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Effects of jackfruit seed powder addition on physicochemical properties and sensory acceptability of Jackfruit Turkish Delight

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Abstract

Botulism is a fatal zoonotic disease caused by neurotoxins secreted by *Clostridium botulinum*, a spore-forming gram-positive anaerobic bacterium. In ruminant animal feeding, infection occurs primarily through contaminated feed, while environmental sources such as soil, water, and manure also play an important role in transmission pathways. *C. botulinum* neurotoxins block acetylcholine release at the neuromuscular junction, leading to progressive muscle paralysis and a clinical presentation characterized by high mortality rates. This situation leads to irreparable economic losses and severe declines in production capacity in the global livestock sector. Due to the limited efficacy of treatment options for the disease and their adverse effect on prognosis, prophylactic approaches aimed at eliminating infection sources have strategic priority in control strategies. Silage, dry feeds, animal-derived feed additives, and manure contamination used in ruminant feeding are identified as the main risk factors. Particularly in silage production processes, insufficient anaerobic fermentation, failure to achieve optimal pH range, and improper storage conditions create favorable microenvironments of critical importance for the germination of *C. botulinum* spores and toxin production. This review study aims to systematically and holistically evaluate etiological factors, molecular pathogenesis mechanisms, epidemiological transmission routes, and evidence-based control strategies of botulism infection in ruminant animal feeding. Considering the ongoing economic losses and public health risks in the livestock industry in Turkey and worldwide, there is an urgent need for multidisciplinary research on botulism pathogenesis, diagnostic methods, and prevention strategies, and this review is expected to provide a conceptual foundation and applied perspective to such scientific studies.

Key Words: *Turkish Delight, Artocarpus heterophyllus, Jackfruit seed powder, By-product, Nutritional enhancement, Sustainable food product*

Introduction

Turkish delight (*lokum*), a confection originating in Anatolia during the 15th century, derives from the Ottoman phrase “*rahat ul-hulküm*,” meaning “comforting to the throat” (Batu & Kirmaci, 2009; Anonymous, 2006). Its modern form was created by Hadji Bekir in the 18th century using refined sugar and starch, gaining global popularity when introduced to Europe in the 19th century (Doyuran et al., 2004; Anonymous, 2006). Primarily composed of starch and sugar, Turkish delight is high in carbohydrates, providing 295 kcal per 100 g, with low protein, fat, and fibre content (Öz et al., 2024). Traditionally flavoured with rosewater, lemon, or fruit extracts, it can also be enriched with nuts or fruit pulps to enhance nutritional value and antioxidant activity (Ozdemir & Akinci, 2004; Hanoğlu et al., 2023).

Jackfruit (*Artocarpus heterophyllus*), the largest tree-borne fruit, is native to South and Southeast Asia and is also cultivated in Africa and South America (Ranasinghe et al., 2019; Lin et al., 2022). Known as a multipurpose crop, jackfruit provides food, fodder, and medicinal applications, and contributes to food security due to its easy cultivation and pest resistance (Fabil et al., 2024; Bangladesh Bureau of Statistics, 2024). It is rich in phytonutrients with antibacterial, antidiabetic, anti-inflammatory, and antioxidant properties that help reduce chronic disease risk (Baliga et al., 2011; Ruiz-Montañez et al., 2014). Nutritionally, jackfruit provides vitamins A, B, and C, fibre, and minerals, with young jackfruit higher in protein and fibre, while ripe fruit contains more carbohydrates and sugars (Swami et al., 2012; Corley, 2007).

Jackfruit seeds, often discarded as waste, are rich in protein, fibre, starch, and essential minerals such as phosphorus, potassium, calcium, magnesium, and zinc, making them a valuable underutilised resource (Spada et al., 2020; Maurya & Mogra, 2016). Nutritional studies report high carbohydrate (73.71%), moderate protein (12.45%), and low fat (1.69%) contents, along with B-vitamins and dietary fibre, highlighting their potential as a functional ingredient (Eke-Ejiofor et al., 2014; Goh et al., 2024). Bioactive compounds including flavonoids, isoflavones, lignans, and saponins provide antioxidant, antimicrobial, and anti-carcinogenic properties, while jacalin, a seed lectin, has applications in immunological studies (Waghmare et al., 2019).

In addition to their nutritional benefits, using jackfruit seeds contributes to sustainability by recycling agricultural waste, supporting the creation of sustainable food systems, and expanding the commercial use of by-products. Adding jackfruit seed powder to Turkish delight offers a practical approach to improve both functional qualities and nutritional composition. To address this potential, the present study aimed to investigate the physicochemical properties and sensory acceptability of Jackfruit Turkish delight enriched with jackfruit seed powder. Studies integrating jackfruit seed powder into Turkish delight remain limited (Kamal et al., 2023; Mohammed et al., 2024), highlighting the novelty and importance of this research in developing healthier and more sustainable confectionery products.

