpm. The chia seed flour (CSF)/wheat flour was introduced after the creaming process and unified for 3 min at a higher speed #8 corresponding to 225 rpm. For cake baking, almost 360 g of prepared batter was dispensed into a circular pan and baked in a preheated oven (Super Systems Inc., USA) for 25 min at 180°C. Before the further analyses, that is, physicochemical and organoleptic evaluation, the cake was permitted to cool for 1 h at ambient temperature and then packed into polypropylene bags. Cakes that had 3, 5, and 7% of chia seed flour (CSF) added with the corresponding egg replacement (25, 50, and 100%) were labeled as CSF3, CSF5, and CSF7. However, without chia seed flour, the control cake was labeled as CSF0.

2.2.2. Batter Density. The prepared batter density (g/cm^3) was estimated as the ratio of the weight of a 50 mL standard graduated cylinder filled with batter to the distilled water filled in the same at room temperature.

2.2.3. Proximate Analysis of Cake

(1) Moisture Content. The moisture percentage of cake was estimated according to the standard method #44-15A (AACC, 2000). In this method, a 10 g sample was heat-dried

Table 1: Cake formulation prepared by adding different levels of chia seed flour (CSF).

Ingredients	Control (CSF0)	CSF3 (25%*)	CSF5 (50%**)	CSF7 (100%**)
Flour (g)	100	100	100	100
Sugar (g)	110	110	110	110
Shortening (g)	50	50	50	50
Milk (g)	14	14	14	28
Baking powder (g)	8	8	8	8
Salt (g)	1.6	1.6	1.6	1.6
Flavor (g)	1	1	1	1
Egg (g)	50	37.5	25	0
Chia seed flour (g)	0	3	5	7
Water	WA*	WA	WA	WA

*WA: water absorption of cake mixes; 25, 50, and 100% are egg replacement percentages.

overnight in a forced draft oven at a temperature of 105 ± 5°C. The loss in weight of the cake was calculated by the given formula and expressed as a percentage of moisture:

$$\text{Moisture}\,(\%) = \frac{\text{Weight of sample before drying} - \text{Weight of the sample after drying}}{\text{Weight of sample before drying}} \times 100. \quad (1)$$

(2) Total Ash. A standard AACC method (#08-01, 2000) was adopted to estimate the ash content of the cake. In this method, 5 g of sample was weighed in a tared porcelain crucible and incinerated at 550°C in a muffle furnace for 5 h till a greyish residue remained. The ash calculation was made through the following formula:

$$\text{Ash}\,(\%) = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100. \quad (2)$$

(3) Crude Protein. Kjeldahl method [26] was adopted to estimate the crude protein in the cake. Roughly, a 2 g sample was digested for 3-4 h in a digestion tube by adding 20 mL of 98% sulfuric acid and digestion tablets for efficient digestion until the digestion mixture became transparent. The mixture was diluted to 50 mL of total volume. Later, alkali solution (40% NaOH) was poured through distillation into the mix that turned the ammonium sulfate into gaseous ammonia, which was collected in a flask having boric acid (4%). This solution was titrated against 0.1 N sulfuric acid using methyl red as an indicator. To calculate the crude protein, the nitrogen (%) was multiplied with a factor of 6.25.

$$\text{Nitrogen}\,(\%) = \frac{\text{Vol. of}H_2SO_4 \times 0.1 \times 0.014}{\text{Weight of sample}} \times 100. \quad (3)$$

(4) Crude Fat. In estimating crude fat, the standard method [26] was followed. Soxhlet apparatus containing 2 g of cake sample was added with petroleum ether, and fat was extracted for 2 to 3 h. Percentage of crude fat was calculated as follows:

$$\text{Crude fat}\,(\%) = \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100. \quad (4)$$

(5) Total Carbohydrates. To estimate total carbohydrates, a subtraction method was adopted as follows:

$$\text{Total carbohydrates}\,(\%) = 100 - (\text{Protein\%} + \text{fat\%} + \text{moisture\%} + \text{ash\%}). \quad (5)$$

2.2.4. Determination of Cake Quality. Cake-specific volume was estimated upon cooling by dividing its volume by weight. Cake weight in grams (g) was measured without the baking pan just after baking, while the volume (cm^3) was estimated using the rapeseed displacement method upon cooling to room temperature. The cake sample was measured for volume index according to AACCI [27] method #10–91. For that, the cake was vertically sliced at the center, and the height was measured from three points (B, C, D) using a template alongside the cross section. "C" indicates the height at the center of the cake, while "B" and "D" denote the heights at 2.5 cm distance towards left and right from the center. Using these measurements, the cake uniformity and symmetry were estimated by the following equations:

$$\text{Symmetry} = 2 \times C - (B + D),$$
$$\text{Uniformity} = B - D. \quad (6)$$

2.2.5. Water Activity (a_w). Water activity (a_w) of cake crumb was measured at ambient temperature using a water activity meter (Aqua Lab, CX-2, Decagon Devices Inc., USA).

2.2.6. Cake Color. Cake crust and crumb color were estimated in terms of "CIE L^*, a^*, b^*" parameters at room temperature through a color grader (Stake, NCGA, Japan) equipped with a D65 light source. L^* denotes lightness and a^* indicates redness, while yellowness is represented by b^*.

2.2.7. Texture Profile Analysis of Cake. Cake texture profile analysis (TPA) was conducted through a TA-XT Plus texture analyzer (Stable Micro Systems, Ltd., Surrey, UK). Cake crumb ($2\,cm^3$) from the center was selected to measure texture using a cylindrical probe (3.6 cm diameter) at a crosshead speed and compression of $1.0\,mm{\cdot}s^{-1}$ and 50%, respectively. A typical 2-cycle compression test was set with 5 g compressing force and $2.0\,mm{\cdot}s^{-1}$ of pretest and posttest speed. The compression curve of cake was evaluated using a built-in software (Texture Expert® 1.05), and the average texture was interpreted as hardness, springiness, cohesiveness, chewiness, and resilience.

2.2.8. Determination of Total Phenols and Radical Scavenging Activity. The cake sample (1 g) was extracted in ethanol (25 mL) in a shaker for 24 h and then centrifuged for 15 min at 10,000 rpm. The mixture was filtered using filter paper (Whatman #41), and transparent supernatant was separated. The volume of the collected supernatant was readjusted to 25 mL and kept at 4°C for estimation of phenolics and radical scavenging activity. The cake extract was estimated for total phenolic contents following [28]. A gallic acid standard curve was prepared for comparison, and results were presented as equivalents of gallic acid per unit weight (g) of cake. However, for radical scavenging activity, the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method was adopted [29].

2.2.9. Fatty Acid Profile. The extracted crude fat was esterified and converted to fatty acid methyl esters (FAME), according to [30]. Esters of fatty acids were further subjected to analysis by capillary gas chromatography (Shimadzu, Kyoto, Japan) attached with a capillary column of a dimension of 100 m × 0.25 mm (HP-88, J & W Scientific, USA) and a flame ionization detector (FID). The temperature program for detection was started with an initial temperature of 125°C and reached 175°C at $10°C{\cdot}min^{-1}$, held for 10 min, and raised to 210°C (@ $5°C{\cdot}min^{-1}$) with holding of 5 min and increased till reaching a final temperature of 230°C (@ $2°C{\cdot}min^{-1}$). The temperature for the injector and detector was maintained at 250°C and 280°C, respectively. Nitrogen was used as carrier gas at a flow rate of $1.33\,mL{\cdot}min^{-1}$. The identification of fatty acid was made by retention time and comparison with the standards (Supelco, Bellefonte, USA).

2.2.10. Cholesterol Content. Cholesterol was determined through high-performance liquid chromatography (HPLC), according to the method given by Maraschiello et al. [31]. One gram of sample was homogenized with 2 mL (0.5 M) potassium hydroxide in methanol. Direct saponification was conducted for 1 h at 80°C and 2 mL distilled water was added, saturated with sodium chloride (NaCl), and vortexed. The mixture was centrifuged at 300 g for 10 min after adding 3 mL of hexane/diethyl ether (1 : 1 ratio). The upper portion of the mixture was separated and extracted twice with hexane/ether and dried under a nitrogen stream. The dried extract was reconstituted with 1 mL of isopropanol-acetonitrile (20 : 80, v/v) and filtered before injection. A $10\,\mu L$ sample was injected at ambient temperature in a chromatograph with a C18 column (150 mm × 3.0 mm, Phenomenex Luna) and equipped with a photodiode array detector (Waters 2695, USA). A mixture of acetonitrile-isopropanol (80 : 20 v/v) was used as a mobile phase with an isocratic flow rate of $1.2\,mL{\cdot}min^{-1}$ and detected at 210 nm. External standards (25 mg to 125 mg/100 g) were prepared to quantify the concentration of cholesterol using Empower® Pro Software.

