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Physicochemical, Antioxidant and Sensory Evaluation of Dark Chocolate Fortified with Sacha Inchi Powder Roasted at Different Condition

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Abstract

The increasing demand for functional foods had led to a raised interest in fortifying chocolate with nutrient-rich ingredients. This research investigates the enhancement of dark chocolate via the incorporation of sacha inchi powder, a natural source of omega-3 polyunsaturated fatty acids (PUFAs), antioxidants and phenolic compounds. The impact of sacha inchi powder, roasted at two temperatures (T80 and T160) for 15 minutes, was assessed on the physicochemical parameters, antioxidant activity, total phenolic content (TPC) and sensory characteristics of fortified dark chocolate. Sacha inchi powder obtained from Pantai, Negeri Sembilan was added at levels of 3, 5 and 7% (w/w) into melted dark chocolate. The hardness of fortified dark chocolate samples obtained are lower (0.82kg±0.02–1.07kg±0.02) compared to control sample (1.10kg±0.07) with fortification significantly ($p<0.05$) reduced the hardness of chocolate, especially at higher fortification levels (5 and 7%). Moisture content of fortified chocolate (0.38%±0.02-0.75%±0.04) increased significantly ($p<0.05$) at 5% and 7% due to hygroscopic nature of sacha inchi powder, while the control sample recorded 0.69%±0.11. The colour parameters (L*, a*, b*) were uniform (ranged from 35.29±0.13 to 37.18±0.54, -1.33±0.19 to -4.87±0.06 and -4.87±0.06 to -4.30±0.09, respectively) among the samples, exhibiting no significant differences ($p>0.05$). Antioxidant activity (72.02%±0.24–89.13%±0.53) and TPC (21.08±0.03–40.82mg GAE/g±0.36) enhanced with elevated amounts of sacha inchi powder, particularly at T160, attributable to the Maillard reaction products and preservation of tocopherols. Sensory evaluation indicated that dark chocolate fortified with 5% of T160-roasted sacha inchi powder (DC5) had the greatest ratings for taste, colour, aroma, texture and overall acceptability among the fortified samples, despite the control sample being favoured overall. This study illustrates the efficacy of sacha inchi powder as a functional component in dark chocolate, improving its nutritional profile while preserving sensory characteristics. Sacha inchi-fortified chocolate can be promoted as a heart-healthy, antioxidant-rich snack that supports well-being.

1. Introduction

Chocolate, originating from cocoa beans, has been regarded as one of the world's most popular functional foods for its unique taste, aroma and texture as well as for its positive benefits on human health. Global chocolate consumption has increased significantly with yearly cocoa output rising from 2 million tonnes in the early 21st century to around 5 million tonnes by 2019 [1]. Although chocolate brings pleasure and satisfaction to individuals of all ages [2], its high fat and sugar content has raised concerns regarding its potential to contribute to health risks such obesity and cardiovascular disease [3]. The increased desire for better food alternatives such as functional chocolate fortified with nutritional and health-promoting ingredients, has been fuelled by these worries. Dark chocolate is admired for its superiority over milk and white chocolates, attributed to its rich polyphenol and flavonoid content which confer notable antioxidant and anti-inflammatory advantages [4]. In response to the growing consumer interest in functional foods, the food industry has adopted fortification as means to elevate the nutritional profile of products while preserving their sensory qualities [5]. The fortification of plant-based extracts and powders into chocolate presents a potential to solve health issues while broadening product lines to satisfy consumer tastes.