Materials and Methods

Chemical Reagents and Equipment

All equipment and chemical reagents used in this study were obtained from the Chemical Laboratory, Faculty of Food Science and Agrotechnology, Universiti Malaysia Terengganu. The instruments included a TA.XT Plus Texture Analyser (Stable Microsystems, UK) for texture profile analysis and a Colourimeter (Konica Minolta, Japan) for colour determination. Moisture and ash contents were determined using crucibles, desiccators, an oven, and a muffle furnace. Fat content was analysed using extraction cups, thimbles, desiccators, and petroleum ether as solvent. Protein analysis was carried out using digestion tubes and racks with sodium hydroxide, boric acid, and sulfuric acid, while fibre content was determined using fibre bags and sulfuric acid solution.

Raw Materials

The raw materials used in the preparation of jackfruit Turkish Delight included sugar, water, lemon juice, corn starch, and cream of tartar, which were purchased from a local supermarket in Gong Badak, Terengganu. Fresh jackfruit (*Artocarpus heterophyllus*) was obtained from a local stall at Teluk Ketapang beach, Terengganu, to prepare jackfruit seed powder and jackfruit puree for the formulation.

Formulations

The formulations for jackfruit Turkish delight incorporating jackfruit seed powder at varying percentages are summarised in Table 1. The table compares the control sample, which does not include jackfruit seed powder, with three formulations (A, B, and C) containing 25%, 50%, and 75% jackfruit seed powder, respectively. It provides a detailed breakdown of ingredient percentages for each formulation, including adjustments to corn starch and jackfruit seed powder to achieve the desired variations.

Table 1. Formulations for jackfruit Turkish delight with the addition of jackfruit seed powder in percentage (%).

Ingredients (%)	Formulation			
	Control	A	B	C
Corn starch	5.95	4.46	2.97	1.49
Jackfruit Seed Powder	0.00	1.49	2.97	4.46
*Sugar	39.63			
*Water	31.04			
*Lemon Juice	0.99			
*Cream of Tartar	0.26			
*Jackfruit Puree	22.13			
Total	100			

Note: Ingredients labelled with (*) show a constant amount of ingredients were used. Formulations: Control, 0% jackfruit seed powder; A, added 25% jackfruit seed powder; B, added 50% jackfruit seed powder; C, added 75% jackfruit seed powder.

Jackfruit Seed Powder Preparation

Seeds were obtained from ripe jackfruit, and the arils and rinds were carefully removed using sharpened knives. The seeds were rinsed thoroughly with water to ensure cleanliness, and the outer skin was peeled off. The cleaned seeds were then boiled for 30 minutes until softened, followed by crushing with a food processor. The crushed seeds were evenly spread on trays and dried in a cabinet dehydrator at 60 °C for 24 hours (12% moisture content). After drying, the seeds were ground using a heavy-duty grinder and sieved through a 125–180 µm mesh to obtain a fine texture. This process resulted in the production of high-quality jackfruit seed powder (Eke-Ejiofor et al., 2014).

Jackfruit Turkish Delight preparation

The preparation of jackfruit Turkish delight incorporating jackfruit seed powder was carried out as follows: all ingredients were weighed, with the percentage of jackfruit seed powder increasing as the cornstarch content decreased (Table 1). Sugar syrup was prepared by dissolving 600 g of sugar in 230 g of water in a stainless-steel pot, bringing it to a boil, and heating it to 120 °C using a candy thermometer, while brushing the pot sides with water to prevent crystallisation. In another saucepan, 240 g of water was mixed with 90 g of flour, 4 g of cream of tartar, and 335 g of jackfruit puree blended to a smooth consistency, and the mixture was stirred over medium heat until thick and pasty. The hot sugar syrup (120 °C) was slowly incorporated into the pasty flour–jackfruit mixture with continuous whisking until homogeneous. The mixture was then simmered on low heat, stirred every 8–10 minutes for approximately one hour, until a thick, gluey, golden-yellow texture was obtained. Finally, the mixture was poured into a mould and chilled overnight without covering, after which the chilled product was cut into uniform cubes and dusted with a refined sugar–cornstarch mixture.

Texture Analysis

The texture of jackfruit Turkish delight was evaluated using a texture analyser (TA.XTPlus, Stable Microsystem, UK) equipped with a cylindrical probe (P36R, 36 mm diameter). The textural attributes measured included springiness, adhesiveness, hardness, cohesiveness, and gumminess (Dogan et al., 2020). Each formulation was tested in triplicate, and mean values were reported.

Colour Analysis

The colour of the Jackfruit Turkish delight was analysed by using a colourimeter (Minolta Chroma Meter CR300, Japan). The colourimeter was calibrated using a white tile, and the value was expressed as L*, a*, and b*. