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Research Article

Quality and Nutritional Value of Functional Strawberry Marmalade Enriched with Chia Seed (*Salvia hispanica* L.)

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The aim of the study was to develop and characterize marmalade having functional food ingredients such as omega-3 fatty acid, dietary fiber, protein, and antioxidants with the addition of chia seed (*Salvia hispanica* L.). During the development of marmalade formulations, sweetener type and chia content in the strawberry marmalade were decided by two-step sensory analysis. In the first step, four different formulas were prepared separately by using sorbitol, isomalt, commercial Stevia™ powder, and isomalt together with sorbitol. The control formula was prepared with sucrose (refined commercial sugar). In the first part of the study, sensorial parameters showed good acceptability for sorbitol. Thereafter, in the second step, marmalades were prepared with 2.5% and 5% (by weight) chia seed including sorbitol. According to sensory panels, sorbitol had the highest acceptance level and the chia seed content was chosen to be used as 5% in the formulations. Chia seed and sorbitol addition increased the phenolic content by 15.45% and the dietary fiber content by 168% and decreased the caloric value by 48% compared to the control prepared with sucrose and without chia seed. The final product had 1.5% omega-3 fatty acid and could be declared as "omega-3 source" in the label. The viscosity of chia-added marmalade was found to be slightly higher than the viscosity of control, even though there was no distinct difference between the two samples. The gel-like character was more dominant in chia-added strawberry marmalade compared to the control. The addition of chia at 5% may contribute to the crosslinking without formation of a gel structure.

1. Introduction

In recent years, functional foods and functional food components have gained interest due to increase in awareness of consumers for more healthier life. In the developed countries, mortal diseases are listed as coronary heart diseases, cancer, and diabetes. By the increased risk of these diseases, people tend to consume functional foods which contain less sugar, more dietary fibers, omega-3 fatty acids, and antioxidants. By considering this, sugar-free foods and foods containing a high amount of dietary fiber and omega-3 polyunsaturated fatty acids (PUFAs) have come into prominence. Sugar alcohols may be used as sweeteners, which is not absorbed in the small intestine and do not cause an increase in the sugar level in the blood [1]. Moreover, dietary fiber is well known for satiety control [2], decreasing the risk of cardiovascular diseases [3, 4], and mitigating cancer [3]. The American Dietetic Association recommends dietary fiber intake of 25 g/day for an adult female and 38 g/day for an adult male [5]. Another important component of chia seed is omega–-3 PUFAs, known for their beneficial health effects on the immune system, cancer types, and schizophrenia [6]. Moreover, they have roles in the brain and eye development, prevent arrhythmias, decrease blood pressure level, and decrease plasma triglycerides, and they are effective in the treatment of cardiovascular illnesses by decreasing inflammation [7]. Omega-3 PUFAs are also effective for controlling obesity by regulating adipose tissue mechanism and functions [8].

Chia seed is an ancient grain used by Aztec people and Central American civilizations as food and animal feed and for medical purposes [9]. Chia seeds are oval-shaped

(1.87 ± 0.1 mm length, 1.21 ± 0.08 mm width, and 0.88 ± 0.04 mm thickness) and they have small white and dark grey spots. It has a composition of 16.5% protein, 30% total fat, 18% omega-3 fatty acid, and 35% total dietary fiber [10].

Dietary fiber content of chia seed is equivalent to 100% of the daily recommendations for the adult population since chia seed contains between 34 and 40 g of dietary fiber per 100 g; the defatted chia seed flour possesses 40% of fiber, 5–10% of which is soluble and forms part of the mucilage. Its omega-3 PUFAs content is higher than quinoa and amaranth [10]; protein content is higher than oats, wheat, barley, corn, and rice [9]. Chia seed has also the ability to form a mucilaginous gel and retains 27 times higher water content than its own mass, when soaked in water [10].

The unique composition of chia seed differs from the other common seed oils and offers opportunities for the development of functional formulations. Iglesias-Puig and Haros [11] developed a bread formula with chia flour and chia seed addition. In their study, both chia flour and chia seed addition yielded a significant increase in the levels of protein, lipids, ash, and dietary fiber in the final product ($p < 0.05$).

Breads with chia seeds or flour showed similar technological quality to the control bread, except for the increase in specific bread volume, decrease in crumb firmness, and change in crumb color. Sensory analysis showed that the inclusion of chia increased overall acceptability. The incorporation of chia inhibited the kinetics of amylopectin retrogradation during storage, which would be directly related to the delay in bread staling. Steffolani et al. [12] used chia seeds and flour to develop a gluten-free bread. The addition of chia seed and flour yielded reduction in specific volume, increase in the hardness of breads, and decrease in weight loss during baking. The addition of chia flour produced a darker crust and crumb. There were no significant differences between the breads in the overall acceptability, but chia seed breads presented better scores in terms of texture than the control. However, besides the well-documented health and nutrition effects, and the use of chia seed in bread formulations, to our knowledge, the current study is the first research for the development of reduced sugar functional marmalade with chia seed addition.

Therefore, the aim of the present study was to determine the possibilities of using chia seeds in the production of new functional marmalade. Moreover, it was also aimed to determine the effects of chia seeds on sensory properties, rheological properties, total phenolics content, antioxidant properties, and fatty acid profiles of strawberry marmalade.

2. Materials and Methods

2.1. Materials. Chia seeds (*Salvia hispanica* L.) of Peruvian origin were purchased from Malatya Pazarı (Turkey). Frozen strawberries were purchased from a local store in Turkey. The sweeteners such as sorbitol, isomalt (derived from natural sugar beet), and commercial Stevia™ powder were kindly provided by ZAG Chemistry and Artisan Company (İstanbul, Turkey), respectively.

The experimental procedure was carried out in three steps. Firstly, chia seeds were characterized for proximate composition and functional components. Secondly, the marmalade formula (chia seed content and sweetener type) was optimized by sensory analyses. Lastly, the marmalade was characterized for its compositional, chemical, functional, and rheological properties.

2.2. Characterization of Chia Seeds. Chia seeds were milled by using laboratory type miller 300–500 W power (IKA A11, Germany) before proximate analysis. The particle size of the material was in the range of $0.42\,\text{mm} < D_p < 0.85\,\text{mm}$ by using −20/+35 mesh Tyler. Chia seeds were characterized by means of composition, fatty acid profiles, and antioxidant capacity.

2.2.1. Proximate Analysis. The composition of chia seeds was evaluated according to AOAC methods [13]. Moisture content was analyzed by AOAC 925.09, direct oven method. Protein content was analyzed by AOAC 979.09, Kjeldahl method. The nitrogen factor was accepted as 6.5 during protein calculation. Ash content was analyzed by AOAC 923.03. Total dietary fiber content was analyzed by AOAC 985.29 [14]. Defatted chia flour was used during total dietary fiber analysis to eliminate the possible errors that may result from high amount of fat. Total fat content was analyzed by using automatic Soxhlet instrument (Gerhardt Soxtherm, Germany) operating at 180°C for 135 min. Hexane was used as the extraction solvent, and after extraction, it was removed by a rotary evaporator using Buchi RII (Switzerland) at 50°C. The percentage of total fat was calculated by the following equation:

$$\text{total fat}\,\% = \frac{\text{weight of fat extracted}}{\text{weight of initial sample}} * 100. \tag{1}$$

Total carbohydrate content was calculated by the difference of 100 to the other components using the following formula:

$$\text{Total carbohydrate} = 100 - (\text{weight in grams [protein} + \text{fat} + \text{water} + \text{ash] in 100 g of food}). \tag{2}$$

The caloric value of the marmalade was calculated using the coefficients of Atwater based on the caloric coefficients corresponding to the protein, carbohydrate, and lipid contents, according to equation (1) [15, 16]:

$$\text{Caloric value}\left(\text{kcal}\cdot 100\,\text{g}^{-1}\right) = (\text{g of protein} * 4) + (\text{g of lipids} * 9) + (\text{g of carbohydrates} * 4). \tag{3}$$

2.2.2. Determination of Functional Properties

(1) Fatty Acid Composition. The oil obtained by the Soxhlet extraction method has been used for GC analysis. The extracted oil was firstly methylated by saponification of glyceride and phospholipids in the presence of boron trifluoride to extract the fatty acids [17].

Fatty acid composition of chia seed was analyzed by using Thermo Quest Trace GC 2000 gas chromatography (GC) (Milan, Italy) equipped with a flame-ionization detector and DB-Wax capillary column (30 m × 0.32 mm ID × 0.25 μm film thickness) (J&W Scientific Folsom, CA). The injector and detector temperatures were held at 250°C and 260°C, respectively. The oven temperature was initially held at 150°C for 3 min and was then programmed to 225°C for 10 min at a rate of 10°C/min, and helium carrier gas flow rate was 1.5 mL/min. 1 μL sample was injected into the GLC, and the relative amounts of FAME were calculated as area % by computer. The average values from the results of duplicate analyses were reported [17].

(2) Total phenolics and antioxidant activity. Before conducting the analysis, extraction of the phenolic compounds was carried out according to Marinelli et al. [18]. One gram of defatted chia seed flour or marmalade sample was extracted with 10 mL of ethanol by continuous shaking at room temperature for 3 hours. The mixture was then centrifuged at 3000 rpm for 15 min. This extract was used for the analysis of total phenolic compounds and antioxidant activity.

The total phenolic content was determined according to Marinelli et al. [18], by using Folin–Ciocalteu's method. 50 μL sample, 800 μL distilled water, and 25 μL 0.25 N of Folin–Ciocalteu's reagent were mixed and incubated at room temperature for 3 min. Then, 100 μL of 1 N Na_2CO_3 solution was added and further incubated at room temperature for 2 hours. The absorbance was read at 725 nm by spectrophotometer (Synergy HT, BioTek, USA). A standard curve was prepared by using gallic acid standard with varying concentrations of 16–500 μg gallic acid/mL water, and the results were expressed as gallic acid equivalent (GAE/g).

Antioxidant capacity was determined by the method expressed by Marinelli et al. [18]. 2,2-Diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity was used to express antioxidant capacity. 33 μL sample was mixed with 1.3 mL DPPH solution prepared in methanol at 0.024 mg/mL concentration, shaken, and incubated at room temperature for 30 min. The absorbance values were read at 515 nm. A standard curve was prepared using Trolox solution of 5–600 μmol concentrations. The results were expressed in Trolox equivalent (μmol·TE/g).

2.2.3. Development of Marmalade Formula.

Strawberry was selected in the marmalade because of the similarity between strawberry seeds and chia seeds in shape and color. The marmalade formula was optimized by a two-step sensory panel. The panelists were asked to evaluate the samples according to a 7-point hedonic scale (7 = like very much, 6 = like moderately, 5 = like slightly, 4 = neither like nor dislike, 3 = dislike slightly, 2 = dislike moderately, and 1 = dislike very much). All evaluations were held in Istanbul Technical University Sensory Analysis Laboratory by a total of nine female and male panelists who were regular consumers of marmalade and their ages were between 25 and 40. The marmalades were prepared by homemade cooking method three days before the sensory analysis, held at 4°C, and were taken out 3 hours before serving.

(1) Sensory Analysis for Determination of Sweetener Type. Four different formulas were prepared separately by using sorbitol, isomalt, commercial Stevia™ powder, and isomalt together with sorbitol. The control formula was prepared with sucrose (refined commercial sugar) which was served in order to analyze the degree of difference. In this step, all formulas involved 2.5% of chia seed (whole) and 50.5% of strawberry and the remaining portion was the individual sweetener or sugar. The formulas of marmalades served in the first sensory analysis are as follows:

Control sample (50.5% strawberry, 47% sucrose, and 2.5% chia seed); marmalade with sorbitol (50.5% strawberry, 47% sorbitol, and 2.5% chia seed); marmalade with isomalt (50.5% strawberry, 47% isomalt, and 2.5% chia seed); marmalade with commercial Stevia™ powder (50.5% strawberry, 47% Stevia™, and 2.5% chia seed); and marmalade with isomalt and sorbitol (50.5% strawberry, 23.5% sorbitol, 23.5% isomalt, and 2.5% chia seed).

(2) Sensory Analysis for Determination of Chia Seed Content. According to the results of the first step of sensory analysis, the sorbitol-containing formula was scored as highest nearest to the control. Therefore, sorbitol involving formula was evaluated for the second step of sensory analysis. In this step, the amount of whole (intact) chia seed addition such as 2.5% and 5% (by weight) was evaluated. In the second sensory analysis, the panelists were also asked to evaluate the purchase intent of the marmalade by a 5-point hedonic scale (1 = definitely would not buy, 2 = probably would not buy, 3 = might or might not buy, 4 = probably would buy, and 5 = definitely would buy).

2.3. Characterization of Strawberry Marmalade.

Strawberry marmalade was characterized by means of compositional, chemical, physical, and rheological properties.

2.3.1. Proximate Analysis.

Moisture content was analyzed according to Mohd Naeem et al. [19]. 10 g of sample was weighed in aluminium dishes and put in 105°C air oven for one night. Exposing to hot air was continued until a constant weight was obtained. Protein and total dietary fiber contents were evaluated as described in Section 2.2.1. Ash content was analyzed by using AOAC 940.26. During ash analysis, the temperature was increased by 50°C intervals to 525°C to prevent sudden splashing. Total carbohydrate content was calculated by the difference of 100 to the other components. The caloric value of the marmalade was calculated using the coefficients of Atwater based on the caloric coefficients corresponding to the protein, carbohydrate, and lipid contents, as described in Section 2.2.1.

2.3.2. Chemical Analysis. Soluble solid content was analyzed by using AOAC 932.12. pH was determined by potentiometer (Hanna HI 2211, Island). Titration acidity was analyzed by using AOAC 942.15. Since the marmalade did not contain sucrose, only invert sugar amount was analyzed by using AOAC 923.09 with a few modifications by diluting the sugar solution to 10%. Hydroxymethylfurfural (HMF) content was analyzed according to AOAC 980.23 method [13]. HMF is formed in Maillard reaction and dehydration of sugars during caramelization. The quantity of HMF occurring in the marmalade was monitored for quality reasons. Antioxidant capacity and total phenolic content were analyzed by using the methods used for evaluating antioxidant capacity and phenolic content of chia seed as described in Section 2.2.2. Prior to analysis, one gram of marmalade sample was extracted with 10 mL of ethanol by continuous shaking at room temperature for 3 hours. The mixture was then centrifuged at 3000 rpm for 15 min. This extract was used for the analysis of phenolic compounds and free radical scavenging activity of marmalades.

2.3.3. Rheological Properties. Rheological properties of both strawberry marmalade with chia seed (SMWC) and the control marmalade were measured by using a rheometer (Rheostress1, Haake, Germany) equipped with a parallel-plate sensor (dia = 35 mm and gap = 1 mm) in duplicate at room temperature.

Viscosity measurements were conducted in the shear rate range of 0.01–100 s^{-1} in 100 s. The viscosity curves (shear rate versus viscosity) were obtained. The measured data were modeled by using a software (Excel 2016, USA) according to the Herschel–Bulkley model for all samples:

$$\tau = \tau_o + K\dot{\gamma}^n, \quad (4)$$

where τ_o is the yield stress (Pa), K is the consistency index (Pa·s^n), $\dot{\gamma}$ is the shear rate (s^{-1}), and n is the flow behaviour index (–). For Herschel–Bulkley fluids, $K > 0$, $0 < n < \infty$ and $\tau_o > 0$.

Frequency sweep measurements were performed from 0.01 to 10 Hz. The viscoelastic parameters including storage modulus (G′), loss modulus (G″), and loss tangent ($\tan\delta$) were measured [20].

2.3.4. Statistical Analysis. All experiments were performed in three replicates. Statistical analyses were conducted by using Minitab Release 17 programme (UK). The difference between the data was evaluated by ANOVA with a confidence interval at 0.05. The mean values were compared by Tukey's post hoc test ($p < 0.05$).

3. Results and Discussion

3.1. Chia Seed Characterization

3.1.1. Results of Proximate Analysis of Chia Seed. Chia seed was found to contain 7.4 ± 0.1% moisture, 3.9 ± 0.3% ash, 19.6 ± 0.5% protein, 29 ± 1.3% lipid, and 38.9 ± 0.5% dietary fiber. These results comply with the data in the literature [10]. The protein content is considerably more than oats, wheat, barley, corn, and rice [9]. High ash content can be related with high amount of minerals. Chia seed is an excellent source of minerals and contains more calcium, phosphorus, potassium, iron, magnesium, zinc, and copper than milk [10]. High dietary fiber content of chia seed allows lower glycemic index. This feature of chia seed helps to maintain body mass control.

Caloric value provided by chia seed was calculated by using the metabolizable energy factors [15, 16]. Taken into account those factors and the proximate analysis results, 100 g of chia seed provides approximately 574 kcal metabolizable energy.

3.1.2. Functional Properties of Chia Seed. Fatty acid composition of chia oil extracted from chia seeds is given in Table 1. These findings are in accordance with the reports of Muñoz et al. and Nitrayová et al. [10, 21]. According to their report, chia seed had more polyunsaturated fatty acid content than amaranth and flaxseed; its total fatty acid content was higher than quinoa and amaranth. Compared to other seeds, it is an especially rich source of alpha-linolenic acid (18 : 3$n-3$, at 18.45 g/100 g) known for dietary precursor for the long chain $n-3$ PUFAs [10]. Of no less importance is that the antioxidant capacity of chia seed was found to be 436.6 ± 2.54 μmol TE/g, associated with beneficial effects for preventing lipid peroxidation better than the antioxidants in vitamin C [14].

3.2. Optimizing Marmalade Formulation. Table 2 shows the statistical results of the sensory analysis for determination of sweetener type. Strawberry flavor, strawberry odor, sweetness, and spreadability were accepted as the most important parameters since they are important for consumers' liking and purchase intent of the marmalade. Based on the scores, the formula with Stevia™ sugar had the highest difference from the control, whereas sorbitol involving formula was regarded as the nearest one to the control. In the next step, sensory analysis was continued with the formula involving sorbitol.

Two different ratios of intact chia seed such as 2.5 and 5% (by weight) were evaluated by using the same parameters used in the first step. Additionally, the purchase intent of the functional marmalade product was also evaluated. Table 3 shows the statistical results of the second sensory analysis. According to the results of this analysis, chia seed addition at 5% was found to be more favorable. Moreover, the texture provided by 5% chia seed addition was more preferred by the panelists. The consistency in mouth and by spoon scores were also higher. Therefore, 5% chia seed addition could be a

Table 1: Fatty acid profile of chia seed.

Fatty acids	g/100 g chia oil	g/100 g chia seed	g/100 g chia oil [21]
Myristic acid (C14 : 0)	0.05	0.015	0.06
Palmitic acid (C16 : 0)	7.6	2.28	7.04
Palmitoleic acid (C16 : 1)	0.01	0.003	0.03
Stearic acid (C18 : 0)	3.4	1.02	2.84
Oleic acid (C18 : 1)	7.3	2.19	7.30
Linoleic acid (C18 : 2)	19.8	5.94	18.89
α-Linolenic acid (C18 : 3$n-3$)	61.5	18.45	63.79
Saturated fatty acids	11.05		9.99
Monounsaturated fatty acids	7.31		7.33
Polyunsaturated fatty acids	81.3		82.68

Table 2: Statistical results of the first sensory analysis.

Sweetener type	Color	Sweetness	Strawberry flavor	Strawberry odor	Consistency in mouth	Consistency by spoon	Spreadability
Control	4.7 ± 1.20^a	5.2 ± 1.01^a	4.7 ± 1.71^a	4.3 ± 1.73^a	5.3 ± 1.00^a	5.3 ± 0.86^a	4.7 ± 1.39^a
Sorbitol	5.2 ± 0.97^a	4.5 ± 0.88^{ab}	4.6 ± 1.00^a	4.8 ± 1.05^a	4.6 ± 0.86^a	4.5 ± 1.01^{ab}	5.4 ± 1.00^a
Stevia™ sugar	5.2 ± 1.39^a	3.0 ± 1.5^b	3.4 ± 1.50^a	4.7 ± 1.39^a	3.0 ± 1.11^b	3.2 ± 0.97^b	3.2 ± 0.83^b
Isomalt	5.3 ± 0.86^a	4.3 ± 1.41^{ab}	4.6 ± 1.58^a	5.3 ± 1.41^a	4.8 ± 0.92^a	5.3 ± 0.86^a	5.2 ± 1.20^a
Isomalt + sorbitol	4.8 ± 1.26^a	4.1 ± 1.36^{ab}	4.6 ± 1.11^a	4.6 ± 1.11^a	5.0 ± 1.00^a	5.4 ± 1.33^a	5.4 ± 1.13^a

[ab]Different letters in row are significantly different ($p < 0.05$).

Table 3: Statistical results of the second sensory analysis.

	Chia seed (%)	
	2.5	5
Color	4.7 ± 1.09^a	5.7 ± 0.83^a
Sweetness	4.4 ± 1.33^a	5.4 ± 0.72^a
Strawberry flavor	5.1 ± 1.36^a	5.1 ± 1.16^a
Strawberry odor	4.6 ± 1.11^a	5.1 ± 1.05^a
Cereal taste	3.4 ± 1.23^a	3.7 ± 1.64^a
Consistency in mouth	4.6 ± 1.00^a	5.0 ± 1.00^a
Consistency by spoon	4.8 ± 1.16^a	5.5 ± 0.72^a
Spreadability	4.4 ± 1.23^a	5.3 ± 0.70^a
Purchase intent	2.7 ± 1.30^a	3.8 ± 0.92^a

[a]Different letters in column are significantly different ($p < 0.05$).

good alternative to replace additional use of pectin for marmalades and jams.

3.3. Characterization of Strawberry Marmalade

3.3.1. Proximate Analysis. Strawberry marmalade with chia seed and without additional sugar (SMWC) was compared to the control (strawberry marmalade without chia seed and with sugar) by means of composition, caloric value, physical, chemical, and rheological properties. Table 4 gives the comparison between the compositions of SMWC and control sample. The most significant effects of chia seed addition were observed for protein, oil and omega-3 fatty acids, fiber, and ash contents. Protein content increased 4 times, oil content increased 17 times, total fiber content increased approximately 3 times, and ash content increased approximately 2 times compared with the control. The aforementioned beneficial properties of these components offer numerous advantages in terms of developing more nutritious and functional marmalade.

Table 4: Compositions of SMWC and control and the difference between them.

g/100 g	SMWC*	Control	% Increase
Moisture	35.16 ± 0.29	31.23 ± 2.83	12.6
Protein	1.30 ± 0.11	0.32 ± 0.087	306.56
Fat	2.46 ± 0.4	0.14 ± 0.07	1600
Omega-3	2.00 ± 0.2	0	
Ash	0.46 ± 0.0	0.23 ± 0.03	99.56
Total fiber	2.70 ± 0.25	1.00 ± 0.10	168
Carbohydrate	61.22 ± 1.15	67.65 ± 2.91	−10

*SMWC: strawberry marmalade with chia seed and sorbitol.

Metabolizable energy provided by 100 g SMWC was calculated as 605 kJ (146 kcal), while it was 1170 kJ (280 kcal) for the control sample. Therefore, energy of the new functional marmalade was decreased by 48%. Due to the energy reduction, it could be a good alternative for people in diet or taking care of body mass control.

3.3.2. Chemical Properties. Chia seed addition and sorbitol substitution did not significantly change the soluble solid content and acidity, but changed the pH value. Soluble solid amounts of SMWC and control were found to be 64.3 and 65.4%, respectively. Acidity values of SMWC and control were found to be 0.49 and 0.48%, respectively. The pH values of SMWC and control were found as 4.43 and 3.28, respectively. Soluble solid amount and acidity value of SMWC are in accordance with the report of Pavlovic et al. [22]. According to this report, soluble solid content of a low-calorie marmalade should be higher than 60%, and the acidity should be higher than 0.45. The pH value of a low-calorie marmalade is advised to be between 2.6 and 3.2. This could make our product more favorable for microbial spoilage than the control. Further studies may focus on the preservation techniques of chia seed-added, sorbitol-substituted marmalade in industrial scale. The use of preservatives could be considered to lower the pH value to the requested range.

Sugar content of SMWC was found to be 4.9%. This value allows the product to be declared as "low sugar" according to EU Food Law 1169 [23].

Hydroxymethylfurfural (HMF) content in jams and marmalades is limited to 80 mg/kg according to Codex Standard for Jams, Jellies and Marmalades [24]. HMF content in the product was found to be 4.64 mg in 100 g sample. It can be interpreted that the cooking process of marmalade was suitable by means of heating time and rate. Further analyses may focus on decreasing HMF content especially during industrial production.

3.3.3. Functional Properties. Antioxidant capacity and total phenolic contents of SMWC were found as 21.9 ± 1.20 μmol TE/g and 4.1 ± 0.06 mg GAE/g, respectively. The total phenolic content of the control marmalade was found as 3.5 mg GAE/g. These results are in accordance with the findings of Marinelli et al. [18]. Chia seed addition increased the phenolic content of the marmalade by 15.4%. The phenolic content of the control marmalade was also noticeable because of the high phenolic content of strawberry itself. As reported by Rababah et al. [25], strawberry has a phenolic content of 8.5 mg·GAE/kg, which is higher than cherry, grape, fig, and orange. The phenolic content of a strawberry jam was reported as 2.85 mg·GAE/g [26]. When compared with our findings, the total phenolic content of SMWC was noticeably higher than that of the control marmalade. This increase allows the chia seed-added marmalade as a preferable functional food.

3.3.4. Rheological Properties. In view of consumer demand for foods, it is critical to characterize the rheological property which will also influence their overall acceptability.

The viscosity curves of SMWC and control are shown in Figure 1. The viscosity of both samples decreased as shear rate increased, indicating a shear-thinning behaviour. This rheological behaviour was also reported for mango jam [19]. It appears that the viscosity of SMWC was slightly higher than the viscosity of control, even though there was no distinct difference between two samples.

The samples exhibited shear-thinning behaviour with yield stress, according to the modelling calculations. The Herschel–Bulkley model parameters are given in Table 5. As seen from the viscosity curves, the model parameters were also very close to each other. In a study, the yield stress, consistency index, and flow behaviour index values of different strawberry jams with different pectin contents at 20°C were reported as 1.5–24.6, 20.3–73.5, and 0.32–0.59, respectively [27].

Figure 2 shows the comparison of storage (G″) and loss modulus (G′) of SMWC and the control. G′ and G″ values for SMWC are greater than that of control. Both moduli are dependent on frequency at lower frequencies. G′ is greater than G″ for all samples at any given point, showing samples having a gel-like character. The gel-like character is more dominant for SMWC compared to the control. However, there is no crossover point for G′ and G″, meaning no real gel formation. This indicated that the weak gel structure may be occurred due to crosslinkings for the control sample and the addition of chia at 5% may contribute to the crosslinkings without formation of a gel structure.

Figure 3 gives the comparison of the loss tangent values of SMWC and the control. Loss tangent of samples which are below 1 indicates a gel-like behaviour. Moreover, the texture provided by 5% chia seed addition was more preferred by the panelists and they scored consistency parameters higher. Therefore, chia seed addition at a level of 5% contributed to both crosslinkings and higher consistency.

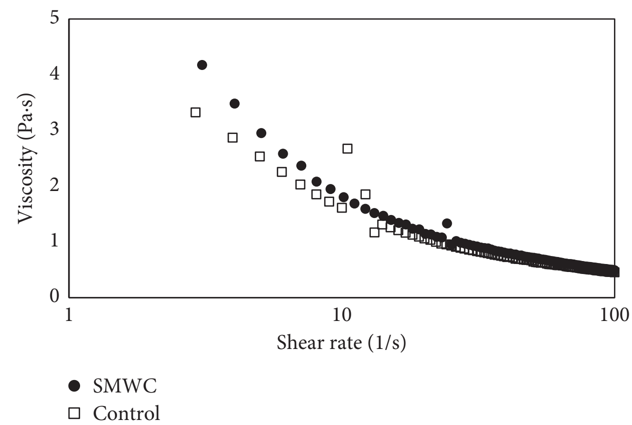

Figure 1: The viscosity curves of SMWC and control samples.

Table 5: Herschel–Bulkley model parameters (τ_o, K, and n) of SMWC and control samples.

Sample	τ_o (Pa)	K (Pa·s^n)	n (−)	R^2
SMWC	6.7	3.2	0.56	0.99
Control	7.4	2.4	0.60	0.99

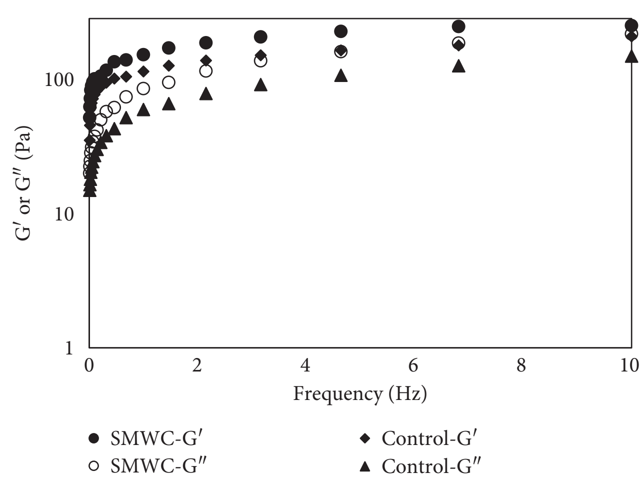

Figure 2: Frequency spectra for the samples.

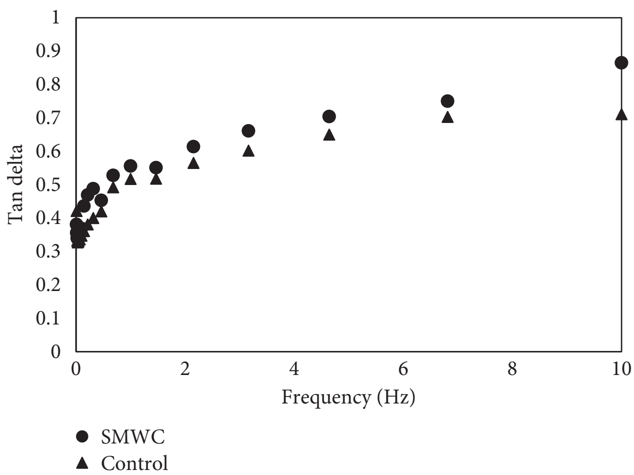

Figure 3: Loss tangent versus frequency data for SMWC and control samples.

Table 6: Nutritional and energy value of SMWC.

Energy and nutrients	Per 100 g product
Energy	604.8 kJ/144.6 kcal
Fat	2.4 g
Saturated fat	0.3 g
Monounsaturated fat	0.2 g
Polyunsaturated fat	2 g
Carbohydrate	61.2 g
Sugar	4.9 g
Sugar alcohol	56.3 g
Dietary fiber	2.7 g
Protein	1.3 g

3.4. Nutritional Labeling of Chia Seed-Added Strawberry Marmalade. Energy value and other nutritional composition are provided in Table 6. A low-calorie marmalade from England market declares the energy value as 647 kcal, dietary fiber content as 0, and protein content as 0.6%. The nutritional label of a low-calorie marmalade from Turkish market declares its energy value as 554 kcal, dietary fiber content as 1.1%, and protein content as 0.3%. These comparisons allow the chia seed-added marmalade with no additional sugar (sucrose) as a promising new functional product in the market.

EU Food Law 1169, Commission Regulation 1924/2006 of the European Parliament and the Council of 20 December 2006 on nutrition and health claims made on foods permit to label food products as "energy reduced" if the product has at least 30% less energy than a similar product. Since SMWC has 48% less energy than the control, it can be declared as "energy reduced" [28]. According to the same regulation, SMWC can be labeled as "low sugar," since its sugar composition is less than 5%, and "source of omega-3" since omega-3 fatty acids content is more than 0.3% [28].

According to EU Food Law 1169, Regulation No 1169/2011, this functional product should be labeled and declared as "involves sweetener" and "excessive consumption may cause laxative effects," since it contains polyol more than 10% [23].

4. Conclusions

In this study, chia seed-added functional marmalade with reduced sugar was developed. During the development of marmalade formulations, sweetener type (sorbitol, isomalt, commercial Stevia™ powder, and isomalt together with sorbitol) and chia seed content (2.5% and 5% by weight) in the strawberry marmalade were decided by two-step sensory analysis. The control formula was prepared with sucrose (refined commercial sugar). In the first part of the study, sensorial parameters showed good acceptability for sorbitol. Therefore, in the second part of the study, marmalades were prepared with 2.5% and 5% (by weight) chia seed including sorbitol. Chia seed at 5% showed good acceptance level and the chia seed content was chosen to be used as 5% in the formulations.

Chia seed and sorbitol addition increased the phenolic content by 15.45% and the dietary fiber content by 168% and decreased the caloric value by 48% compared to the control prepared with sucrose and without chia seed. The final product had 1.5% omega-3 fatty acid and could be declared as "omega-3 source" in the label.

In terms of process parameters, SMWC exhibited more gel-like character compared to the control and the addition of chia at 5% may contribute to the crosslinkings without formation of a gel structure. Therefore, chia-added, sorbitol-containing strawberry marmalade proved to be a new alternative by preserving the quality attributes and making them healthier foods.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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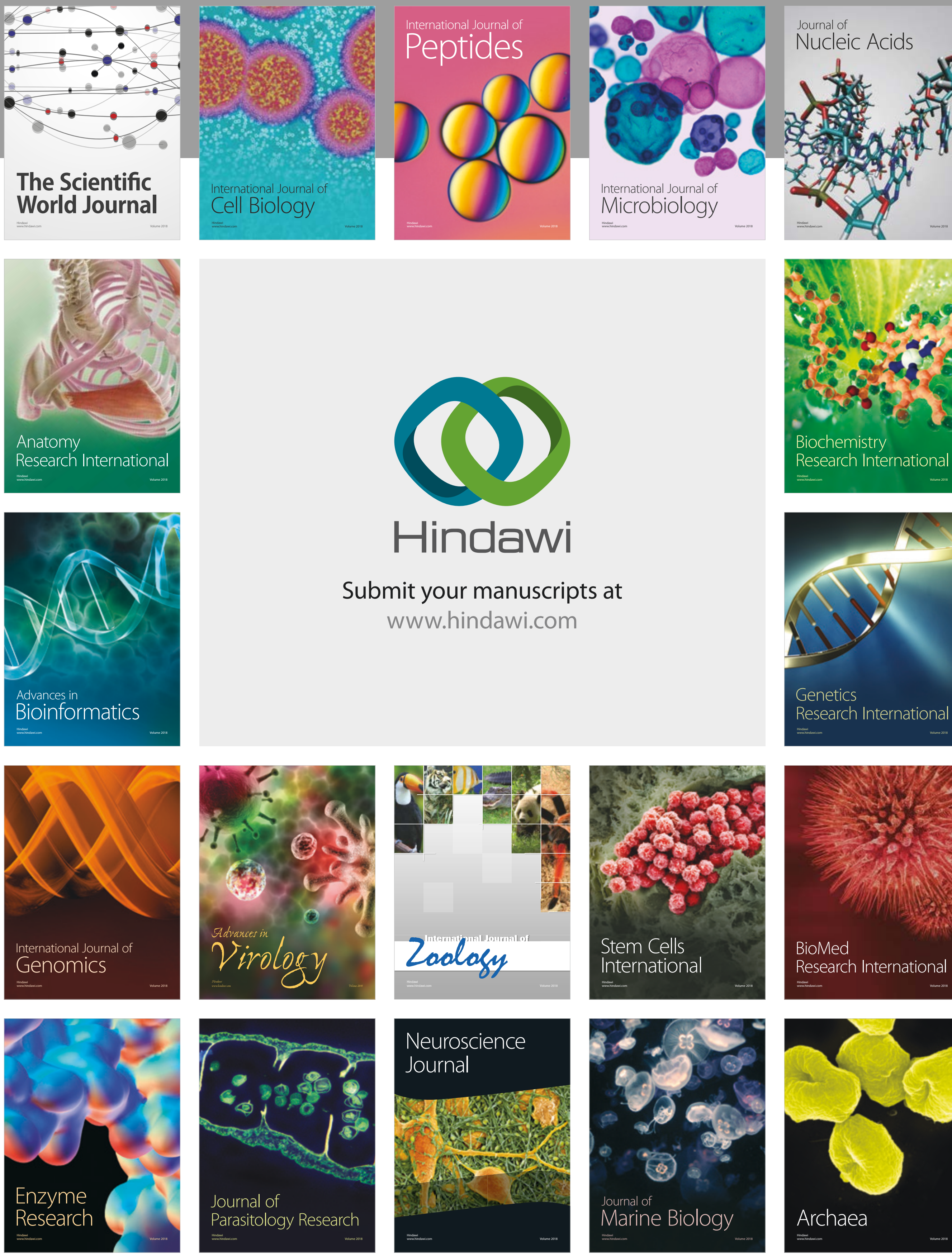
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