Sacha inchi (*Plukenetia volubilitis*), commonly referred to as Inca peanut, is a seed abundant in nutrients and indigenous to the Amazon rainforest. These seeds are valued for their elevated levels of unsaturated fatty acids, specifically omega-3, omega-6 and omega-9 as well as protein, phenolic compounds and antioxidants [6]. Moreover, these seeds are typically roasted to diminish antinutritional factors, including tannins and phytic acid, while enhancing sensory qualities [7]. Sacha inchi seeds have been added into multiple food products such as dairy, meat substitutes and snacks with those researches indicating enhanced antioxidant activity, nutritional composition and sensory acceptability. According to [8], sacha inchi products are exported in various types such as oil, toast, powder, seeds, natural, snacks and capsules. Despite the acknowledged advantages of sacha inchi, its incorporation into food products, particularly in powdered form remains constrained. This is because sacha inchi powder which is derived from grounded seeds has a distinct, earthy and nutty flavour which may not appeal to all consumers and requires grinding and sieving process to obtain uniform particle size to improve mixture consistency. Additionally, the pronounced astringency and pungent aftertaste of sacha inchi require meticulous roasting and formulation to harmonize its nutritional benefits with sensory acceptability [9]. [10] reported that there was a rise in antioxidant activity when the seeds were roasted at 80℃ for 10 minutes. Lower temperature such as 80℃ allows for gentle roasting, preserving the nutritional properties while slightly enhancing flavour and aroma without causing significant changes. Besides, according to [9], subjecting the seeds at a temperature of 160℃ for 15 minutes resulted in decreased in presence of antinutrients and a rise in antioxidant activity of the compounds in the seeds. Higher roasting temperature enhances the distinct peanut-like odour and reduces the characteristically bitter flavour of the seeds [10]. Thus, this study intends to investigate the potential of enhancing dark chocolate with sacha inchi powder roasted at varying temperatures (T80 and T160 for 15 minutes). Specifically, it examines the impact of fortification on the physicochemical properties, antioxidant activity and total phenolic content (TPC) and sensory attributes of dark chocolate. By addressing these factors, this research aspires to advance the development of healthier dark chocolate alternatives that satisfy consumer preferences for both nutritional value and sensory characteristics.

2. Materials and Methods

2.1 Materials

Sacha inchi seeds were obtained from a local farm in Pantai, Negeri Sembilan. The dark chocolate compound used was from Beryl's brand, purchased from a local shop.

2.2 Methods

2.2.1 Preparation of Sacha Inchi Powder

The preparation of sacha inchi powder from sacha inchi seeds was conducted using methods by [11] with slight modifications. The seeds were properly cleaned to eliminate dirt and contaminants. They were then roasted in a Memmert oven at 80℃ and 160℃ for 15 minutes [9]. After roasting, the non-edible shells around the seeds were removed to reveal the edible kernels. Once cooled, the roasted kernels were then crushed into a fine powder with an electric blender to ensure consistent particle size. The powder was sieved to a particle size of less than 20µm, resulting in a uniform texture suited for fortification. Finally, the fine sacha inchi powder was stored at room temperature in a sealed container.

(a) (b)

Fig. 1 (a) Sacha inchi powder roasted at T80 (b) Sacha inchi powder roasted at T160

2.2.2 Preparation of Dark Chocolate

Dark chocolate was prepared by placing dark chocolate compounds in a hot water bath at 50°C for 15 minutes until fully melted [11]. The melted chocolate was then continuously stirred to ensure uniformity and avoid overheating.

2.2.3 Preparation of Fortified Dark Chocolate with Sacha Inchi Powder

Sacha inchi powder roasted at T80 and T160 were added into dark chocolate at levels of 0, 3, 5 and 7% weight/weight (w/w) [11]. The sacha inchi powder was added to the dark chocolate when it was still warm, just after melting. The dark chocolate and sacha inchi powder were mixed thoroughly until homogenous. The resulting chocolate mixture was then poured into plastic moulds (22.5cm x 10.8cm x 0.7cm), wrapped with aluminium foil and refrigerated for 24 hours. Table 1 presented the formulation of dark chocolate fortified with sacha inchi powder.

Table 1 Formulation of dark chocolate fortified with sacha inchi powder

Roasting condition	Sample	Dark chocolate (%)	Sacha inchi powder (%)
-	Control	100	0
T80	DC1	97	3
	DC2	95	5
	DC3	93	7
T160	DC4	97	3
	DC5	95	5
	DC6	93	7

2.3 Analysis on Physicochemical Properties

2.3.1 Hardness

The texture of dark chocolate samples was assessed utilizing a texture analyzer (Stable Micro System Co. Ltd, Surrey, England) equipped with cylindrical stainless-steels probe (diameter 35 mm) with 5 kg load cell [12]. Each dark chocolate sample was cut into dimensions of 15 mm x 10 mm x 15 mm [13]. One-hour prior testing, all samples were kept at room temperature. The hardness of control and fortified chocolate were determined.