2.2.11. Sensory Evaluation. Sensory evaluation of cake was conducted using a 9-point hedonic scale by 16 semitrained panelists. In the 9-point hedonic scale, 1 indicates "dislike extremely," while 9 stands for "liked extremely." The cake preference was ranked from 1 to 9 based on the color of crust and crumb, tenderness, flavor, feeling after taste, mouth-feel, and overall acceptability. To avoid biased results, all the cake samples with or without chia seed flour (CSF) were presented in a random order to the panelists.

2.3. Statistical Analysis. All the measurements were made in triplicate and averaged. A one-way analysis of variance (ANOVA) was adopted to analyze the obtained data to estimate the significance (at $p \leq 0.05$) of chia seed concentration on cake quality. To compare means, Duncan's multiple range (DMR) test was conducted by using PASW® 18 software.

3. Results and Discussion

3.1. Proximate Analysis. The proximate composition of the cake with and without chia seed flour is presented in Table 2. Moisture indicates food quality and a highly sought sensory characteristic for soft and fluffy bakery products like cake and sweetbreads. The addition of the chia seed flour (CSF) to replace the egg increased the moisture percentage of the cake. The increased moisture with greater incorporation of the CSF could be due to the higher water retention contributed by the soluble mucilage in the seed. The cake's most elevated moisture percentage was seen with the 7% chia seed substitution (CSF7).

Similarly, the samples that had chia added also depicted an increasing crude fat level. However, 5% and 7% addition of chia provided significant ($p < 0.5$) changes in the fat contents of cakes. The highest crude fat of 21.06% was noticed for the samples with a 7% addition of CSF. This rise in fat might be attributed to the more elevated total lipids of the chia seed flour.

Conversely, Felisberto et al. [5] reported a reduction in fat contents in pond cake when chia mucilage was added to replace fat, and this was similarly noticed in the case of moisture. An uplift in protein content of chia-containing

Table 2: Proximate analysis of cake that had chia seed flour added (CSF).

Sample	Moisture (%)	Crude fat (%)	Crude protein (%)	Ash (%)	Carbohydrates (%)
CSF0	21.44 ± 0.37^a	17.22 ± 0.09^c	4.21 ± 0.72^b	2.51 ± 0.98^b	54.63 ± 1.92^a
CSF3	21.57 ± 0.72^a	18.40 ± 0.13^{ab}	4.55 ± 0.59^b	3.45 ± 0.72^{ab}	52.03 ± 1.23^a
CSF5	23.92 ± 0.59^a	19.39 ± 0.66^b	4.93 ± 0.43^b	3.91 ± 0.49^{ab}	47.81 ± 1.68^{ab}
CSF7	24.38 ± 0.79^a	21.06 ± 0.27^a	7.23 ± 0.33^a	4.31 ± 0.58^a	43.02 ± 1.18^b

Values are presented as mean ± standard deviation. [a,b]Means followed by different uppercase letters in the same column are significantly different ($p < 0.05$).

cake was noticed, though the only significant change was observed for the cake with the highest chia seed (CSF7). However, the sample with lower addition of chia seed flour, that is, 3% and 5%, could not depict a major change in the total proteins (Table 2). It is worth mentioning that the samples were not only lowered in egg percentage but also a simultaneous replacement was made with chia seed flour (CSF) that might have balanced the crude proteins to a somewhat similar concentration, especially at a lower level of chia seed addition (3 and 5%). However, Borneo et al. [32] reported a significant reduction in proteins in cake that had chia gel added while replacing egg. In the case of ash, a higher concentration of minerals in CSF might be the reason for higher ash contents in the cake. The sample with 7% chia seed (CSF7) depicted the highest ash content (4.31%), which was almost 2 times higher than the control sample without chia seed flour (CSF0). The higher concentrations of crude fat and proteins in chia seed flour directly impacted the reduction of total carbohydrates in the samples, as the control presented the highest carbohydrates. Coelho and Salas-Mellado [33] also documented increased moisture, ash, fat, and proteins in the bread with chia seeds.

3.2. Batter Density. Batter density indicates the successful air incorporation in the cake crumb structure and the cake volume upon baking. The presence of proteins and fats other than natural or added emulsifiers impacts the batter density. The batter density was significantly ($p < 0.05$) increased with the addition of 3 and 5% of chia seed flour that was lowered a bit by further addition of chia seed flour (7%), though it remained higher than the control sample where no chia was added and no egg was replaced (Table 3). The increased density of the batter could be correlated to the lowering of egg proteins, that is, the lecithoproteins of egg yolk and albumins of egg white [10]. The lighter and most aerated sample was the control sample (CSF0), having a full proportion of egg proteins that might have imparted a better foaming ability to the batter. In a previous study, the addition of chia seed in the eggless cake as an egg replacer increased the batter density of the composite cake prepared from wheat, amaranth, malted finger millet, and sprouted soy [34].

3.3. Cake Quality. The quality of the cake was evaluated in terms of weight, volume, specific volume, uniformity, and symmetry, and the data is presented in Table 4. The sample without chia seed flour (CSF0) presented the highest weight among the cakes with chia seed flour. Similarly, the highest volume of the cake was noticed for the control (CSF0)

Table 3: Effect of replacing egg by chia seed flour (CSF) on batter density.

Sample	Batter density (g/cm^3)
CSF0	1.11 ± 0.02^c
CSF3	1.23 ± 0.03^a
CSF5	1.23 ± 0.02^a
CSF7	1.17 ± 0.02^b

Values are presented as mean ± standard deviation; means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

without chia seed flour addition. The uniform air incorporation during batter preparation and better holding of gas bubbles during baking by the egg proteins might have resulted in a higher cake volume. This result of cake volume could be correlated with the batter density data suggesting an inverse relation between cake volume and batter density. However, the addition of chia seed along with the replacement of egg showed a significant ($p < 0.05$) reduction in the cake volume and provided denser cake crumbs (Figure 1). Agrahar-Murugkar et al. [34] observed that the addition of chia seed in the eggless cake as an egg replacer reduced the volume of the composite cake prepared from wheat, amaranth, malted finger millet, and sprouted soy. Similarly, a significant reduction in cake volume was observed when 25 and 50% chia seed gel was added as an egg replacer [32].

In the case of specific volume, a somewhat similar reduction of the specific volume was noticed following the volume data, as the specific volume is derived from the ratio of the cake volume to the weight. Cake uniformity is another interesting quality parameter representing the evenness of baking and the gas holding capacity of the batter. The most uniform cake was seen with a 3% addition of chia seed flour (CSF3), where a 25% reduction of the egg proteins was made. The chia seed mucilage and proteins' oil and water holding capacities might have resulted in an optimum evenness of cake during baking. However, further addition of chia seed (5 or 7%) and egg replacement (50% and 100%) could not retain the uniformity of the cake and presented a nonuniform and rougher crumb (Table 4).

Cake symmetry is another parameter dictating the quality and acceptability of cake. In line with uniformity data, the sample with 3% chia seed flour (CSF3) along with 25% egg replacement presented the best symmetry of the cake. The least symmetric samples were with the highest concentration of chia seed (CSF7%) with 100% egg replacement. These results could be interpreted and correlated directly with the absence of egg proteins that might have damaged the cake symmetry. The chia seed proteins

Table 4: Effect of replacing egg by chia seed flour (CSF) on cake quality parameters and water activity of cake.

Sample	Weight (g)	Volume (cm^3)	Specific volume (cm^3/g)	Uniformity (mm)	Symmetry (mm)	Water activity
CSF0	354.93 ± 1.66^{a}	872.33 ± 3.80^{a}	2.46 ± 0.03^{a}	1.00 ± 0.01^{b}	5.00 ± 1.60^{b}	0.85 ± 0.01^{b}
CSF3	339.06 ± 1.70^{b}	759.00 ± 5.18^{b}	2.29 ± 0.07^{ab}	0.00 ± 0.01^{c}	3.33 ± 1.70^{c}	0.86 ± 0.01^{b}
CSF5	315.10 ± 1.31^{c}	723.33 ± 6.76^{c}	2.21 ± 0.05^{ab}	2.00 ± 0.01^{a}	5.33 ± 1.10^{b}	0.88 ± 0.00^{a}
CSF7	344.58 ± 1.61^{b}	695.00 ± 5.23^{d}	2.00 ± 0.01^{c}	2.00 ± 0.00^{a}	10.00 ± 1.76^{a}	0.88 ± 0.01^{a}

Values are presented as mean ± standard deviation. Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

Figure 1: Photograph of cakes. (a) CSF0. (b) CSF3. (c) CSF5. (d) CSF7.

and mucilage might not interact well. They could not hold the air bubbles as efficiently as egg proteins, thus resulting in poor cake quality, especially at elevated levels of CSF (i.e., 5 and 7%). Borneo et al. [32] also reported a negative impact of chia seed gels on the symmetry of the cake when 75% replacement of egg was made. The water activity (a_w) is crucial in estimating the shelf life of bakery products. The a_w data showed the highest value for the sample with the highest chia seeds (CSF7). A higher water holding capacity of chia seed flour might have contributed to greater a_w of the cake. The a_w result supports the higher moisture of the cake samples.

3.4. Texture Profile Analysis of Cake. Instrumental cake texture measurements were made in hardness, cohesiveness, springiness, chewiness, and resilience. The samples showed a dose-dependent increase in the hardness for adding chia seed (Table 5). The highest hardness was noticed for the sample with maximum replacement of chia seed flour (CSF7) with 100% egg replacement. The dense batter with the addition of 7% chia seed flour might be the possible cause of the highest firmness of the cake. The control sample without chia seed flour (CSF0) with egg proteins in the formulation retained the best volume and remained the most tender with the least hardness (104.7 g). A greater bread firmness was also reported when chia seeds were added [33].

In the case of cohesiveness, the chia seed flour addition and egg replacement provided a relatively cohesive crumb as compared to the control (CSF0). The cohesion indicates the intermolecular bonding that holds the structure of the cake crumb. The higher water-holding and relatively dense batter in the presence of CSF might have resulted in a more cohesive foam structure at the end of baking. The cake with 5% chia seed flour (CSF5) along with 50% replacement of egg provided the most cohesiveness value. Contrarily, the cake without adding chia seed flour (CSF0) but with 100% egg depicted the least cohesive crumb texture.

Similarly, CSF and partial egg replacement provided relatively higher springiness than the control without chia. The highest springiness of 9.23 g was depicted by the cake having the highest level of chia addition with no egg (CSF7). The presence of higher chia seed flour might have resulted in thicker walls of air bubbles in the cake crumb and resulted in higher springiness. In the case of chewiness, the highest chewiness value was recorded for the cake with the 5% chia seed flour (CSF5) addition with a 50% reduction in egg amount. An optimum combination of the chia seed mucilage with egg proteins might have resulted in a chewy cake crumb texture. The chewiness of the cake with 7% chia was still higher than control, yet it was lower than the samples with 3 and 5% chia seed. The control cake without chia seed flour showed the most increased resilience.

However, not much variation was observed in the cake resilience when CSF was added at 3 and 5%. The least resilient cake was the one having 7% chia seed flour (CSF7) with total replacement of egg, though the change was statistically insignificant ($p > 0.05$). The addition of chia seed might have manipulated the crumb structure negatively and resulted in reduced resilience of the cake. Agrahar-Murugkar et al. [34] reported chia seed's addition in the eggless composite cake (wheat, amaranth, malted finger millet, and sprouted soy) as egg replacer lowered the firmness, springiness, cohesiveness, chewiness, and resilience.

Table 5: Effect of replacing egg by chia seed flour (CSF) on texture profile parameters of cake.

Sample	Hardness (g)	Cohesiveness	Springiness (mm)	Chewiness (g)	Resilience
CSF0	104.7 ± 1.42^{d}	0.32 ± 0.00^{c}	6.60 ± 0.3^{d}	224.01 ± 2.39^{d}	1.56 ± 0.17^{a}
CSF3	123.7 ± 1.15^{c}	0.45 ± 0.00^{b}	7.40 ± 0.01^{c}	408.98 ± 1.23^{c}	1.38 ± 0.33^{b}
CSF5	158.3 ± 1.08^{b}	0.52 ± 0.001^{a}	7.90 ± 0.54^{b}	650.89 ± 4.20^{a}	1.34 ± 0.45^{b}
CSF7	163.3 ± 1.51^{a}	0.42 ± 0.00^{b}	9.23 ± 0.12^{a}	629.32 ± 3.47^{b}	1.04 ± 0.14^{bc}

Values are presented as mean ± standard deviation. Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

3.5. Cake Color. Color is the first and foremost parameter that appeals to customers and urges them to buy the cake. The cake color data was measured in terms of L^* (lightness), a^* (greenness), and b^* (yellowness). In the case of crust color, a significant ($p < 0.05$) reduction in cake lightness was noticed with increasing the CSF level from 0 to 7% (Table 6). The carotenoids and chlorophyll in the chia seed coat [22] might have rendered the cake color relatively darker than the control (CSF0). Moreover, the enhanced production of Maillard reaction products due to higher proteins in the cake batter might have enhanced the darkness of the cake crust. However, no significant change in the greenness (a^*) of the cake was noticed with increased CSF incorporation, except the cake with 7% chia seed flour (CSF7), where the least greenness was noticed. Increased yellowness was noticed (a higher b^* value) with increasing the CSF concentration, whereas the most reddish tinge was observed for the sample incorporated with chia seed flour at 7% (CSF7).

On the other hand, the lightest (L^*) crumb was noticed for the control sample (CSF0) where no chia seed flour was added in the formulation. The highest level of chia seed addition (7%) resulted in darker crumbs might be due to the presence of carotenoids from the chia seed coat. The crumb showed more greenness (a^*) with the presence of chia seed than the control (CSF0), which again could be correlated with the pigmentation of the chia seeds. While crumb yellowness (b^*) was reduced with increasing the chia seed level, it remained statistically similar to the control (CSF0) at the highest chia seed addition (7%). Coelho and Salas-Mellado [33] prepared functional bread with chia flour and chia seed and reported a lighter crust and a darker crumb.

3.6. Sensory Evaluation. Sensory evaluation of cakes with and without chia seed flour (CSF) was estimated in terms of appearance as crust and crumb color, flavor, mouthfeel, tenderness, feeling after taste, and overall acceptability (Figure 2). The cake crust color was preferred when no chia seed (CSF0) was added and egg solids were replaced. The addition of CSF in the cake resulted in lower organoleptic scoring for the crust color. Similarly, the panelists ranked the control sample (CSF0) highly acceptable for the crumb color, while the sample with 7% addition of chia seed (CSF7) was ranked the least preferred one. In the case of flavor, a comparable preference was noticed for the control and sample with 3% addition of chia seed (CSF3), and both remained equally flavoring. The most disliked sample was the 7% chia seed (CSF7). The presence of higher chia seed together with low egg proteins might have rendered the cake bland in flavor, as fewer aromatic compounds might have been produced during baking and could not match the expectation of the panelists. Following the flavor pattern, the most preferred feeling after taste was noticed for the control cake (CSF0) and cake with 3% chia seed flour (CSF3). However, the feeling after taste for CSF5 and CSF7 was detected the same by the panelists. The mouthfeel scores for the cake with chia followed the pattern CSF0 > CSF3~CSF5 > CSF7%. On the other hand, the cake tenderness remained the same for CSF0 and CSF3, which further lowered by increasing the chia seed flour concentration (5 or 7%). The sensory data support the subjective hardness of the cake measured in the texture analysis. Borneo et al. [32] reported a lower sensory preference for the color and taste of the cakes when chia gel was added for replacing egg. For the overall acceptability, the panelists disliked the cake with the elevated amount of chia seed flour, while the cake with 3% chia seed (CSF3) remained equally acceptable as control (CSF0). Silva et al. [35] reported an intermediate preference and acceptability of cheese bread when chia seed (5 and 7.5%) was incorporated.

3.7. Total Phenolics and Antioxidant Activity. Phenolics are bioactive compounds attributed with diverse functionality and are believed to improve consumers' health. The addition of CSF (from 0 to 7%) significantly enhanced the total phenolic content (TPC) of the cake (Table 7). The chia seed addition brought about 15.1, 23.5, and 54.2% improvement in the TPC for CSF3, CSF5, and CSF7, respectively, compared to the control (CSF0). This improvement in total phenolics could be correlated with the high polyphenols and isoflavones in chia seeds [15]. Thus, chia seed could be a favorable additive in enhancing the functionality of cake.

Similarly, the free radical scavenging activity of the cake extracts with chia seed flour was estimated, and the results are shown in Table 7. The DPPH assay was conducted to evaluate free radical scavenging to evaluate the extent of antioxidant activity. The cake containing CSF depicted an enhanced inhibition of DPPH radical. The control (CSF0) showed the least DPPH scavenging activity, while cake with 7% chia seed (CSF7) provided the best inhibition of DPPH (29.3%). The chia seed phenolics (hydroxycinnamic acid, caffeic acid, and rosmarinic acid) and other bioactives might have imparted a better antioxidant activity to the cake [15, 36]. This also suggested that fair amounts of polyphenols and bioactives from the chia seed remained stable during the baking process and imparted antioxidative properties to the cake. In line with our results, Romankiewicz et al. [37] also reported an improved TPC and radical scavenging activity for the bread incorporated with chia seed.

Table 6: Effect of replacing egg by chia seed flour on color characteristics of cake.

Sample	Crust color			Crumb color		
	L^*	a^*	b^*	L^*	a^*	b^*
CSF0	64.06 ± 1.27^{a}	12.80 ± 0.57^{a}	26.48 ± 1.24^{b}	50.79 ± 1.91^{a}	-3.29 ± 0.38^{a}	25.96 ± 1.88^{a}
CSF3	64.72 ± 1.02^{a}	12.43 ± 0.29^{a}	25.51 ± 2.33^{b}	37.84 ± 1.33^{b}	-4.20 ± 0.23^{b}	21.69 ± 1.84^{b}
CSF5	61.45 ± 2.08^{a}	12.41 ± 0.23^{a}	28.20 ± 1.13^{b}	39.67 ± 1.13^{b}	-5.00 ± 0.82^{c}	20.85 ± 0.76^{b}
CSF7	55.49 ± 1.91^{b}	8.84 ± 1.14^{b}	37.09 ± 1.19^{a}	39.26 ± 1.24^{b}	-7.16 ± 0.52^{d}	23.25 ± 0.59^{ab}

Values are presented as mean ± standard deviation. Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

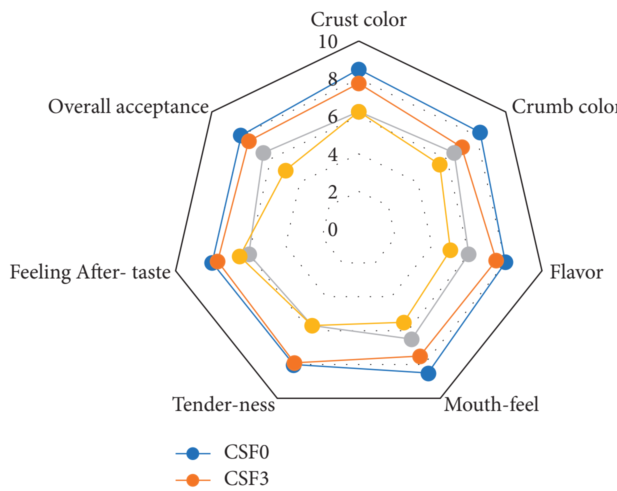

Figure 2: Sensory profile of cake with chia seed flour.

Table 7: Total phenolic content (TPC) and antioxidant activity of cake.

Sample	Value	
Total phenolic content (TPC)	Total phenolic content (mg GAE/100 g)	DPPH (inhibition %)
CSF0	0.140 ± 0.02^{d}	14.97 ± 0.02^{d}
CSF3	0.165 ± 0.01^{c}	22.39 ± 0.06^{c}
CSF5	0.183 ± 0.01^{b}	26.18 ± 0.01^{b}
CSF7	0.306 ± 0.03^{a}	29.28 ± 0.07^{a}

Values are presented as mean ± standard deviation. Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

3.8. Fatty Acid Profile and Cholesterol Content of the Cake. The amount and type of fatty acids have a significant impact on the sensory and nutritional quality of cake. For instance, short chain fatty acids generally boost the aroma of the cake, while the presence of unsaturated fatty acids is strongly correlated with healthy nutritional profile of the cake. Thus, the fatty acid profile and cholesterol content of the cake were estimated upon addition of chia seed. Greater variations in the fatty acids, that is, saturated and unsaturated fractions, was noticed with the addition of CSF in cake (Table 8).

In case of saturated fatty acids (SFA), lauric acid (C12:0) and arachidic acid (C20:0) reduced at higher level of CSF addition in cake. Contrarily, concentrations of stearic acid (C18:0) and palmitic acid (C16:0) increased, where the greatest amount of stearic acid was noticed in CSF7. For the monounsaturated fatty acids (MUFA), oleic acid (C18:1) peaked in relation with the subsequent increase in the chia seed addition from 3 to 7%. Another monounsaturated fatty acid found in cake was the elaidic acid (C18:1t), a *trans* isomer of oleic acid. A massive reduction in elaidic acid (C18:1t) was noticed in the cake at elevated level of chia seed flour (CSF5 and CSF7). In the case of polyunsaturated fatty acids (PUFA), only three fatty acids were majorly detected, namely, linoleic acid (C18:2), conjugated linoleic acid (C18:2 conj.), and α-linolenic acid (C18:3).

Thus, among the saturated fatty acids (SFA), stearic acid (C18:0) remained the highest followed by the palmitic acid (C16:0) in cakes incorporated with chia seed (CSF3-CSF7). In the case of unsaturated fatty acids, linoleic acid (C18:2, ω-6), polyunsaturated, was found in the highest concentration with a similar amount of conjugated linoleic acid (C18:2 conj.) followed by the α-linolenic acid (C18:3, ω-3). It is worth mentioning that, compared to the control (CSF0), the cake with chia seed presented an enhanced amount of essential fatty acids such as ω-3 and ω-6 (except the linoleic acid), whose concentration soared up with increasing amount of chia seed.

