DOI: https://doi.org/10.22104/ift.2024.6982.2179

Innovative Food Technologies, 11(3), 276-294,Spring 2024

Research Article

Characterization of Functional White Chocolate Enriched by Mango Peel and Tagatose: A Practical Investigation

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(Received Date: 07 July 2024, Revised Date: 02 December 2024, Accepted Date: 04 December 2024)

Abstract

With the increasing prevalence of diabetes and growing consumer interest in functional foods, the formulation of dietary products has gained significant attention. In this context, the current study explored the incorporation of mango peel powder at levels of 0%, 5%, 10%, and 15%, along with tagatose at levels of 0%, 11%, 22%, and 33% in white chocolate. The chocolates were evaluated for their rheological, sensory, and physicochemical properties, including moisture, total sugar, acidity, fat, water activity, and color indices. Additionally, their calorie content, phenolic compound levels, and free radical scavenging activity were assessed. The results indicated that increasing the mango peel content significantly ($p \leq 0.05$) enhanced the moisture, water activity, total sugar, and fat levels in the chocolates. Conversely, the use of tagatose significantly ($p \leq 0.05$) reduced moisture and water activity. In conclusion, the T10 sample, containing 5% mango peel powder and 11% tagatose, was identified as the optimal formulation for enriching white chocolate due to its favorable characteristics and high organoleptic value. The addition of mango peel not only improved the nutritional profile of the chocolate but also enhanced its nutraceutical properties by significantly boosting its antioxidant activity.

Keywords: Antioxidant activity, Mango peel, Phenolic compounds, White chocolate.

How to cite this article:
Rahimi, S., Mikani, M., Roustaee, M. (2024). Characterization of functional white chocolate enriched by mango peel and tagatose: A practical investigation. *Innov. Food Technol.*,11(3), 276-294.
DOI: https://doi.org/10.22104/ift.2024.6982.2179

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1. Introduction

Chocolate is one of the most widely consumed confectionery products, appreciated for its exceptional taste, flavor, and texture [1]. Additionally, it serves as a rich source of biologically active compounds, such as polyphenols, which possess significant antioxidant properties and exert beneficial effects on human health [2]. The composition of chocolate plays a crucial role in its processing, as it determines the interactions between ingredients, which in turn influence the final product's microstructure. This microstructure impacts key properties such as crystallization, melting behavior, and the formation of fat bloom [3]. Chocolate consists of semi-solid suspensions of fine particles, primarily sugar and cocoa (approximately 70% of the total composition), dispersed in a fat phase. The main types of chocolate—milk, dark, and white—differ in their cocoa solids, cocoa butter, and milk fat content [4]. Sucrose-free chocolates can be successfully produced, and researchers have extensively studied their properties. These studies include characterizing their rheological performance and texture [5], investigating the effects of various bulking agents on the rheological and sensory properties of low-sucrose, low-calorie chocolate [6], and optimizing formulations based on sensory acceptance, rheological behavior, microstructure, and physical quality characteristics [1, 6].

Currently, there is a growing demand for healthier functional foods, including low-calorie options. At present, only a limited selection of sugar-free chocolates is commercially available. In these products, sugar is commonly replaced with maltitol. Low-energy sweeteners combined with low-energy bulking agents offer an alternative approach [5]. "Calorie restriction" is a key strategy used to address obesity, often accompanied by changes in dietary habits. To support this effort, recent years have seen increased efforts to reduce sugar and saturated fat content in food products. To achieve this goal, sucrose substitution is often avoided by using sugar alcohols. The primary sugar alcohols used in chocolate formulations as sucrose replacements include maltitol, isomalt, lactitol, mannitol, sorbitol, and xylitol [4, 7–8]. Tagatose, a significant prebiotic compound, has gained attention in food manufacturing. Chocolate, in particular, serves as an excellent vehicle for delivering prebiotics. Additionally, the incorporation of prebiotics into chocolate allows for an expansion of its health claims [9]. Therefore, replacing sucrose with tagatose in chocolate formulations is one of the main objectives of this research, making the product more suitable for certain consumers, particularly those with diabetes. Mango is one of the most important tropical fruits, and during its processing, the peel becomes a significant by-product. Mango peel has been recognized as a valuable source of bioactive compounds, including antioxidants, polyphenols, vitamins, carotenoids, and dietary fibers [10]. The objective of the current investigation was to develop white chocolate enriched with mango peel powder, which is rich in phytochemicals. The study aimed to evaluate the quality of the resulting white chocolate, including its polyphenol content and free radical scavenging activity. Several studies have

explored enriching chocolate with various ingredients, such as red wine and blueberry powders [11], rose hip shell fruit extract [12], Barbados cherry [13], seaweed [14], microalgae [15], phenolic extracts of cocoa bean shells [16], grape pomace [17], and more. Given the high nutritional value of mango peel and its light yellow color, it was selected for inclusion in the formulation of white chocolate.

The current study aimed to enhance white chocolate by incorporating mango peel powder, rich in phytochemicals, and tagatose, a low-calorie sweetener, to evaluate their effects on the physicochemical and sensory properties. The primary goal of this study was to develop a diabetic-friendly product with improved health benefits.

2. Materials and methods

For the production of white chocolate, cocoa butter (Cargill, Malaysia), milk powder (Palood Parsian Food Industries, Iran), sucrose (Shahrood, Iran), soy lecithin (Behpak Industrial Company, Iran), mango (Takchin Industrial Company, Iran), and D-tagatose (Damhert, Belgium) were used. Analytical-grade acetic acid, potassium hydroxide, phenolphthalein indicator, gallic acid, DPPH (2,2-diphenyl-1-picrylhydrazyl), and ethanol were obtained from Merck, Germany. The Folin-Ciocalteu reagent was purchased from Sigma-Aldrich, USA.