2.3.2 Moisture Content

The moisture content of dark chocolate samples was determined using the rapid moisture analyzer. 1 g of dark chocolate samples was weighed and placed on an aluminium pan located inside the MS-70 moisture analyzer (A&D Company, Limited). The heating temperature was standardized to 140°C for 6 minutes (MS-70 Users' Handbook) and all readings obtained were presented in percentage (%). The analysis was performed in triplicate and the average of data obtained was recorded.

2.3.3 Colour

The colour of dark chocolate samples was determined using a colorimeter (MiniScan EZ Hunter Lab 4500) with colour indices L*, a* and b* (white to black, green to red and blue to yellow) were determined [13]. The colorimeter was calibrated and then the analysis was performed in triplicate.

2.4 Analysis on Antioxidant Activity and Total Phenolic Content

2.4.1 Sample Extraction

Dark chocolate sample extraction was conducted based on methods demonstrated by [14]. The dark chocolate samples were defatted by washing the samples twice with n-hexane (1:5 w/v). Then, the defatted samples were extracted twice with a solvent mixture of acetone, distilled water, and acetic acid (70:29.8:0.2) and stirred for 10 minutes. The resulting extracts were then filtered for further analysis.

2.4.2 Antioxidant Activity

The antioxidant activity of dark chocolate samples was determined using DPPH-radical scavenging analysis according to methods by [15]. 200 µL of dark chocolate samples was added to 800 µL of Tris-HCl 100 Mm solution (Ph 7.0), followed by addition of 1000 µL of methanolic solution of DPPH 250 Mm. The tubes were kept dark for 20 minutes. Next, the absorbance was measured at 517 nm using a UV-visible spectrophotometer. Ascorbic acid was used as a positive control and a mixture of DPPH solution and methanol as the negative control. Percentage of radical scavenging activity was calculated using the formula in equation (1),

$$\%\text{ radical scavenging activity} = \frac{A_{DPPH} - A_S}{A_{DPPH}} \times 100 \quad (1)$$

where, A_{DPPH} = Absorbance of DPPH and methanol and A_S = Absorbance of solution with dark chocolate extracts.

2.4.3 Total Phenolic Content

The total phenolic content of dark chocolate samples was analysed using the Folin-Ciocalteu method, referring to [14] procedure. About 0.2 Ml of dark chocolate extracts was added to 0.2 Ml Folin-Ciocalteu reagent and 1 Ml of distilled water. After that, the samples were incubated for 6 minutes. Next, a solution containing 2.5 Ml of 7% sodium carbonate and 2.1 Ml of distilled water were transferred to the mixture and incubated at room temperature for 90 minutes. Following that, UV-Visible was quantified at 760 nm. The total phenolic content was determined as milligrams of gallic acid equivalent per gram of samples (mg GAE/g).

2.5 Sensory Evaluation

For sensory evaluation of dark chocolate samples, a method of 9-point hedonic test was adopted. The 50 untrained panellists were selected based on specific criteria such as panellists had good understanding of chocolate flavour profiles and had no allergies to the ingredients used in this study. The panellists were served with seven samples of dark chocolate with varied quantities of sacha inchi powder. Each of the panellists rated each of the samples based on their liking on the samples using a 9-point hedonic scale (1= Extremely Dislike to 9= Extremely Like) based on attributes such as taste, colour, aroma, texture and overall acceptability [28].

2.6 Statistical Analysis

Statistical analysis was conducted using Minitab Software and the data was analysed using analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) post hoc test. The data was conducted in triplicate. A difference of $p<0.05$ was considered significant. The findings were demonstrated as mean values ± standard deviation (SD) [12].

3. Result and Discussion

3.1 Physicochemical Properties

3.1.1 Texture, Moisture Content, Colour

Hardness which is the significant element that affects consumer choice is the primary attribute analysed in a chocolate bar. Table 2 indicates that the control sample had hardness of 1.10±0.07 but the fortified dark chocolates demonstrated reduced hardness values (0.82±0.03-1.07±0.02). Increased levels of sacha inchi powder significantly reduced ($p<0.05$) the hardness of the chocolate, suggesting that fortification softens the product. Similar findings by [16] which reported that moisture content of chocolate (milk and dark) significantly reduced (p<0.05) by incorporation of sacha inchi ganache. Nevertheless, no significant difference (p>0.05) was detected between control and DC4 samples. As observed by [17], this decrease in hardness may be attributed to moisture content and particle size distribution (PSD). Although moisture can increase hardness by improving particle cohesion, PSD seems to exert a more significant impact in this study. The average particle size of chocolate is less than 30μm, while the average particle size of sacha inchi powder is <841μm, which probably changes the structure of chocolate and makes it softer. Powder alters the viscosity of the mixture and disrupts the fat separation and crystallization processes [18]. It was therefore believed that ingredients with larger particle sizes had a reduced solid volume fraction, leading to lower hardness level. Other than that, fortification with T80-roasted sacha inchi powder resulted in slightly softer chocolate (0.82-0.86kg) compared to T160-roasted powder (0.86-1.07kg). This may be due to the higher fat content T80-roasted seeds (54.8g/100g) compared to T160-roasted seeds (54.3g/100g) [9]. According to [19], higher fat content reduces the hardness of chocolate. Higher temperature during roasting may break down the fat content which influences the hardness of dark chocolate samples. However, additional research is required to verify these findings.

Table 2 Hardness, moisture content and colour of dark chocolate samples

Sample	Hardness (kg)	Moisture content (%)	Colour		
			L*	a*	b*
Control	1.10±0.07a	0.69±0.11ab	37.90±1.13a	-0.20±0.18a	-4.07±0.21a
DC1	0.86±0.06bc	0.59±0.04bc	35.29±0.13a	-1.33±0.19b	-4.87±0.06a
DC2	0.82±0.03c	0.67±0.03ab	36.40±1.71a	-0.77±0.62ab	-4.45±0.53a
DC3	0.82±0.02c	0.75±0.04a	37.84±0.48a	-0.64±0.06ab	-4.30±0.09a
DC4	1.07±0.02a	0.38±0.02d	37.00±1.70a	-1.31±0.45b	-4.83±0.38a
DC5	0.96±0.03b	0.52±0.01c	37.18±0.54a	-0.71±0.51ab	-4.42±0.39a
DC6	0.86±0.00bc	0.63±0.02abc	35.60±1.29a	-0.58±0.18ab	-4.31±0.13a

*Values are presented as mean±SD.
**$^{a\text{-}c}$ Mean values with different superscript letters within the columns are significantly different (p<0.05).

Moisture content significantly influences the properties of chocolate such as its melting point, hardness, fluidity and visual [20]. Increased moisture levels can result in agglomeration which impacts the texture and quality of chocolate [17]. This is because increased moisture content can alter the physical texture of chocolate which leads to grainy or unappealing texture and mouthfeel. In addition, since chocolate is a high-fat product [21], water absorption can disturb the crystalline structure of fat, causing fat bloom or sugar bloom which adversely affect the product's sensory qualities. Furthermore, chocolate is typically a low-moisture food that naturally hinders the growth of most microorganisms. Water activity (a_w) of chocolate is highly sensitive to variations in moisture content at a given temperature compared to other low-moisture products [21]. Nevertheless, elevated moisture content can generate microenvironments conducive to microbial growth inside the chocolate matrix where a_w is higher. Previous study by [22] showed that at high relative humidity levels (80% RH), fungal growth can develop quickly which causes the chocolate to be unsafe to be consumed due to spoilage and risk of foodborne illnesses. Thus, such microbial activity can greatly reduce the shelf life of chocolate. Optimal chocolate must possess a moisture percentage of 2% [23]. In this study, all samples fulfilled the requirement, with the control exhibiting 0.69±0.11, whereas fortified samples varied from 0.38±0.02 to 0.75±0.04. The outcomes showed consistency with [11] who observed a rise in moisture content in chocolate enhanced with cactus stem powder at increased fortification levels. No significant influence (p>0.05) on moisture content was detected in dark chocolate fortified with up to 5% of sacha inchi powder roasted at T80. A notable increase (p<0.05) was observed at 7% fortification. For T160-roasted powder, substantial increases (p<0.05) were seen up to 5% fortification, with no significant variation (p>0.05) at 7%. The rise in moisture content with increased levels of sacha inchi powder may result from the powder's capacity to absorb moisture from the surroundings. Roasting temperature significantly affected the moisture content as T80-roasted powder exhibited higher moisture (6.94%) than T160-roasted powder (4.91%). Higher temperature effectively removed the moisture in seeds.

