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Research Article

Calorie content, physicochemical properties, and textural characteristics of dark chocolate enriched with date pulp and sesame fiber

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Abstract This study explores the use of date pulp (DP) and sesame fiber (SF) as replacements for sucrose and milk powder in dark chocolate to improve its nutritional profile. DP, extracted from Shahani dates, and SF, derived from sesame flour, are known for their antioxidant properties and health benefits. Chocolate formulations were prepared by substituting sucrose with DP and milk powder with SF in varying ratios. Fundamental analyses included antioxidant activity (DPPH assay), moisture, acidity, fat, sugar content, texture, and calorie value, with statistical evaluation using ANOVA and DMRT. Results indicated that increasing DP and SF levels enhanced antioxidant activity, with the highest DPPH inhibition observed at 20% DP and 8% SF ($p<0.05$). Moisture, acidity, and fat content rose, while sugar content declined significantly ($p<0.05$). Texturally, chocolates became softer with decreased yield stress and maximum force as DP and SF increased. Calorie content also rose notably with higher DP and SF proportions. In conclusion, substituting DP and SF improves dark chocolate's antioxidant capacity, moisture, and texture while reducing sugar content. However, it also results in increased fat and calorie content. These findings suggest that DP and SF may enhance the nutritional value of dark chocolate as well as its textural properties when applied in a balanced ratio.

Keywords dark chocolate, date pulp, sesame fiber, by-product, fortification

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1. Introduction

The burgeoning domain of food functionalization necessitates the exploration of novel bioactive constituents to foster the development of innovative functional products underpinned by scientifically substantiated assertions. Recent emphasis has been placed on investigating natural compounds and their associated bioactive properties. Nonetheless, given the finite nature of natural reservoirs, a critical imperative exists to identify alternative reservoirs to cater to the escalating requisites of the food industry for ingredients and additives (Faustino et al., 2019).

In addition, globally, food production yields a significant volume of by-products, ranging from fruit and vegetable peels to animal bones and unused portions from processing operations, constituting a substantial portion of the total food produced annually. It has been estimated that approximately one-third of all food intended for human consumption is lost or wasted worldwide each year, encompassing edible food and generated by-products throughout the food supply chain. This waste contributes to environmental issues such as greenhouse gas emissions and pollution and signifies a loss of valuable resources. Therefore, there is an increasing emphasis on minimizing food waste and valorizing by-products through strategies like recycling and conversion into value-added products (Parfitt et al., 2010).

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Hence, fortification of the food products with by-products such as date pulp (DP) and sesame fiber (SF), which are by-products of date and sesame seed processing, can be an effective way to improve the nutritional value of foods while managing the by-products. Investigated the effects of incorporating DP into wheat flour cookies across various proportions have already shown significant alterations in composition, physical traits, antioxidant activity, and sensory aspects, with cookies containing DP showing increased phenolic and flavonoid content, improved antioxidant activity, and favored sensory attributes, albeit higher concentrations leading to changes in color and sensory profiles (Tahir et al., 2023). Also, another study aimed to create functional ice cream by adding varying percentages of Medjool DP, observing increases in total solids, ash, crude fibers, iron, potassium, and magnesium content, as well as viscosity, specific gravity, and weight per gallon, while pH, freezing point, overrun, and melting resistance decreased, with ice cream containing up to 15% DP receiving higher sensory scores, indicating its potential as a source of dietary fibers and minerals to enhance the product's nutritional and functional value (Farahat et al., 2011). Supplementing halva with by-products like defatted sesame seed coats and date fiber concentrate in research by Elleuch et al. (2014) improved its nutritional and sensory properties, offering high fiber content and technological advantages in water and fat retention, with the addition of both fibers along with an emulsifier notably enhancing emulsion stability and increasing halva hardness, thus promoting health and nutrition through the supply of polyphenol antioxidants and potential laxative effects (Elleuch et al., 2014).

The 70% dark chocolate is renowned for its robust flavor profile and potential health advantages, primarily attributed to its abundant cocoa solids, which are rich in antioxidants like flavonoids, polyphenols, and catechins. These antioxidants are linked to various health-enhancing effects, including better cardiovascular health, improved blood circulation, and a lowered risk of specific chronic ailments. Moreover, indulging in dark chocolate with high cocoa content may positively impact mood and cognitive function, courtesy of its moderate caffeine and theobromine levels, offering a subtle energy lift. However, it is crucial to exercise moderation in consumption due to its high calorie and fat content. Opting for dark chocolate with at least 70% cocoa content and minimal added sugar is advisable to maximize potential health perks (Katz et al., 2011; Nehlig, 2013).

This study focuses on producing novel functional chocolate, we investigated the effects of incorporating DP and SF on the physicochemical and textural characteristics of 70% dark chocolate. Considering the interest in dietary fibers for their health-promoting properties and the increasing utilization of date products as natural sweeteners, our research aims to optimize the chocolate formulation. Sucrose in dark chocolate was partially substituted with DP at concentrations of 5% and 10% and SF at concentrations ranging from 2% to 8%. Various analyses, including 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical inhibition, acidity, fat, sugar, and moisture content, as well as textural properties and caloric content, were conducted to assess the effects of these by-products to be utilized in the formulation of functional food.

2. Materials and methods

2.1. Extraction of date pulp (DP)

A modified extraction procedure, based on the methods of Muñoz-Tebar et al. (2023) and Tahir et al. (2023), was applied to obtain date pulp (DP). First, Shahani dates (Tekchin Food Products Co., Tehran, Iran) were peeled and then immersed in boiling water, stirring with a magnetic stirrer for 15 min to dissolve sugars (sucrose, glucose, and fructose). After complete sugar dissolution, the date fibers were separated using a 2.0 mm sieve. The fibers were then rinsed at 40℃, filtered to remove impurities, and dried in an oven at 65℃ for 24 h. Once dried, the fibers were milled initially at 2,890 rpm and then at 5,000 rpm. Finally, the milled material was sieved through a 0.2 mm mesh to produce the DP.

2.2. Extraction of sesame fiber (SF)

A novel methodology, inspired by the techniques of Zhang et al. (2021), was developed for producing sesame fiber extract (SF). Sesame fiber (Damhert Nutrition Co., Heusden-Zolder, Belgium) at a concentration of 1 g (dry weight) was combined with a solvent mixture of distilled water (50% w/w), ethanol (1% w/v), and sodium hydroxide (2% w/v). This blend was heated in a water bath at 90℃ for 25 min, after which any residual alcohol was removed through evaporation with a condenser.

The methanol-ethanol solution was then boiled at 77℃ before being transferred to a 90℃ water bath, creating a controlled environment for partial evaporation. This step allowed the concentration of the solution without complete solvent depletion, thereby optimizing the solvent balance and enhancing compound extraction from the sesame flour matrix in the 90℃ phase. Following a 30-min extraction period, the solution was centrifuged at 2,600 ×*g* for 15 min in room temperature to separate the supernatant, yielding the SF.

To neutralize alkaline components, a 3M chlorine hydroxide solution was added, followed by a second round of centrifugation. The resulting supernatant extract was further processed using a rotary vacuum evaporator (model A-1000S, EYELA Co., Tokyo, Japan) at 60℃, allowing the efficient solvent removal and preservation of heat-sensitive compounds in sesame flour extract, while also enhancing concentration and freeze-drying efficiency. Finally, the extract was freeze-dried and reconstituted in 10 mL of methanol.

2.3. Formulation of fortified dark chocolate

The research focuses on functional dark chocolate with a cocoa content of 70%. The methodology outlined by Tolve et al. (2018) served as the model for preparing the chocolate in this study. The formulation for the dark chocolate comprised 28% milk powder, 39% cocoa butter, and 33% sugar for the control chocolate. The compositions for the treatment groups were determined based on Table 1, which specified the replacement proportions of sucrose with DP and the substitution of milk with SF. The determination of the mentioned concentrations, including date pulp percentage of ≤20% and sesame fiber percentage of ≤8%, was obtained through a pre-test, considering overall texture; this was also followed by the determining the combination type for treatments according to textural properties of dark chocolate highlighted by Iranian National Standard Organization No. 608 (INSO, 2016). Furthermore, the cocoa fiber content was reduced in the treatment formulations. The percentage composition of each component can be observed in the table below.

2.4. Measurement of DPPH free radical scavenging activity

In the measurement of antioxidant activity through DPPH radical inhibition, a control sample (containing only the DPPH solution without any extract) was measured to establish a baseline absorbance at 517 nm. Additionally, a known antioxidant standard, ascorbic acid, was used to compare and quantify the antioxidant capacity of the sample. The procedure entailed mixing 4 mL of a 0.1 mM DPPH solution with 0.2 mL of the sample, measuring the absorbance at 517 nm, and adding the extract to the DPPH solution. After thoroughly mixing, the solution was allowed to stand at room temperature for 60 min. Absorbance was re-recorded at 517 nm, and the antioxidant activity was calculated as the percentage of DPPH inhibition relative to the control using the equation provided by Abdolmaleki et al. (2023).

$$\text{Antioxidant activity (\%)} = \frac{A_s - A_c}{A_c} \times 100 \qquad (1)$$

Where A_s is sample absorption, and A_c is control absorption.

2.5. Moisture measurement

Initially, the platinum capsule underwent a 30 min autoclaving procedure within a temperature range of 100-105℃. Subsequently, it was removed from the autoclave and allowed to cool within a desiccator until it reached equilibrium with the surrounding ambient temperature, following which its mass was recorded. A specific amount of the finely diced chocolate sample under scrutiny (minimum 2 g) was introduced into the capsule. Following this addition, the capsule containing the sample was precisely weighed to ensure accurate

Table 1. The percentage ratio of ingredients utilized across different treatments

Treatments	Milk powder	Cocoa butter	Sucrose	Date pulp (DP)	Sesame fiber (SF)
T	28	39	33	-	-
T_1	27	38	28	5	2
T_2	26	37	23	10	4
T_3	24	35	18	15	6
T_4	20	31	13	20	8

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measurements. The capsule with the sample was then subjected to a temperature range of 100-105℃ until a consistent mass was achieved. Subsequently, it was placed within a desiccator to cool before being reweighed. This heating, cooling, and weighing cycle was repeated until a stable and consistent mass was consistently obtained (Latifi et al., 2021). The following equation was used to determine the moisture percentage.

$$\text{Moisture (\%)} = \frac{W_1 - W_2}{W_{sc}} \times 100 \qquad (2)$$

Where W_1 is the first-stage sample weight, W_2 is the second-stage sample weight, and W_{sc} is the sum of the sample and container weight.

2.6. Acidity determination

The acidity evaluation followed the methodology outlined by Latifi et al. (2023). The acidity of the samples was assessed by titrating lipid fraction samples dissolved in a blend of ethanol and diethyl ether (1:1 v/v) with a 0.1 M potassium hydroxide solution, employing phenolphthalein as an indicator until a consistent pink coloration persisted for a minimum of 10 sec.

2.7. Fat content measurement

The fat content was assessed utilizing the methodology described by Mirzaei and Ardakani (2023), with modifications. In this process, the chocolate samples underwent melting at room temperature, followed by precise weighing of approximately 4-5 g into designated tubes. The inner surface of the tubes was thoroughly rinsed with 2 mL of hot water, after which they were subjected to a 20-min immersion in a water bath maintained at 60℃, intermittently shaken. Post-bath, 10 mL of ethyl alcohol was introduced into each tube, sealed, and shaken vigorously for 15 sec. The fat percentage was then computed using the following equation.

$$\text{Fat (\%)} = \frac{W_f - W_{fe}}{W_i} \times 100 \qquad (3)$$

Where W_i is the initial weight of the sample, W_f is the final weight of the sample and W_{fe} is the sample weight after fat extraction.

2.8. Sugar content measurement

A sugar analysis procedure involved preparing and clarifying the sample using potassium ferrocyanide (0.5% w/v) to create a proper solution, according to Ranganna (1986), with modifications. After sedimentation and filtration, the clarified filtrate was placed in a burette. Fehling's solutions A (copper sulfate) and B (sodium hydroxide) were mixed, heated, and reacted with 19 mL of the sugar solution. The titration began after the solution boiled, with sugar solution added dropwise until a brick-red precipitate formed. The endpoint, marked by the disappearance of the blue color, was confirmed with methylene blue, continuing titration until the indicator color disappeared. The quantity of the sugar was calculated according to the following equation.

$$\text{Sugar (\%)} = \frac{V_F - F_F}{W_s} \times 100 \qquad (4)$$

Where V_F is the volume of Fehling's solution used, F_F is Fehling's factor, and W_S is the sample weight.

2.9. Measurement of texture characteristics

A modified method, as outlined by Torbica et al. (2016), was implemented to evaluate the texture properties of the chocolate sample. Hardness evaluation involved placing the chocolate samples in a freezer for 2 h, followed by transfer to a refrigerated incubator (Zhal Tehiz Co., Karaj, Iran) maintained at 20℃. Subsequently, using a texture tester (Koopa Co., Iran), the hardness of the rectangular chocolate samples (50×25×10 mm) was determined. This tester featured a 1.6 mm smooth-bottom probe and operated at a penetration speed of 1.5 mm. The maximum force recorded at a depth of 6 mm was documented as the hardness index.

2.10. Determination of calorie content

The total calorie content (KJ) was determined using a bomb calorimeter (DA-TE10, Azad Azma Co., Tehran, Iran). This involved a specialized method that utilized oxygen and measured the energy released because of burning the sample (Hopper et al., 2024).

2.11. Statistical analysis

The experimental results are presented as the mean±standard deviation (SD) from three replications of each experiment. Statistical analysis was conducted using one-way analysis of variance (ANOVA) followed by Duncan's multiple-range test (DMRT) at a 0.05 significance level. The analysis was performed using SPSS Statistics (Ver. 27.0), and graphical representations of the data were created with Excel software (Ver. 2020).

3. Results and discussion

3.1. Free radical (DPPH) inhibition rate

The DPPH free radical inhibition measurement is a dependable, precise, cost-effective, and widely utilized method in research laboratories for evaluating the antioxidant efficacy of plant extracts (Latifi et al., 2019). As illustrated in Fig. 1, a clear upward trajectory in the rate of free radical inhibition of the chocolate formulations was observed with increasing percentages of DP and SF substitution ($p<0.05$). The formulation comprising 20% DP and 8% SF was particularly noteworthy, demonstrating the highest free radical inhibition level. In contrast, the control formulation containing DP and SF exhibited the lowest rate of free radical inhibition ($p<0.05$).

The control group (T) has the lowest inhibition rate at approximately 75 µg/mL, while T1 (5% DP-2% SF) slightly increases to 80 µg/mL, indicating a modest improvement with the addition of low levels of DP and SF. T2 (10% DP-4% SF) further enhances the inhibition rate to 87.75 µg/mL, showing a clear trend of increasing antioxidant

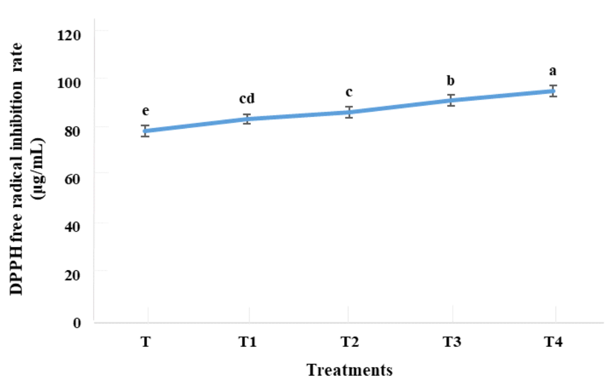

Fig. 1. The comparison of DPPH free radical inhibition rate (µg/mL) across different treatments of chocolate. Values are mean±SD (n=3). Different letters ([a-c]) on the bars indicate significant differences ($p<0.05$) between the DPPH inhibition rates of treatments (T, control; T1, 5% DP-2% SF; T2, 10% DP-4% SF; T3, 15% DP-6% SF; T4, 20% DP-8% SF).

activity as the concentrations of DP and SF double. In T3 (15% DP-6% SF), the inhibition rate rises significantly to 92.66 µg/mL, reinforcing the dose-dependent effect. Finally, T4 (20% DP-8% SF) achieves the highest inhibition rate of 96.62 µg/mL, marking a substantial improvement of more than 20 µg/mL compared to the control.

Analysis of the results presented in Fig. 1 reveals an escalating trend in the free radical inhibition rate in correlation with the augmentation of SF and DP in the chocolate formulations. While the observed increase in free radical inhibition with higher concentrations of SF and DP in the chocolate formulations may suggest the presence of phenolic compounds, no direct analysis was conducted in this study to confirm their presence. Therefore, the antioxidant activity observed is attributed to SF and DP based on their known composition from prior studies, which frequently highlight their phenolic content. Natural plant antioxidants containing phenolic compounds can engage in the oxygen chain by neutralizing singlet oxygen, chelating metals, and inhibiting oxidizing enzymes. These antioxidants act as electron donors, conferring stability to materials susceptible to oxidation. Sesame, for instance, contains various lignans, including sesamin and sesaminol, which account for many of its distinctive physiological and biochemical properties. The antioxidant, anti-mutagenic, and anti-inflammatory properties of sesame align with these findings, as the extracts' ability to inhibit free radicals is concentration-dependent and becomes more pronounced with higher concentrations. DP, likewise, is known to contain antioxidant compounds such as gallic acid, protocatechuic acid, parahydroxybenzoic acid, vanillic acid, caffeic acid, paracoumaric acid, ferulic acid, metacoumaric acid, and orthocoumaric acid, supporting similar findings in existing literature.

Recent studies have explored the potential of fortifying confectionery products with by-products to enhance their nutritional value and antioxidant properties. Researchers have investigated the use of freeze-dried raspberry pomace (Szymanowska et al., 2021), dried cranberry and cowberry extracts (Zambulaeva and Zhamsaranova, 2018), bee-keeping products with oat and pea meal (Chernenkova et al., 2019), and green and yellow tea leaves (Gramza-Michałowska et al., 2016) in various confectionery items. These fortified products demonstrated increased antioxidant capacity, with higher radical scavenging abilities and inhibition of enzymes involved in free radical generation (Szymanowska et al., 2021;

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Zambulaeva and Zhamsaranova, 2018). These by-products also resulted in elevated levels of phenolic compounds, dietary fiber, vitamins, and minerals (Chernenkova et al., 2019; Gramza-Michałowska et al., 2016). Sensory evaluations indicated consumer acceptance of the fortified products, with optimal scores achieved at specific fortification levels (Szymanowska et al., 2021). In a study aligned with the results of the present study, an evaluation of the antioxidant potential of dietary fiber extracted from plant by-products, such as date seed and sugarcane bagasse, revealed that at a concentration of 500 ppm, date seed dietary fiber exhibited a notably superior DPPH inhibition rate of 89.12% compared to ascorbic acid at 85.4%. Furthermore, elevating the concentration of dietary fiber resulted in a proportional increase in antioxidant activity (Afrazeh et al., 2021). Elleuch et al. (2012) reported that the scavenging effect on the DPPH radical by sesame seed coat extracts was inferior to that of BHA, with the lowest activity observed in the water extract, while at 0.5 mg, the scavenging effect of aqueous ethanol and methanol extracts were comparable (~94.4%) and surpassed those of aqueous acetone and water extracts, which were 92.4% and 90.2%, respectively. Additionally, in a study aimed at formulating a nutritious snack bar by incorporating date pit powder and soy protein isolate in date paste, antioxidant activity in date bars varied from 663.09 to 401.86 μg/g Trolox equivalents, with the treatment containing the date pit powder demonstrating the highest antioxidant activity, while the lowest was observed in the control treatment (Rukh et al., 2021).

3.2. Moisture content

As illustrated in Fig. 2, there was a noticeable increase in the moisture levels of chocolate treatments as the proportion of DP and SF replacement rose ($p<0.05$). Notably, the treatment containing 20% DP and 8% SF displayed the highest moisture percentage, while the control treatment with DP and SF exhibited the lowest moisture content ($p<0.05$). These findings, as depicted in Fig. 2, further affirm that augmenting the quantity of SF and DP significantly enhances the moisture percentage of chocolate treatments ($p<0.05$).

The control group (T) has the lowest moisture content, approximately 1.2%, while T1 (5% DP-2% SF) shows a slight increase to 1.3%, indicating a minor effect of DP and SF on moisture content at low concentrations. T2 (10% DP-4% SF) further raises the moisture content to 1.4%, demonstrating a clear upward trend. In T3 (15% DP-6% SF), the moisture content rises significantly to 1.6%, and T4 (20% DP-8% SF) reaches the highest moisture content of approximately 1.8%, marking a total increase of 0.6% compared to the control.

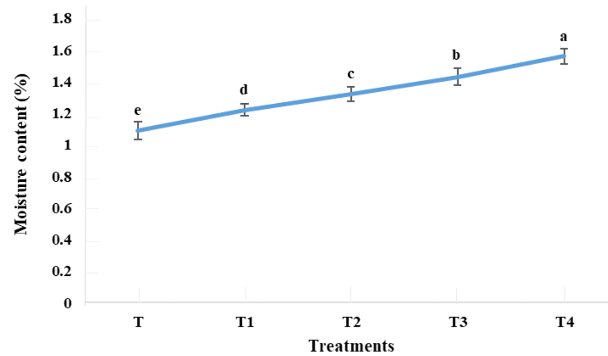

Fig. 2. The comparison of average moisture content (%) across different treatments of chocolate. Values are mean±SD (n=3). Different letters ([a-d]) on the bars indicate significant differences ($p<0.05$) between the average moisture content of treatments (T, control; T1, 5% DP-2% SF; T2, 10% DP-4% SF; T3, 15% DP-6% SF; T4, 20% DP-8% SF).

Moisture percentage plays a critical role in influencing the textural properties and shelf life of chocolate. Incorporating DP and SF in chocolate formulations increase moisture percentage ($p<0.05$). DP, possessing a natural moisture content of 21%, enhances the moisture level of chocolate treatments, particularly when combined with SF, which contains approximately 9% moisture. Moreover, the presence of polyphenolic and antioxidant compounds in sesame seeds and DP notably improves water retention ($p<0.05$). With an increase in the concentration of SF and DP, the abundance of hydroxyl groups rises, resulting in the T4 treatment reaching its peak moisture level. The Pearson correlation also demonstrates a positive and significant correlation between moisture percentage and sugar content in chocolate treatments. The transition from sucrose to fructose sugars leads to an elevation in hydroxyl groups within the product, consequently enhancing the moisture content of chocolate treatments. Considering all the outcomes, the increase in moisture content with higher proportions of DP and SF in chocolate formulations may be attributed to the inherent moisture levels of DP (21%) and SF (approximately 9%), as well as the abundance of hydroxyl groups in these ingredients, which contribute to enhanced water retention ($p<0.05$); additionally, the transition from sucrose to fructose sugars introduces more hydroxyl groups, further promoting moisture absorption and retention in the chocolate matrix.

Confectionery products fortified with by-products exhibit varying moisture content, which affects their texture, shelf life, and microbial stability. Citrus by-products used as fat replacers in bakery items can increase moisture content and improve textural properties (Caggia et al., 2020). Similarly, extruded snacks enriched with food processing by-products show increased dietary fiber and protein content, with optimal expansion achieved at 13-15% feed moisture (Korkerd et al., 2015). In a study examining dietary fibers extracted from plant by-products using alkaline hydrogen peroxide extraction, it was found that the moisture content of date seed dietary fiber was higher than that of bagasse dietary fiber (Afrazeh et al., 2021). Another study investigating the effect of date powder and peach pomace powder on the microstructure and functional attributes of cookies revealed that the moisture content of cookies rose with higher concentrations of date and peach powder blend, likely attributed to the elevated water retention capacity of peach and date powder, with more significant sugar and fiber in the dough, leading to increased water retention; thus, cookies formulated with the highest percentage of peach and date powder exhibited the highest moisture content (Shabnam et al., 2020). Reporting a similar outcome of the present study, Lončarević et al. (2021) showed that moisture content will significantly increase by substituting different percentages of white chocolate with resistant starch compared to the control sample.

3.3. Acidity

The Fig. 3 depicts a significant increase in the acidity levels of chocolate treatments with increasing percentages of SF and DP replacement ($p<0.05$). Remarkably, the treatment featuring 20% DP and 8% SF exhibited the highest acidity level, whereas the control treatment with DP and SF exhibited the lowest acidity level ($p<0.05$).

The control group (T) has the lowest acidity, approximately 0.2%, whereas T1 (5% DP-2% SF) shows a slight increase to 0.22%, indicating a minimal impact of DP and SF at lower concentrations. T2 (10% DP-4% SF) raises the acidity content further to 0.25%, while T3 (15% DP-6% SF) continues the trend, reaching 0.28%. The highest acidity is observed in T4 (20% DP-8% SF), with a value of 0.32%, representing a total increase of 0.12% compared to the control.

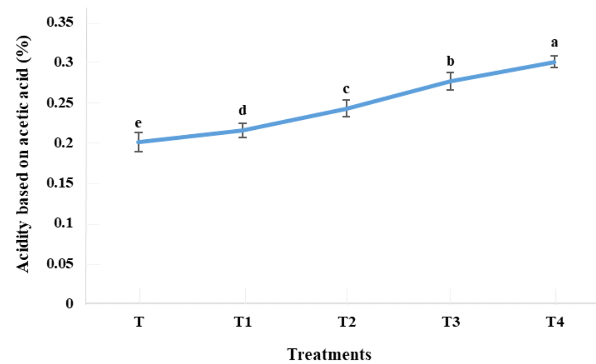

Fig. 3. The comparison of average acidity content according to acetic acid (%) across different treatments of chocolate. Values are mean±SD (n=3). Different letters ([a-d]) on the bars indicate significant differences ($p<0.05$) between the average acidity content of treatments (T, control; T1, 5% DP-2% SF; T2, 10% DP-4% SF; T3, 15% DP-6% SF; T4, 20% DP-8% SF).

Furthermore, SF is rich in fatty acid compounds, including linolenic acid, linoleic acid, palmitic acid, and arachidic acid. The heightened integration of SF into the dark chocolate formulation notably elevated the acidity level, aligning with the results observed in the present study. This elevation of acidity with increasing extract concentration may be due to the consequent increase of organic acids.

Recent studies have explored fortifying confectionery products with fruit by-products to enhance their nutritional value and reduce waste. Gummy candies enriched with pineapple and papaya peel powders maintained stable acidity and pH levels (Romo-Zamarrón et al., 2019). Similarly, watermelon-based jelly candies fortified with orange by-products showed improved chemical composition (Marinelli et al., 2020). The addition of oatmeal, pea meal, and bee-keeping products to traditional confectioneries increased vitamin and mineral content (Chernenkova et al., 2019). Rosehip powder was an effective natural antioxidant and colorant in BIO candies, with the acidity index remaining within permissible limits (Popovici et al., 2019). However, higher concentrations of rosehip powder increased acidity, which could be a disadvantage. Research on sponge cake fortification with quinoa flour, oolong, and white tea powder reported that white tea powder and oolong tea powder raised the acidity of samples, mainly white tea powder, due to its abundant polyphenols and organic acids such as ascorbic acid; over the storage period, acidity increased in sponge

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cake samples due to processes including the breakdown of sugars into lactic acid, denaturation of proteins, triglyceride breakdown, and hydroperoxide production (Ardeshir et al., 2024). In contrast, Latifi et al. (2023) reported that higher concentrations of green tea extract led to lower peroxide values in cupcakes during a six-day storage period. Similarly, Pourzafar et al. (2023) showed that in functional sponge cakes, green and white tea extracts significantly decreased acidity, mainly green tea extract, while higher concentrations of ginger, green tea, and white tea extracts resulted in lower peroxide values and increased total phenolic content.

3.4. Fat content

The Fig. 4 displays a discernible upward trend in the fat content of chocolate treatments as the replacement percentage of SF and DP increased. Notably, the treatment containing 20% DP and 8% SF exhibited the highest fat content, while the control treatment with DP and SF demonstrated the lowest fat content ($p<0.05$).

As can be seen in Fig. 4, The control group (T) has the highest fat content, approximately 40%, whereas T1 (5% DP-2% SF) shows a slight decrease to about 37.5%, indicating a minimal reduction in fat content with the addition of low concentrations of DP and SF. T2 (10% DP-4% SF) reduces the fat content further to around 35%, while T3 (15% DP-6% SF) continues the trend, decreasing it to approximately 33.5%. The lowest fat content is observed in T4 (20% DP-8% SF), with a value of around 31%, representing a total

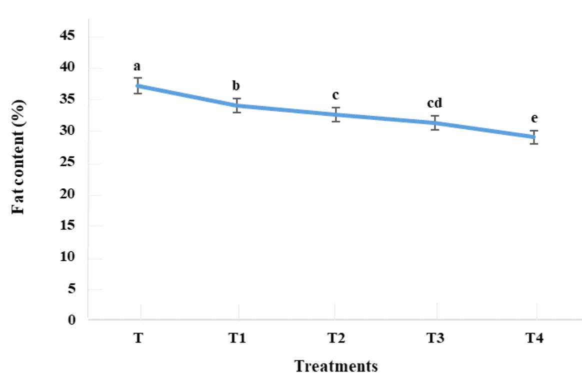

Fig. 4. The comparison of average fat content (%) across different treatments of chocolate. Values are mean±SD (n=3). Different letters ([a-e]) on the bars indicate significant differences ($p<0.05$) between the average fat content of treatments (T, control; T1, 5% DP-2% SF; T2, 10% DP-4% SF; T3, 15% DP-6% SF; T4, 20% DP-8% SF).

decrease of 9% compared to the control.

These results can be attributed to the substantial percentage of fatty acids present in SF, which is generally a type of water-insoluble fibre. As a result, there is always a fat content associated with extracted fiber, thereby influencing the overall fat content of the product. Consequently, an increase in the use of SF in the formulation of dark chocolate leads to a higher fat content. However, it is worth noting that the T1 treatment, which involves a reduction in the amount of base cocoa butter in the chocolate formulation, did not exhibit significant differences in fat content. The upward trend in fat content with increased SF and DP proportions in chocolate formulations can be attributed to the high fatty acid content in SF, a water-insoluble fiber that inherently contains fat. This fat content from SF accumulates as its concentration rises, resulting in an elevated fat content in the chocolate treatments. However, the T1 treatment, which includes a reduced amount of base cocoa butter, showed no significant difference in fat content, highlighting that the rise in fat content primarily stems from SF addition rather than cocoa butter modification.

Research on confectionery fortification with byproducts has shown promising results in reducing fat content and improving nutritional profiles. Citrus byproducts, specifically debittered orange fiber, have been successfully used as fat replacers in bakery products, resulting in increased fiber content and improved textural properties (Caggia et al., 2020). Similarly, vegetable oil-based confectionery creams fortified with dietary fibers and omega-3 fatty acids have been developed, offering reduced calorie content and modified carbohydrate profiles suitable for individuals with obesity and diabetes (Zaytseva et al., 2022). Studies have revealed significant variability in fat content and fatty acid composition among confectionery products, with some items containing high levels of trans fatty acids (Daniewski et al., 2000). Additionally, kokum butter, derived from kokum kernel byproducts, has been identified as a potential cocoa butter alternative in the confectionery industry due to its similar physicochemical properties and fatty acid composition (Kalse et al., 2021). In a study by Marand et al. (2020), enriching yogurt with flaxseed powder significantly altered its properties, decreasing saturated fatty acids and the omega-6 to omega-3 fatty acid ratio while increasing polyunsaturated fatty acids and antioxidant activity, with acceptable organoleptic characteristics. In contrast, Elshehy et al. (2018) investigated the nutritional benefits of flaxseed, particularly its omega-3 fatty acid and calcium content, by fortifying biscuits with varying concentrations, revealing increased fat content with acceptable sensory scores at 20% substitution.

3.5. Sugar content

The Fig. 5 illustrates a noticeable downward trend in the sugar content of chocolate treatments as the replacement percentage of SF and DP increased ($p<0.05$). Remarkably, the treatment containing 20% DP and 8% SF exhibited the lowest sugar percentage, while the control treatment with DP and SF had the highest sugar percentage ($p<0.05$).

The control group (T) has the highest sugar content, 36.95%, whereas T1 (5% DP-2% SF) shows a slight decrease to 33.85%, indicating a minor reduction in sugar content with the introduction of low concentrations of DP and SF. T2 (10% DP-4% SF) reduces the sugar content further to 32.43%, while T3 (15% DP-6% SF) continues the decreasing trend, reaching about 31.11%. The lowest sugar content is observed in T4 (20% DP-8% SF), with a value of 28.81%, representing a total reduction of around 9% compared to the control.

These findings indicate a direct relationship between the replacement of SF and DP and the reduction in sugar content within the chocolate formulations. As the percentage of these components increased, and the sugar content decreased significantly. This trend aligns with efforts to reduce sugar in food products, given the health risks associated with excessive sugar consumption. In summary, the results highlight the potential of using SF and DP as sugar replacements in chocolate formulations, contributing to the production of healthier chocolate products with reduced sugar content. The significant decrease in sugar content with increased DP and SF proportions in chocolate formulations likely result in the displacement of sugar by these ingredients, as DP and SF contribute natural fiber, moisture, and bulk, which reduces the need for added sugar while enhancing the nutritional profile of the chocolate.

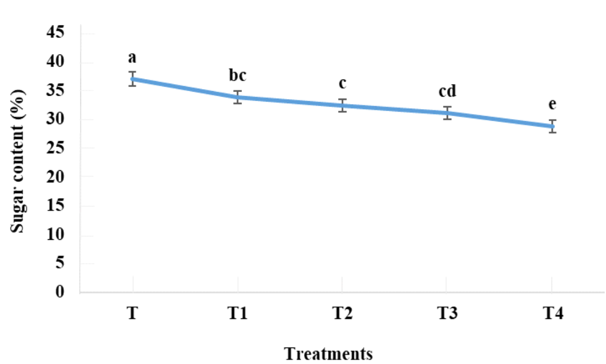

Fig. 5. The comparison of the average sugar content (%) across different treatments of chocolate. Values are mean±SD (n=3). Different letters ([a-e]) on the bars indicate significant differences ($p<0.05$) between the average sugar content of treatments (T, control; T1, 5% DP-2% SF; T2, 10% DP-4% SF; T3, 15% DP-6% SF; T4, 20% DP-8% SF).

Recent studies have explored the fortification of confectionery products with byproducts and alternative ingredients to enhance nutritional value and reduce sugar content. Developing sugar-free or low-sugar confectionery creams fortified with omega-3 fatty acids and dietary fibers, has proved to be suitable for consumers with obesity and diabetes (Zaytseva et al., 2022). Uvaia fruit byproduct has shown potential as a natural coloring agent in sugar hard-panning confections, offering a sustainable alternative to synthetic colorants (Avelar et al., 2019). In a study investigating the substitution of wheat flour with olive stone powder (OSP) in sponge cakes, significant increases in dietary fiber and antioxidant phenolic compounds were observed with rising OSP levels, while sugar levels remained unchanged, preserving the taste integrity of the final product (Jahanbakhshi and Ansari, 2020). Another study examined substituting sugar with grape syrup in low-calorie cakes, revealing significant reductions in sugar content with increased grape syrup levels, particularly in cakes made with 100% grape syrup, which had the lowest sugar content on the seventh day and were favored for their superior quality and taste (Mehrabi et al., 2017). Abbas et al. (2020) investigated doughnuts fortified with a micronutrient premix, revealing that 20% supplementation led to decreased carbohydrates, potentially offering a strategy to reduce sugar intake while improving nutritional value. Similarly, Gökçe et al. (2023) found that substituting sugar in cake production with carob flour and stevia resulted in reduced sugar content without significant changes in quality.

3.6. Textural characteristics

Table 2 provides insights into the texture characteristics of chocolate treatments. The maximum force is a critical parameter in assessing food texture, representing the force

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Table 2. The average value of maximum force and yield point across different treatments of the chocolate

Parameters	T[1)]	T1	T2	T3	T4
Maximum force (N)	70.33±0.57[2)a3)a]	64.33±0.57[a]	60.66±0.67[b]	55.66±0.57[c]	50.66±0.57[d]
Yield point (N/m^2)	9.23±0.21[a]	96.80±0.01[a]	61.80±0.31[b]	14.80±0.24[c]	73.70±0.02[d]

[1)]T, control; T1, 5% date pulp (DP)-2% sesame fiber (SF); T2, 10% DP-4% SF; T3, 15% DP-6% SF; T4, 20% DP-8% SF.
[2)]Values are mean±SD (n=3).
[3)]Different superscript letters within the same row indicate significant differences ($p<0.05$) by Duncan's multiple range test.

required to compress and shear a sample, which correlates with the biting force needed to cut the food with our teeth during the first bite. The yield point, in addition, is a critical concept in materials science and engineering, including the study of food texture, representing the stress at which a material transitions from elastic deformation, where it can recover its original shape after deformation, to plastic deformation, where it undergoes permanent changes.

According to the obtained results, it was observed that the control treatment and the T1 treatment had the highest yield stress and maximum force values, while the lowest values were recorded for the T4 treatment ($p<0.05$). Generally, there was a consistent decreasing trend in the texture components of chocolate treatments as the replacement percentage of SF and DP increased ($p<0.05$). Further examination of the texture indicators revealed reduced yield stress and maximum force with increased replacement of DP and SF. Several factors contribute to these changes, including the higher moisture and fat content in dark chocolate treatments when DP and SF are replaced. The results also demonstrated a significant negative correlation between the maximum force index and, moisture percentage and fat content in chocolate treatments ($p<0.05$). Increased moisture content generally leads to a softer chocolate texture, while the added oil from SF decreases the maximum required force. The lowest force values were observed in treatments with the highest percentage of SF (8%) and DP (20%) ($p<0.05$). Similarly, the breaking point of the chocolate decreased in line with these changes and exhibited a negative and significant correlation with moisture and fat content in chocolate treatments ($p<0.05$).

Recent studies have explored the texture characteristics of confectioneries fortified with byproducts. Cookies incorporating whey residue exhibited improved textural properties, including low hardness and chewiness, and high springiness and cohesion (Guiné et al., 2020). The addition of oatmeal, pea meal, and bee-keeping products to traditional confectioneries enhanced their nutritional value and functional properties (Chernenkova et al., 2019). In Xixona turron, a traditional Spanish confectionery, texture profile analysis provided comprehensive information on hardness, adhesiveness, cohesiveness, springiness, and chewiness, with manufacturers focusing on producing softer and less oily products to meet consumer demands (Vázquez-Araújo et al., 2006). Razavizadeh and Tabrizi (2021) examined the texture of fortified compound milk chocolates with microcapsules containing chia seed oil at different percentages. They found no significant impact on taste, texture, or overall acceptance compared to the control, although slight decreases were observed after 120 days of storage. Notably, chocolates containing 10% microcapsules maintained acceptable physicochemical properties with slightly lower hardness and altered melting behavior due to the microcapsule wall material. However, these chocolates exhibited significant blooming compared to the control, suggesting that the characteristics of fortified chocolates were preserved despite these changes. In another study conducted by Ekantari et al. (2019), the texture stability of milk and dark chocolates fortified with nanocapsules of carotenoids from *Spirulina platensis* was investigated. The results indicated no significant differences in aroma, taste, or texture between fortified and control chocolates, with both displaying similar dominant profiles of aroma and chocolate flavor, albeit with slightly different intensities. Furthermore, Subroto et al. (2022) studied the optimization of solid lipid nanoparticles (SLN) containing gallic acid to fortify chocolate bars. They found that higher concentrations of SLN-gallic acid increased total phenolic and antioxidant activity but negatively affected the color, texture, and organoleptic properties. The optimal fortification was achieved with 5% SLN-gallic acid, resulting in favorable sensory preferences and spherulite beta crystal morphology, suggesting SLN-gallic acid as a suitable method for fortifying chocolate bars up to 5%.

3.7. Energy content analysis

Based on the findings presented in Fig. 6, there is a notable increase in the caloric content of chocolate treatments with a higher percentage of substitution with SF and DP ($p<0.05$). Specifically, the treatment containing 20% DP and 8% SF exhibits the highest calorie content. Conversely, the control treatment with DP and SF has the lowest calorie content ($p<0.05$). Further analysis of the calorie content of chocolate treatments reveals a significant rise with increased use of SF and DP ($p<0.05$).