2.1. Mango peel powder preparation

After washing and manually peeling the fruits, the peels were dried using a microwave (LG, Intellowave model, Korea) at 180 W for a maximum of 10 minutes, with 2-minute intervals, to achieve approximately 1% moisture content. The drying process was optimized to minimize the exposure time and preserve the mango peel components from heat damage. The dried peels were then milled (Toos Shekan, Iran), sieved using a 100 μm mesh (Restch, Germany), and packaged in polyethylene terephthalate (PET) bags.

2.2. White chocolate preparation

The white chocolate was prepared following these stages: First, sugar and powdered milk were crushed and ground together using a mill (Corn-Grain-Cereal-Mill, Germany). Next, cocoa butter was melted in a water bath. The sugar, milk powder, and melted cocoa butter were combined in a planetary mixer (Santini, Italy) for 5 minutes. The mixture was refined using a multi-hole screw extruder for 1 hour at 35 ± 1°C and 50 rpm. Conching was performed with continuous stirring for 7 hours at 45 ± 1°C and 200 rpm. Lecithin and vanilla were added during the final 30 minutes of the conching process. The chocolate was tempered by cooling to 32 ± 1°C for 5 minutes, followed by further cooling to 28 ± 0.5°C for 10 minutes. The tempered samples were then precast and cooled at 7 ± 1°C for 2 hours. After cooling, the samples were kept at 25°C for 24 hours before being packed in sealed bags. The packaged samples were stored at ambient conditions with a relative humidity of 55%.

The basic formulation tested consisted of cocoa butter (39%), sugar (33%), whole milk powder

(27.5%), and soy lecithin (0.5% w/w). Additional ingredients, such as tagatose and mango peel powder, were incorporated into the formulation and evaluated using an appropriate experimental design. The detailed formulations for the white chocolate are presented in Table 1

Table 1. The formulation of treatments for production of 100 g white chocolate

Treatment	Mango peel powder (g)	Lecithin (g)	Cocoa butter (g)	Milk powder (g)	Sugar (g)	Tagatose (g)
T1	15	0.5	31.5	20	33	0
T2	15	0.5	31.5	20	22	11
T3	15	0.5	31.5	20	11	22
T4	15	0.5	31.5	20	0	33
T5	10	0.5	34	22.5	33	0
T6	10	0.5	34	22.5	22	11
T7	10	0.5	34	22.5	11	22
T8	10	0.5	34	22.5	0	33
T9	5	0.5	36.5	25	33	0
T10	5	0.5	36.5	25	22	11
T11	5	0.5	36.5	25	11	22
T12	5	0.5	36.5	25	0	33
T13	0	0.5	39	27.5	33	0
T14	0	0.5	39	27.5	22	11
T15	0	0.5	39	27.5	11	22
T16	0	0.5	39	27.5	0	33

2.3. White chocolate's composition determination

2.3.1. Proximate properties

Fat content was measured using the Soxhlet extraction method with hexane as the solvent for 1 hour [18]. Total sugar content was determined using the Lane-Eynon method, following AOAC 923.09 (2005) guidelines [18]. The caloric value of the chocolate was analyzed using an automated bomb calorimeter (C 2000 Basic Version 1, IKA®, USA) [18].

Moisture content was determined by measuring the weight loss before and after drying in an oven at 105°C, following AOAC 925.10 (2005) guidelines [18]. Water activity of the chocolates was measured using a Lab-Master aw analyzer (Novasina, Switzerland) as described by Konar (2013) [17].

The acid index (AI), which indicates the level of free fatty acids, is considered one of the most critical parameters for assessing chocolate quality. The acid index was determined through titration after dissolving the sample in 50% (v/v) ethanol,

using phenolphthalein as an indicator and a 0.1 M NaOH solution as the titrant. The acid index was calculated using the following formula [3]:

$$AI = V \times N \times meq\ oleic\ acid \times \frac{100}{w} \quad (1)$$

Where www represents the sample weight, VVV is the volume of NaOH solution used in the titration, and NNN is the normality of the NaOH solution.

2.3.2. Color attributes

Color parameters (CIE L*, a*, b*) were measured using a colorimeter (Minolta Model CR-400, Minolta, Japan) under standard ambient illumination. The device was calibrated against a white reference plate. The a∗a^*a∗ value represents the green-to-red spectrum, the b∗b^*b∗ value corresponds to the blue-to-yellow spectrum, and the L∗L^*L∗ value indicates lightness, ranging from dark to light.

2.3.3. Determination of total phenolic compounds

The total phenolic content was measured using the Folin-Ciocalteau method. The samples were homogenized with 80% acetone and then centrifuged for 15 minutes at 800g. A 0.5 ml aliquot of the clear supernatant was mixed with 5 ml of Folin-Ciocalteau reagent and allowed to react for 5 minutes. Then, 4 ml of 1% Na_2CO_3 was added. The absorbance of the reaction was measured at 765 nm after 1 hour of incubation at room temperature. Results were expressed as gallic acid equivalents, with a calibration curve for gallic acid prepared beforehand for the calculations [10].

2.3.4. Antioxidant activity

Various methods have been used to assess the antioxidative potential of materials. The DPPH (1,1-diphenyl-2-picrylhydrazyl) assay is a quick and cost-effective technique commonly employed to evaluate the antioxidative potential of natural products. The DPPH radical scavenging activity was determined using a method previously described by some authors, with slight modifications. After homogenizing the samples in methanol as the solvent, the mixture was centrifuged for 15 minutes at 800g. A 1 mL aliquot of the supernatant was mixed with 4 mL of a 0.004% methanolic DPPH solution. The percentage of DPPH decolorization in the samples was calculated using equation 4 [10].

$$Antioxidant\ Activity = \frac{(Absorbance\ of\ control - Absrbance\ of\ sample)}{Absorbance\ of\ control} \times 100 \quad (2)$$

2.3.5. Rheological measurements

The rheological characteristics of the white chocolate samples were measured using a rheometer (Anton Paar, MCR301, Austria) at ambient temperature. In aqueous solutions, viscosity significantly influences the 'mouthfeel' during consumption. Therefore, rheological properties can provide valuable information about the sensory characteristics of the chocolate [4]. Before quantification, the samples were melted by incubation for 75 minutes at 50°C and pre-sheared for 15 minutes at a shear rate of 5 s^{-1} at 40°C prior to starting the measurement cycles. Shear stress was then determined as a function of shear rate over a range of 5 to 50 s^{-1} [19]. The data were fitted to various mathematical models, including Power Law, Bingham, Herschel-Bulkley, and Casson models. To select the best model that described the steady rheological properties of the samples, two statistical indices—Root Mean Square Error (RMSE) and the coefficient of determination—were used. Additionally, rheological parameters such as plastic viscosity and yield stress values of the selected models were assessed.

2.3.6. Sensory evaluation

The goal of the sensory analysis was to assess consumer preference for chocolate with total sucrose replacement and chocolate with partial sucrose replacement. Sensory attributes of the white chocolates, including color, appearance, flavor, texture, and overall acceptability, were evaluated in individual booths under white light at ambient temperature. In accordance with ethical guidelines, a trained panel of 20 participants, aged between 27 and 40 years, rated the samples using a five-point hedonic scale (1 = extremely undesirable, 5 = extremely desirable). The samples were presented to the panelists in random order, each identified with a three-digit code, and water was provided for mouth rinsing between samples.

2.4. Statistical analysis

Quantitative data are presented as mean ± SD values from three replicates. Statistical analysis was conducted using a two-level full factorial design for four factors with SAS (version 9.2) software. One-way ANOVA, followed by Duncan's multiple comparison test, was used to determine significant differences ($P < 0.05$) between the means of the analyzed values. Sensory evaluation results were analyzed using the Kruskal-Wallis test. Additionally, Pearson correlation analysis was performed to explore interactions between the factors.

3. Results and discussion

3.1. Fat content and total sugar

The fat content of sucrose-free chocolates ranged from 30% to 34%, while the total sugar content ranged from 21% to 30%. Variations in fat and sugar content among the samples were directly related to the mango peel powder, which contained 4.2 ± 0.1% fat and 8.8 ± 0.8% total sugar. Increasing the amount of mango

peel powder significantly increased both fat and sugar content, whereas tagatose did not affect these values (Table 2). These changes in fat and sugar content influenced the physicochemical properties of the chocolate. These findings are in line with those reported by Kayode and Sani (2008) [20]and Ajila et al. (2010) [21], which demonstrated that increased incorporation of mango peel powder significantly raised fat content in cake and pasta, respectively.

Table 2. The proximate properties of treated white chocolates (per 100 g) (T1 to T16 are the codes of treatments according to Table 1).

Data represent averages of three independent repeats ± standard deviation. [a-d] For the same parameter means within the same column and line effect with different superscript letters are significantly different ($p< 0.05$) employing One-way ANOVA followed by Duncan's multiple comparison test.

Treatment	Fat (%)	Total sugar (%)	Calorie (kJ)	Moisture (%)	a_w	Acidity (mg NaOH/g)	L*	a*	b*
T1	34.11±0.00^{a}	30±0.00^{a}	455±0.00^{a}	1.09±0.00^{a}	0.369±0.00^{a}	0.20±0.00^{a}	15±0.00^{e}	0.355±0.00^{c}	15±0.00^{d}
T2	34.11±0.00^{a}	30±0.00^{a}	423±0.00^{a}	0.98±0.00^{b}	0.343±0.00^{b}	0.20±0.00^{a}	16±0.00^{d}	0.411±0.00^{a}	16±0.00^{d}
T3	34.11±0.00^{a}	30±0.00^{a}	397±0.00^{b}	0.92±0.00^{c}	0.338±0.00^{b}	0.20±0.00^{a}	19±0.00^{c}	0.421±0.00^{a}	19±0.00^{c}
T4	34.11±0.00^{a}	30±0.00^{a}	385±0.00^{b}	0.90±0.00^{c}	0.324±0.00^{c}	0.20±0.00^{a}	21±0.00^{b}	0.435±0.00^{a}	25±0.00^{a}
T5	33.00±0.00^{b}	27±0.00^{b}	409±0.00^{a}	0.99±0.00^{b}	0.351±0.00^{a}	0.18±0.00^{b}	19±0.00^{c}	0.344±0.00^{c}	19±0.00^{c}
T6	33.00±0.00^{b}	27±0.00^{b}	393±0.00^{b}	0.97±0.00^{b}	0.343±0.00^{b}	0.18±0.00^{b}	21±0.00^{b}	0.355±0.00^{b}	21±0.00^{c}
T7	33.00±0.00^{b}	27±0.00^{b}	384±0.00^{b}	0.95±0.00^{c}	0.321±0.00^{b}	0.18±0.00^{b}	22±0.00^{b}	0.361±0.00^{b}	22±0.00^{b}
T8	33.00±0.00^{b}	27±0.00^{b}	375±0.00^{c}	0.93±0.00^{c}	0.314±0.00^{b}	0.18±0.00^{b}	23±0.00^{a}	0.371±0.00^{b}	23±0.00^{b}
T9	31.00±0.57^{c}	23±0.00^{c}	375±0.00^{c}	0.98±0.00^{b}	0.333±0.00^{b}	0.16±0.00^{c}	21±0.00^{b}	0.331±0.00^{d}	21±0.00^{d}
T10	31.001±0.57^{c}	23±0.00^{c}	356±0.00^{c}	0.96±0.00^{b}	0.315±0.00^{b}	0.16±0.00^{c}	22±0.00^{b}	0.338±0.00^{d}	22±0.00^{c}
T11	31.00±0.57^{c}	23±0.00^{c}	325±0.00^{d}	0.94±0.00^{c}	0.205±0.00^{d}	0.16±0.00^{c}	23±0.00^{a}	0.343±0.00^{d}	23±0.00^{c}
T12	31.00±0.57^{c}	23±0.00^{c}	305±0.00^{d}	0.93±0.00^{c}	0.200±0.00^{d}	0.16±0.00^{c}	24±0.00^{a}	0.355±0.00^{d}	24±0.00^{b}
T13	30.00±0.00^{d}	21±0.00^{d}	329±0.00^{c}	0.97±0.00^{b}	0.325±0.00^{b}	0.14±0.00^{d}	21±0.00^{b}	0.325±0.00^{d}	18±0.00^{d}
T14	30.00±0.00^{c}	21±0.00^{d}	301±0.00^{d}	0.95±0.00^{c}	0.310±0.00^{c}	0.14±0.00^{d}	22±0.00^{b}	0.333±0.00^{c}	19±0.00^{c}
T15	30.00±0.00^{c}	21±0.00^{d}	275±0.00^{c}	0.91±0.00^{c}	0.209±0.00^{d}	0.14±0.00^{d}	23±0.00^{a}	0.342±0.00^{c}	20±0.00^{c}
T16	30.00±0.00^{c}	21±0.00^{d}	255±0.00^{e}	0.87±0.00^{d}	0.198±0.00^{d}	0.14±0.00^{d}	25±0.00^{a}	0.348±0.00^{c}	21±0.00^{b}

3. 2. Calorie estimation

Table 2 presents the assessed caloric values of the sucrose-free and control chocolate formulations. Samples containing mango peel powder show a significant difference compared to the control. Increasing the amount of mango peel powder leads to an increase in the caloric value. The highest caloric value is found in chocolates with 15% mango peel powder, while the lowest caloric value is in chocolates without any mango peel powder. In contrast, the addition of tagatose results in a reduction in caloric value. Tagatose powder (<0.5 kJ/100 g)

has a lower caloric value compared to mango peel powder (>90 kJ/100 g), so the highest caloric value corresponds to the T1 sample, which contains the most mango peel powder and the least tagatose. The control formulation (without mango peel powder and tagatose, T13) had a composition and caloric value (329 kJ/100 g) similar to that of commercial white chocolate.

3. 3. Moisture content and water activity

Increasing the amount of mango peel powder leads to an increase in moisture content (Table 2). The highest moisture content is found in chocolates containing 15% mango peel powder, while the lowest moisture content is in the chocolate sample without any mango peel powder. Conversely, the addition of tagatose results in a reduction in moisture content. Tagatose powder (<0.2%) has a lower moisture content compared to mango peel powder (max 1%), and tagatose itself demonstrates less tendency to absorb and retain moisture. The mean values and standard deviations of the water activity for all the white chocolate samples are presented in Table 2. For the samples containing mango peel powder and tagatose, water activity ranged from 0.198 to 0.369, while for the sucrose-containing samples, it ranged from 0.202 to 0.399. The water activity of the chocolate samples was within the acceptable limit (aw < 0.4), which is below the threshold for microbial growth in food [8]. The findings indicate that the water activity values were suitable for the shelf life and stability of the samples. The increase in tagatose resulted in a significant reduction in water activity, likely due to its lower water absorption compared to sucrose-sweetened white chocolate. On the other hand, increasing the level of mango peel powder led to a significant increase in water activity, which is attributed to the higher moisture content (Table 2).

3. 4. Acidity

The results (Table 2) show that the acidity value is influenced by the fat content of the sample, increasing with higher fat or fatty acid content. Tagatose had no significant effect ($p > 0.05$) on the acidity value of the white chocolates. Increasing the concentration of mango peel powder led to a significant rise in the acidity value. The highest total acidity value was observed in chocolates containing 15% mango peel powder, while the lowest acidity value was found in the control sample, which did not contain any mango peel powder (Table 2).

3. 5. Color attributes

Chocolate is designed to meet consumer expectations, and color is one of its most important commercial attributes [22]. The results presented in Table 2 show significant differences ($P < 0.05$) in color. The findings indicate that mango peel powder and tagatose affected the L*, a*, and b* values in a linear manner, but these parameters were also influenced by interactions between the

ingredients. The differences in L* values could be attributed to variations in the surface properties, particularly roughness, of the chocolate, which were influenced by the combination of mango peel powder and tagatose. This is despite the fact that the composition and processing were consistent across all the samples [5]. Increasing the tagatose content leads to a significant increase in L* values (Table 2), making the white chocolate appear lighter as tagatose levels rise. Tagatose, being a reducing sugar, contributes to the fading of color, with L*, a*, and b* values increasing as tagatose content improves. The presence of water primarily influenced L*, which increased linearly as water content decreased. The lightness of the chocolate samples with tagatose differed significantly from the control (the chocolate sample with sucrose) [10]. Replacing sucrose with mango peel powder as a source of β-carotene resulted in darker chocolate. This effect was most pronounced in the T10 sample (containing 15% mango peel powder), which was significantly darker ($P<0.05$) than the other samples. In terms of L* values, chocolate samples containing mango peel powder exhibited lower L* values compared to the reference sample made with sucrose. The results showed that decreasing the amount of mango peel powder and increasing tagatose in the formulation led to increased lightness, with the highest L* values observed in sample 16. The presence of yellow and red tones in the enriched chocolates significantly ($p<0.05$) increased with the addition of mango peel powder. The increase in b* values can be attributed to the β-carotene content in mango peel powder. These findings align with the results reported by Ajila et al. (2010) [21]. The highest values for the a* and b* parameters were observed in sample 4, while the lowest values for both parameters were found in the reference sample.

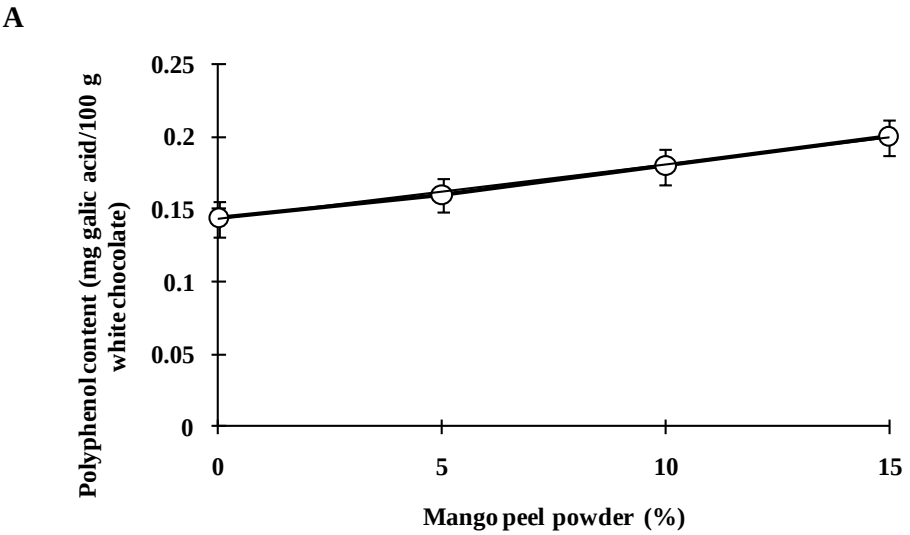
3. 6. Total phenolic content

The results of the phenolic content in chocolate samples, as shown in Fig. 1A, indicated that the addition of tagatose had no significant effect ($p>0.05$) on the total phenolic content of the white chocolates. However, an increase in the mango peel powder concentration led to a significant rise in the total phenolic content. As previously mentioned, mango peel is a rich source of dietary antioxidants, such as phenolic compounds [23]. The total phenolic content of the mango peel powder used in the study was approximately 105.6 ± 0.2 mg gallic acid/100 g. The most abundant phenolic compounds in mango peel are flavonoids and mangiferin [24]. The highest total phenolic content (0.2 mg gallic acid/100 g) was found in the chocolate sample containing 15% mango peel powder, while the lowest phenolic content was observed in the chocolate sample that did not contain any mango peel powder. Numerous studies have demonstrated the health benefits of the phenolic

compounds in mango peel, including their bioaccessibility and bioavailability [25].

3.7. Scavenging free radicals activity

As can be observed, tagatose had no statistically significant effect ($p>0.05$) on the free radical scavenging activity of the white chocolates. However, increasing the levels of mango peel powder resulted in a substantial increase in free radical scavenging activity. This enhancement in scavenging activity can be attributed to the increase in polyphenols and carotenoids content as a result of incorporating the mango peel powder [21]. Mango peel has significant antioxidant activity due to its richness in bioactive compounds, including phenolic compounds (such as quercetin, quercetin O-glycosides, isoquercitrin, quercitrin galactoside, 3,4-dihydroxybenzoic acid, ellagic acid, mangiferin, isomangiferin, homomangiferin, mangiferin 3-C-6-O-p-hydroxybenzoic acid, and xanthones), carotenoids, tocopherols, and sterols (such as ß-sitosterol, Δ-avenasterol, campesterol, and stigmasterol) [23]. The highest free radical scavenging activity was observed in the chocolate sample containing 15% mango peel powder, while the lowest scavenging activity was found in the control sample, which did not contain any mango peel powder (Fig. 1B).



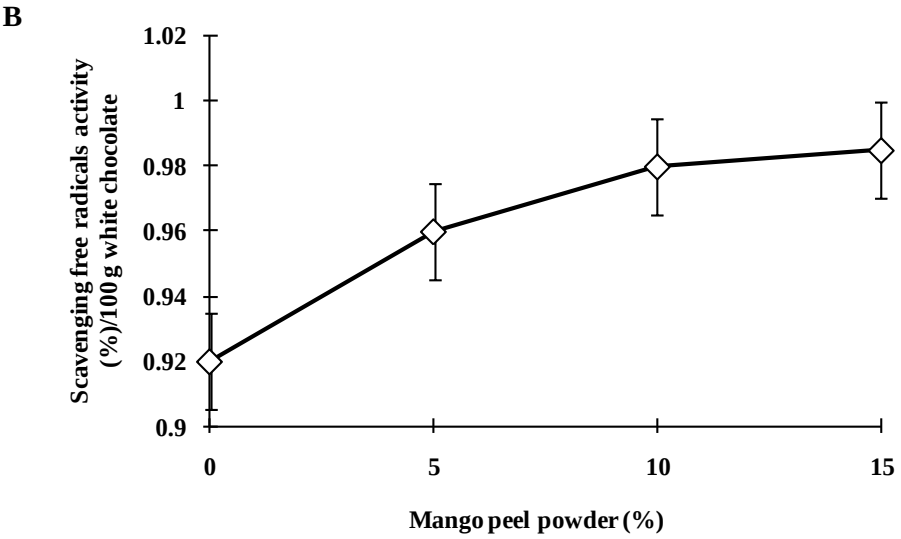


Fig 1. The effects of mango peel powder on total phenolic content (A) and scavenging free radicals activity (B) of white chocolates prepared in this research.
Data represent averages of three independent repeats.

3. 8. Rheological properties

Rheological properties directly impact the texture of chocolate. Harder chocolates are achieved when the melted product has lower plastic viscosity, while an increase in viscosity results in a softer final product. These characteristics of the samples have been previously established [6]. The rheological properties of chocolate are crucial in industrial processes for achieving high-quality yields with consistent quality. Chocolates with high viscosity tend to have a pasty mouthfeel, lingering in the mouth. Shear stress refers to the energy required to initiate flow and is related to the interparticle interaction forces at rest. Yield stress is a material property that denotes the minimum shear stress needed to initiate flow, marking the transition from elastic to viscous deformation [4].

To evaluate the rheological properties, the shear rate was plotted against shear stress (Fig. 2), providing a clear and concise representation of the data. The results revealed significant differences ($p \leq 0.05$) between the formulated chocolates containing mango peel powder and tagatose compared to the control. The findings demonstrated that incorporating mango peel powder and tagatose into the white chocolate formulation altered its rheological properties. Notably, the lowest yield stress was observed in sample T4, which contained 15% mango peel powder and 33% tagatose powder. The results

showed that there was no significant difference between the control and sample T10, which contained 5% mango peel powder and 11% tagatose powder. Chocolate viscosity is crucial for pumping purposes. The apparent viscosity of chocolates containing high concentrations of mango peel powder (15%) and tagatose (33%) was significantly lower than that of the control. Consequently, it can be concluded that replacing sucrose with mango peel powder and tagatose reduces the yield stress. The low yield stress in samples with a high percentage of mango peel powder and tagatose indicates that the interaction forces between particles were weak, requiring less force to overcome these forces and facilitate the flow of chocolate. To find a suitable model, the fitting of experimental data was assessed based on the coefficient of determination (R^2) and standard error (SE) parameters. At lower levels of mango peel powder and tagatose, the chocolate behavior resembled that of a Bingham fluid, while at higher levels, the behavior was more like that of a Casson fluid. The statistical calculations showed that the Casson model provided the highest R^2 value and the lowest standard error (Table 3).

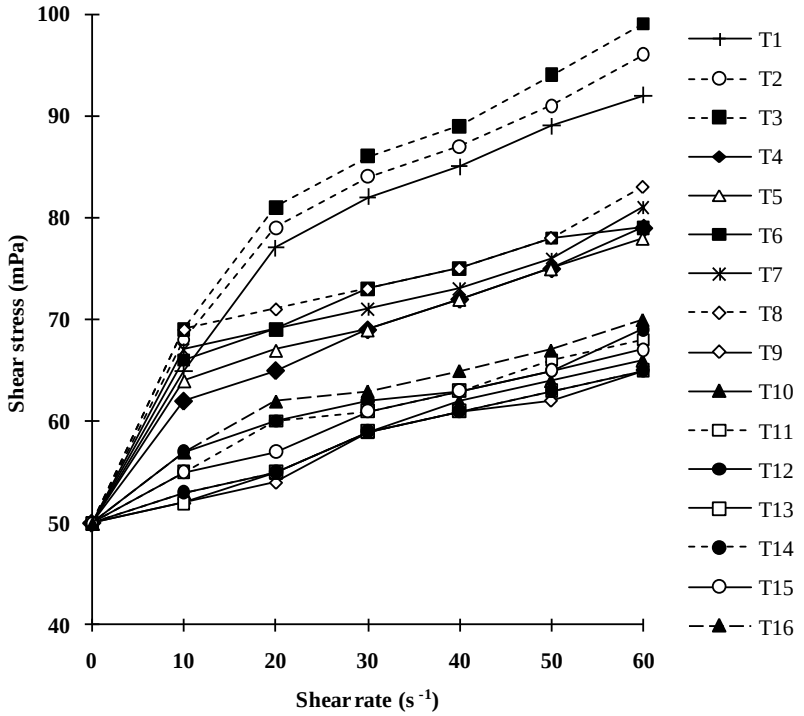


Fig 2. Rheological properties of treated white chocolates (T1 to T16 are the codes of treatments according to Table 1) (Data represent averages of three independent repeats).

Table 3. Effects of mango peel powder and tagatose on fitting of experimental data with mathematical models based on coefficient of determination (R^2) and standard error (SE) parameters

T1 to T16 are the codes of treatments according to Table 1.

Treatment	Model	R^2	SE	Treatment	Model	R^2	SE
T1	Herschel-Bulkley	0.99971	0.0886	**T9**	Herschel-Bulkley	0.99974	0.00623
	Bingham	0.99773	0.009		Bingham	0.99775	0.00534
	Casson	0.99965	0.008		Casson	0.99967	0.00119
T2	Herschel-Bulkley	0.99970	0.083	**T10**	Herschel-Bulkley	0.99974	0.00567
	Bingham	0.99771	0.009		Bingham	0.99775	0.00523
	Casson	0.99967	0.009		Casson	0.99967	0.00167
T3	Herschel-Bulkley	0.99969	0.0754	**T11**	Herschel-Bulkley	0.99974	0.00478
	Bingham	0.99767	0.0087		Bingham	0.99775	0.00517
	Casson	0.99963	0.0093		Casson	0.99967	0.231
T4	Herschel-Bulkley	0.99967	0.0723	**T12**	Herschel-Bulkley	0.99974	0.00451
	Bingham	0.99767	0.00765		Bingham	0.99775	0.00456
	Casson	0.99961	0.0123		Casson	0.99967	0.221
T5	Herschel-Bulkley	0.99973	0.0709	**T13**	Herschel-Bulkley	0.99972	0.0346
	Bingham	0.99773	0.0081		Bingham	0.99774	0.00345
	Casson	0.99965	0.0135		Casson	0.99967	0.209
T6	Herschel-Bulkley	0.99972	0.0712	**T14**	Herschel-Bulkley	0.99972	0.04445
	Bingham	0.99771	0.00756		Bingham	0.99773	0.00267
	Casson	0.99964	0.0129		Casson	0.99966	0.0118
T7	Herschel-Bulkley	0.99974	0.0657	**T15**	Herschel-Bulkley	0.99971	0.00332
	Bingham	0.99770	0.00712		Bingham	0.99772	0.0335
	Casson	0.99963	0.0113		Casson	0.99965	0.119
T8	Herschel-Bulkley	0.99974	0.633	**T16**	Herschel-Bulkley	0.99970	0.801
	Bingham	0.99769	0.00564		Bingham	0.99771	0.233
	Casson	0.99962	0.00123		Casson	0.99963	0.0334

3. 9. Sensory properties

The results are displayed in Fig. 3. As observed, there was a substantial difference between the treatments in terms of all properties. Panelists preferred the chocolates that did not contain any mango peel powder. The results confirmed that increasing the levels of tagatose and mango peel powder led to a significant decrease in the scores for the treatments. Other formulations, though the difference was small, were significantly ($P<0.05$) less preferred than T13 and T14. Regarding the panelists' perception of good-quality chocolate, texture is considered one of the most important attributes. The texture of all chocolate samples in this study ranged from 2.5 to 5. Replacing sucrose with tagatose significantly ($P<0.05$) lowered the texture suitability. The texture value of sample no. 10, which contained 5% mango peel powder and 11% tagatose, was higher than the other treatments containing mango peel powder. Flavor is another sensory property that plays a crucial role in the sensory impression of foods. The evaluation of flavor in our study showed that sucrose-free chocolates were significantly ($P<0.05$) less preferred than the control. The T10 sample, which contained 5% mango peel powder and 11% tagatose, was again perceived as the most liked (5). For overall acceptability, the study revealed that the mean overall liking for the chocolates containing tagatose and mango peel powder was lower than the control. However, sample T10 exhibited the highest overall acceptability among the treatments. The highest sensory scores were attributed to the control white chocolate, followed by the T10 sample. This suggests that improving sucrose-free chocolate is crucial for achieving high sensory acceptance.