The colour of chocolate contributes critically to consumer acceptance, since it is among the initial attributes perceived prior to taste and texture [24]. Given that, consumers perceive a rich, uniform dark brown colour as an indicator of premium quality and freshness in dark chocolate. Conversely, any discolouration such as dullness, lightening and uneven colouration may lead consumers to infer poor storage or handling practices. Despite the potential of unchanged taste or flavour, these visual defects can cause consumers to mistakenly perceive the product as stale or poorly handled. Based on Table 2, the control sample exhibited a L* value of

37.90±1.13, whereas the fortified dark chocolate samples displayed values ranging from 35.29±0.13 to 37.18±0.54. The incorporation of sacha inchi powder resulted in a slight darkening of the chocolate. However, no significant differences in L* values were observed. [24] reported similar findings, indicating that the incorporation of plant-based powders diminished the lightness of chocolate. The a* and b* values for control sample were -0.20±0.18 and -4.07±0.21, respectively. In contrast, the fortified samples exhibited a* values ranging from -1.33±0.19 to -0.58±0.18 and b* values from -4.87±0.06 to -4.30±0.09. The fortification did not significantly impact these values. Moreover, uncommon negative a* values in chocolate may result from fat or sugar bloom induced by storage conditions., which influence light reflection and perceived colours [25]. Furthermore, surface texture variations may also affect colour measurements [26].

Fig. 2 Colour of dark chocolate samples

3.2 Antioxidant Activity

Table 3 Antioxidant activity and TPC of dark chocolate samples

Sample	Antioxidant activity (%)	TPC (mg GAE/g)
Control	71.51±0.24^{d}	11.20±0.01^{g}
DC1	72.02±0.24^{d}	21.08±0.03^{f}
DC2	72.22±0.22^{d}	25.95±0.03^{e}
DC3	73.69±0.27^{c}	29.94±0.06^{d}
DC4	84.09±0.43^{b}	31.98±0.02^{c}
DC5	84.38±0.86^{b}	40.42±0.02^{b}
DC6	89.13±0.53^{a}	40.82±0.36^{a}

*Values are presented as mean±SD.
**$^{a-f}$ Mean values with different superscript letters within the columns are significantly different (p<0.05).

The fortification of sacha inchi powder into dark chocolate aims to improve its nutritional and antioxidants characteristics. Antioxidants are essential in inhibiting oxidation, thereby preventing rancidity, nutritional degradation and physical deterioration of food products. The antioxidant activity varies between 71.51% and 89.13%. The control, DC1 and DC2 demonstrated the lowest antioxidant activity (71.51-72.22%), whereas DC3 (73.69%), DC4 (84.09%), DC5 (84.38%) and DC6 (89.13%) showed significantly higher values (p<0.05). Dark chocolate containing 7% sacha inchi powder roasted at T160 (DC6) exhibited the highest antioxidant activity at 89.13% which suggests that increased fortification level enhances the antioxidant properties. The results were aligned with [27], who identified elevated tocopherol levels in sacha inchi seeds, and [28] who demonstrated that the addition of sacha inchi oil improved antioxidant activity in chocolate-based products. Sacha inchi seeds are rich in vitamin E, particularly tocopherols such as gamma (γ) and delta (δ) with total tocopherol content ranging from 78.6 to 137.0 mg/100g [29]. In addition to tocopherols, sacha inchi seeds also contain flavonoids, phytosterols, tannins and terpenoids which work together to provide enhance protection against oxidative damage [30]. Additionally, 21 phenolic compounds were identified sacha inchi oil with their levels increasing during roasting [31]. These compounds can effectively combat oxidative stress by scavenging free radicals and chelating metal ions, which are key mechanisms of cellular damage [31]. Furthermore, dark chocolate containing T160-roasted sacha inchi powder (84.09-89.13%) exhibited greater antioxidant activity compared to those with T80-roasted powder (71.51-72.22%). The formation of Maillard browning compounds at high roasting temperature may account for this phenomenon, as these compounds exhibit antioxidant properties that preserve tocopherols from degradation [32]. According to [33], Maillard reaction generates compounds such as melanoidins which possess antioxidant properties such as metal chelation and oxygen radical scavenging. Consequently, sacha inchi powder roasted at T160 enhances the antioxidant activity of fortified dark chocolate more effectively.