The control group (T) has the lowest caloric content, approximately 400 KJ/100 g, whereas T1 (5% DP-2% SF) remains relatively unchanged at the same level, indicating no significant impact of DP and SF at this concentration. T2 (10% DP-4% SF) shows a slight increase in caloric content to about 425 KJ/100 g. T3 (15% DP-6% SF) continues this upward trend, reaching around 450 KJ/100 g. The highest caloric content is observed in T4 (20% DP-8% SF), with a value of approximately 475 KJ/100 g, representing an increase of 75 KJ/100 g compared to the control.

This increasing trend in calorie content can be attributed to several factors. Dates contain 300 calories per 100 g, and since each gram of sucrose provides four calories, their inclusion contributes significantly. Additionally, dates contain 50% glucose, further elevating the overall calorie count. Furthermore, SF is rich in oil, and each gram of fat yields more calories than glucose, further adding to the calorie content. Consequently, when the amount of SF is augmented in the chocolate formulation, it leads to an increase in the final calorie count of the product.

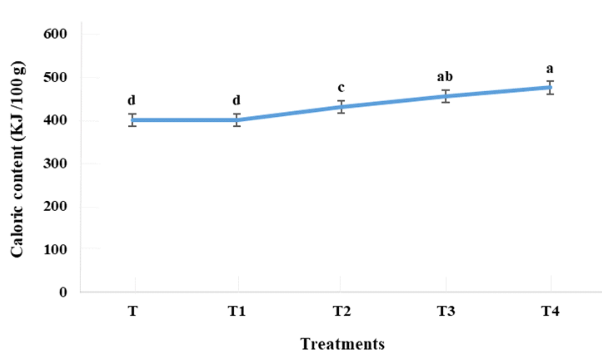

Fig. 6. The comparison of average calorie content (KJ/100 g) across different treatments of chocolate. Values are mean±SD (n=3). Different letters ($^{a\text{-}d}$) on the bars indicate significant differences ($p<0.05$) between the average caloric content of treatments (T, control; T1, 5% DP-2% SF; T2, 10% DP-4% SF; T3, 15% DP-6% SF; T4, 20% DP-8% SF).

Recent research has explored fortifying confectioneries with byproducts to enhance nutritional value while managing caloric content. Youssef and Mousa (2012) found that fortifying wheat biscuits with citrus peel powders enhanced nutritional value and sensory characteristics while potentially reducing caloric content for weight management. In a study by Kaur et al. (2021), a composite meat chocolate was developed to enhance nutritional value and stability in tropical temperatures. This chocolate exhibited a significant decrease in calorie content without an increase in cholesterol, suggesting its potential as a lower-calorie chocolate option. Saber et al. (2018) focused on creating low-calorie chocolate milk by replacing sugar with stevioside and incorporating inulin as a texturizing agent. They found that adding 2% inulin increased viscosity, and the samples with 50% sugar replaced by stevioside and 2% inulin received the highest overall acceptability scores. This suggests that such formulations could offer satisfying low-calorie options for individuals with obesity and diabetes. Additionally, Lenka et al. (2020) developed a high-protein, low-calorie cake using chickpea flour in conjunction with whole wheat flour. They determined that a 4:1 ratio of chickpea to wheat flour provided the best balance of nutritional value and sensory characteristics, presenting a cost-effective option for addressing malnutrition in children and starvation in adults. Amini et al. (2022) created a gluten-free cake mix based on quinoa flour, targeting celiac patients and those sensitive to gluten. Their formulations varied in quinoa flour and inulin content, included fat reduction through oil powder, and added the probiotic bacteria *Bacillus coagulans*. The resulting cake mix was higher in minerals, protein, and fiber, while exhibiting lower fat, carbohydrate, and calorie content compared to the control. These studies demonstrate that incorporating byproducts into confectioneries can enhance nutritional profiles, modify carbohydrate content, and potentially reduce caloric value, offering healthier alternatives to traditional high-calorie sweets.

4. Conclusions

In conclusion, this research focused on the preparation and evaluation of dark chocolate incorporating DP and SF. The physicochemical and textural analyses revealed significant differences between each treatment and the control. With an

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SF content exceeding 2% and DP exceeding 5%, the chocolate quality deteriorated significantly, displaying unfavorable physicochemical characteristics and reduced consumer acceptance. Therefore, considering the national dark chocolate standard, as well as textural, physicochemical, and calorie-related properties, it is advisable to limit the use of DP to 5% in chocolate formulation. Higher percentages are discouraged due to structural, physicochemical, and sensory drawbacks, rendering them impractical for use.

To extend the findings of this study to practical applications, future research should explore scalable production methods to incorporate DP and SF effectively while maintaining quality standards. Investigating the potential of these fortifying agents in other confectionery products, such as snack bars, cookies, or even non-chocolate items like beverages or spreads, could reveal versatile applications across various segments. Additionally, exploring modifications to the processing techniques, such as particle size reduction or pre-treatment of DP and SF, could help optimize textural and sensory properties, enabling higher inclusion rates without compromising product quality.

Further studies could also focus on assessing the stability of these ingredients in long-term storage or under different packaging conditions, which would be essential for commercial scaling. Collaborating with industry partners to pilot these formulations on larger production scales could provide insights into processing adjustments and potential cost implications, facilitating smoother integration of DP and SF in broader chocolate manufacturing practices.

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Conflict of interests

The authors declare no potential conflicts of interest.

Author contributions

Conceptualization: Abdolmaleki F, Daneshniya M. Methodology: Abdolmaleki F, Maleki MH. Formal analysis: Abdolmaleki F. Validation: Abdolmaleki F. Writing - original draft: Daneshniya M, Maleki MH. Writing - review & editing: Daneshniya M, Maleki MH.

Ethics approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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