Generally, the polyunsaturated fats oxidize in the presence of heat during cake baking (180°C); however, higher concentrations of unsaturated fatty acids (linolenic

Table 8: Fatty acid profile and cholesterol content of cake.

Fatty acid (%)	Control (CSF0)	CSF3	CSF5	CSF7
C12:0 (lauric acid)	3.75	—	—	—
C16:0 (palmitic acid)	17.1	18.38	18.76	—
C18:0 (stearic acid)	0.05	8.51	8.03	19.4
C20:0 (arachidic acid)	1.36	0.43	0.4	—
C22:0 (behenic acid)	—	—	—	—
C18:1 9-*cis* (oleic acid)	0.26	1.25	20.92	20.84
C18:1 9-*trans* (elaidic acid)	36.91	21.87	—	8.55
C18:3 (α-linolenic acid)	—	5.4	6.59	6.49
C18:2 9-*cis*,11-*trans* (conjugated linoleic acid)	—	0.13	43.63	42.63
C18:2 9-,12-*cis* (linoleic acid)	—	42.02	—	—
Unknown*	40.57	2.07	1.67	2.09

Unknown shows undetected fraction of fatty acids; values are presented as mean ± standard deviation. Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

Table 9: Total cholesterol contents of cakes with chia seed flour (CSF).

Sample Total cholesterol contents (TC)	Value mg/100 g sample
CSF0	38.28 ± 0.11^{a}
CSF3	31.21 ± 0.18^{b}
CSF5	14.16 ± 0.13^{c}
CSF7	0.39 ± 0.01^{d}

Values are presented as mean ± standard deviation. Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

acid and conjugated linoleic acid) indicate that the particulated chia seed remained heat-stable, which might be due to the presence of seed coat fractions and mucilaginous matrix. However, at higher concentration of chia seed, no linoleic acid was detected in cake, indicating an unfavorable interaction between chia mucilage and fatty acid, which resulted in heat damage of the fatty acid. Coelho and Salas-Mellado [33] replaced wheat flour by chia seed flour in bread and observed a significant rise in polyunsaturated fatty acids (PUFA) along with lower saturated fatty acids (SFA) than the control bread. Similarly, cake with chia seed gel presented a greater reduction in saturated fatty acid concentrations, yet improved polyunsaturated fatty acids were noticed [32]. According to the dietary recommendations, the adequate intake (AI) of polyunsaturated fats is expressed as the percentage of total energy (E%), which is 4E% and 0.5E% for the linoleic acid and α-linolenic acid, respectively [38]. Thus, the cake with chia seed flour (CSF) would better satisfy the AI for linoleic acid and α-linolenic acid. Giaretta et al. [39] also proved that the addition of chia seed favored the upshift of polyunsaturated fatty acids in the wheat bread with a simultaneous decline of saturated counterparts.

Cholesterol is attributed to diverse types of cardiovascular ailments in humans. Thus, with the consumers' growing understanding and scientific proof, a lower intake of cholesterol is recommended. Thus, the replacement of chia seed was made to minimize the cholesterol concentration in the cake found in the egg yolk (Table 9). The substitution of CSF significantly ($p < 0.05$) yet favorably lowered the cholesterol content of the cake. Hence, cake with 3% (CSF3), 5% (CSF5), and 7% (CSF7) chia seed presented 18%, 63%, and 98% reduction in the cholesterol concentration, respectively. Borneo et al. [32] also substituted chia seed gel in cakes as an egg and fat replacer and found a substantial reduction in the cholesterol content.

4. Conclusion

The functional and nutritional cake was made by incorporating chia seed flour (CSF) instead of egg. The addition of CSF in cake enhanced the nutritional value with higher total proteins, fats, and mineral elements. A higher concentration of CSF with simultaneous lower egg proteins modified the cake volume, symmetry, and uniformity after baking. Cake showed a firmer and more springy texture with a higher egg replacement with CSF. Except for the cake with 3% CSF, all the cakes depicted darker crust, crumbs, and inferior sensory acceptability. However, CSF substitution in cakes augmented the antioxidative properties, enhanced healthy fats, especially polyunsaturated fats, and dropped the cholesterol percentage. Moreover, chia seed was found as a nice alternative to fish oil to improve the polyunsaturated fatty acids of food products with no fishy odor. Thus, the functional chia seed cake made with reduced cholesterol and elevated essential fatty acids could be a pertinent choice to uplift the vigor of the consumer and could mitigate the occurrence of cardiovascular ailments.

Data Availability

The data used to support the findings of this study are included in the article.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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