3.3 Total Phenolic Content

Phenolic compounds serve an essential function in inhibiting the oxidation of polyunsaturated fatty acids (PUFAs) and offer health benefits, including the reduction of hypertension, atherosclerosis and certain cancers, in addition to enhancing immune function [34]. Dark chocolate generally exhibits TPC values between 12-15mg GAE/g [35] and 9.1-40.55 mg GAE/g, influenced by bean origin and roasting processes [36]. Based on Table 3, TPC values were between 11.20±0.01 and 40.82±0.36mg GAE/g, consistent with earlier findings. The TPC exhibited a significant increase (p<0.05) with increased percentages of sacha inchi powder. Previous study by [28] revealed that compared to control sample, incorporation of 2.5%, 5% and 10% of sacha inchi oil in dark chocolate granola bar were considerably greater (p<0.05). Similarly, [12] reported that incorporation of sacha inchi oil exhibited elevated phenolic content in chocolates. Simple phenols, isocoumarin, lignans (19.69%), flavonoids (14.4%) and secoiridiods (40.96%) were the five primary phenolic classes identified in sacha inchi oil [8]. Furthermore, sacha inchi seeds exhibit significantly higher phenolic content (64.8-91.5 mg GAE/100g) compared to sacha inchi oil (6.20 mg GAE/100g) [37] [38] [29]. In addition, [16] also discovered that among the chocolate formulations tested, dark chocolate filled with sacha inchi ganache demonstrated the highest total phenolic content (12.21±0.68 mg GAE/g), significantly surpassing other formulations (3.57±0.26 mg GAE/g-10.54±0.21 mg GAE/g). These findings are comparable with study by [39] which reported that fortifying dark chocolate with turmeric or sakura green tea leaves significantly increases its TPC content. Turmeric-fortified chocolate exhibited a TPC of 1094.03±10.15 mg/100g while green tea-fortified chocolate reached 1035.45±14.81mg/100g. Similar to sacha inchi, turmeric and green tea both are rich in flavonoids which are potent antioxidants known for their ability to scavenge free radicals and mitigate oxidative stress [39]. Compared to dark chocolate with T80-roasted sacha inchi powder (21.08-29.92mg GAE/g), fortified dark chocolate with T160-roasted powder exhibited a greater TPC (81.98-40.82 mg GAE/g). This observation agreed with [40] which indicated that roasting sesame seeds at elevated temperatures resulted in an increased TPC. Elevated roasting temperatures enhance the formation of Maillard browning compounds, which exhibit antioxidant properties and contribute to preservation of tocopherols [32]. Thus, dark chocolate fortified with T160-roasted sacha inchi powder exhibited the highest TPC.

3.4 Sensory Evaluation

Table 4 Sensory evaluation of dark chocolate samples

Sample	Taste	Colour	Aroma	Texture	Overall acceptability
Control	8.04±1.07a	7.90±0.97a	7.90±0.97a	7.84±1.50a	8.02±0.89a
DC1	5.60±2.01c	6.28±1.89a	6.28±1.89b	7.24±1.48ab	6.38±1.58b
DC2	6.00±1.71c	6.60±1.50a	6.60±1.50b	7.12±1.42ab	6.44±1.61b
DC3	6.60±1.69bc	6.52±1.68a	6.52±1.68b	7.02±1.64ab	6.88±1.42b
DC4	6.54±2.01bc	7.02±1.53a	7.02±1.53ab	7.02±1.74ab	6.78±1.73b
DC5	7.06±1.75ab	7.06±1.36a	7.06±1.36ab	7.42±1.40ab	7.16±1.50ab
DC6	6.48±1.87bc	6.86±1.58a	6.86±1.58b	6.94±1.72b	6.78±1.71b

*Values are presented as mean±SD.
**$^{a-c}$ Mean values with different superscript letters within the columns are significantly different (p<0.05).