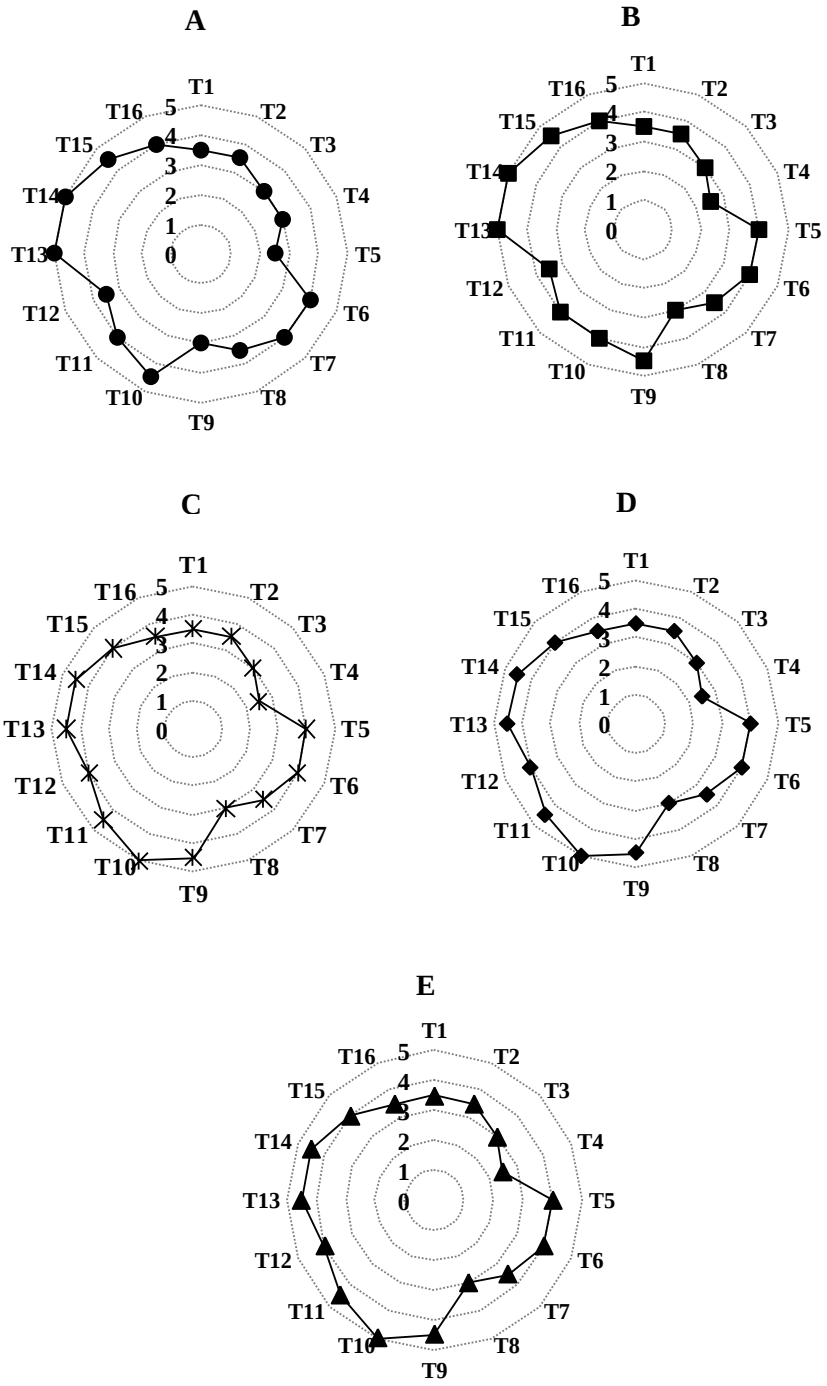


Fig 3. Effects of sugar substitutes on sensory properties of treated white chocolates; color (A), appearance (B), flavor (C), texture (D), and overall acceptability (E) (T1 to T16 are the codes of treatments according to Table 1) Data represent averages of three independent repeats.

4. Conclusion

Health concerns have grown due to the increasing prevalence of overweight and obesity in today's world, creating a need for products with reduced sugar and fat content. This demand has become a market trend. A sucrose-free white chocolate bar with tagatose as a sweetening agent and mango peel powder was successfully developed. Mango peel, often discarded as waste, is an excellent source of antioxidant compounds. The combination of tagatose and mango peel powder in the chocolate resulted in physico-chemical and sensory characteristics very similar to those of sucrose-sweetened white chocolate. The addition of mango peel powder to sucrose-free chocolate formulations did not significantly affect the composition. It can be concluded that chocolate samples containing mango peel powder and tagatose are suitable sucrose substitutes, as mango peel powder is a source of dietary fiber and tagatose possesses prebiotic properties. Chocolate samples made with these ingredients are not only nutritionally beneficial but also have the potential to be considered functional foods. Mango peel powder significantly ($p<0.05$) affected the scavenging free radicals activity, total polyphenol content, and acidity value of the white chocolates, increasing these properties. While there were some limitations in this project, such as a shortage of equipment and resources, we aim to expand this research on a larger scale to introduce this new functional product to the market. Additionally, further research on incorporating mango peel as a source of bioactive components into other functional foods would be valuable.

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فصلنامه فناوری‌های جدید در صنعت غذا، دوره ۱۱، شماره ۳، صفحه ۲۹۴– ۲۷۶، بهار ۱۴۰۳

مقاله پژوهشی

تعیین خصوصیات شکلات سفید فراسودمند غنی شده با پوست انبه و تاگاتوز: تحقیق کاربردی

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(تاریخ ارسال: ۱۴۰۳/۰۴/۱۷، تاریخ بازنگری: ۱۴۰۳/۰۹/ ۱۲، تاریخ پذیرش: ۱۴۰۳/۰۹/۱۴)

چکیده

امروزه با گسترش روز افزون دیابت و تمایل مصرف کنندگان به مصرف محصولات فراسودمند، فرمولاسیون محصولات رژیمی به طور گسترده ای مورد توجه قرار گرفته است. برای این منظور در این تحقیق، از پودر پوست انبه در سطوح ۰، ۵، ۱۰ و ۱۵ درصد و همچنین تاگاتوز در سطوح ۰، ۱۱، ۲۲ و ۳۳ درصد در فرمولاسیون شکلات سفید استفاده شد. نمونه های شکلات از نظر ویژگی های رئولوژیکی، حسی و فیزیکوشیمیایی (رطوبت، اسیدیته، قند کل، چربی، فعالیت آبی و شاخص های رنگی) و هم چنین میزان کالری، محتوای ترکیبات فنلی و قدرت مهارکنندگی رادیکال آزاد مورد ارزیابی قرار گرفتند. نتایج نشان داد که با افزایش میزان پودر پوست انبه، میزان رطوبت، فعالیت آبی، قند کل و چربی در نمونه های شکلات به طور معنی داری افزایش و با استفاده از تاگاتوز، رطوبت و فعالیت آبی کاهش یافتند ($p\leq ۰/۰۵$). در مجموع، نمونه T10 حاوی ۵٪ پودر پوست انبه و ۱۱٪ تاگاتوز به سبب ویژگی های مناسب و امتیاز ارگانولپتیکی بالا، به عنوان بهترین فرمولاسیون جهت غنی سازی شکلات سفید انتخاب شد. افزودن پودر انبه، باعث ارتقای ویژگی های تغذیه ای شکلات شده و هم چنین با افزایش قدرت آنتی اکسیدانی، پتانسیل آن به عنوان یک فرآورده غذادارو را بهبود بخشید.

واژه‌های کلیدی: فعالیت آنتی اکسیدانی، پوست انبه، ترکیبات فنلی، شکلات سفید.

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