Based on Table 4, taste attributes vary from 6.00 to 7.06, suggesting preferences for "like slightly" and "like moderately". The control sample received the best score, while DC5 (5% T160-roasted powder) was the most favoured among fortified dark chocolate samples. DC1 (3% T80-roasted powder) received the lowest score, perhaps due to grassy aftertaste due to volatile substances like hexanal, 3-pentanone, and 1-penten-3-ol [8], resulting from inadequate roasting. Roasting temperature of T160 eliminates the pungent aftertaste and roasted sacha inchi seeds have taste that resembles almonds which is desirable. Colour ratings for fortified samples ranged from 7.38 to 7.84, comparable to the control (8.08), with no significant changes found (p>0.05). All samples preserved their shiny and dark appearance. In terms of aroma, the control received the highest rating (7.90), followed by DC5 (7.06). No significant difference (p>0.05) was observed among aroma attributes of those dark chocolate samples. Moreover, samples fortified with T160-roasted powder had higher score (6.86-7.06) than sample with T80-roasted powder (6.28-6.52). Eight volatile acids were recognized in sacha inchi seeds at various stage of germination such as 1-penten-3-ol, 1-pentanol, 3-hexen-1-ol, (Z)-2-heptenal and 2-octen-1-ol which linked to green, beany and grassy smells [41]. These volatile compounds strongly influence sensory experience and preference of consumers about the products. Following this, proper roasting techniques and temperature help to reduce the undesirable aroma and promote the formation of more appealing aromatic compounds. High temperature can promote intensive chemical reactions such as Maillard reaction and caramelization which produce aromatic compounds that contribute to aroma [42]. Appealing aromas can improve perceived flavour and quality, resulting in increased customer satisfaction and repeat purchases. Hence, higher temperature such as 160℃ is required as it eliminates the grassy aroma and is more preferred by the panellists. The texture score varied from 6.94 to 7.42, with no significant variations (p>0.05) amongst the samples. Besides control, DC5 was most favoured and DC6 was least favoured. Fortified chocolate samples had scores ranging from 6.38 to 7.16, equivalent to "like slightly" and "like moderately". Among the fortified samples, DC5 was most preferred.

4. Conclusion

This study successfully assessed the physicochemical properties, antioxidant activity, TPC and sensory evaluation of dark chocolate fortified with sacha inchi powder roasted at T80 and T160. Fortification significantly decreased the hardness of chocolate, affected by the variations in sacha inchi powder fortification level, particle size and roasting temperature. Moisture content rose with increase of sacha inchi powder fortification, however, it stayed below 2%, preserving acceptable chocolate quality. Chocolate with T160-roasted sacha inchi powder imparted lower moisture content compared to the T80-roasted powder. The lower moisture content observed in T160-roasted sacha inchi powder enhances the stability and chocolate's shelf life by minimizing the risk of mold growth and rancidity as it inhibits fats oxidation and degradation of other sensitive compounds. High moisture content causes undesirable textural changes (softening and graininess) and promotes microbial growth which negatively impacts the quality and consumer perception. The colour parameters (L*, a*, b*) exhibited negligible alterations, maintaining an acceptable range despite the effects of storage and surface texture. The addition of 7% T160-roasted sacha inchi powder yielded the greatest antioxidant activity and total phenolic content. Higher roasting temperature, such as T160, promotes extraction and formation of new bioactive and phenolic compounds through thermal reactions like Maillard reaction. These newly formed compounds effectively scavenge free radicals, leading to improved health benefits for the resulting chocolate. Sensory analysis indicated that fortification was well-received by panellists. Among all samples, 5% of T160-roasted sacha inchi powder (DC5) was the most favoured for taste, colour, aroma, texture and overall acceptability. This may be due to higher roasting temperature that eliminates the pungent, raw and grassy taste and aroma of sacha inchi seeds. Furthermore, temperature of T160 likely enhanced the formation of desirable roasted flavour such as nutty, toasty and caramel notes which complement the inherent taste of chocolate and contribute to an overall positive sensory experience. The demand for functional chocolate is growing as consumers look for products that offer health benefits beyond basic nutrition. Sacha inchi-fortified chocolate can be marketed as a heart-healthy, antioxidant-rich snack that supports overall well-being. Future research could explore proximate analysis and impact of prolonged shelf life regarding the fortified chocolate as detailed nutritional analysis is essential to validate the health claims of the fortified product.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Fathiah Nabila Azhar, Hatijah Basri;* ***data collection:*** *Hatijah Basri;* ***analysis and interpretation of results:*** *Fathiah Nabila Azhar, Hatijah Basri;* ***draft manuscript preparation:*** *Fathiah Nabila Azhar, Hatijah Basri. All authors reviewed the results and approved the final version of the manuscript.*

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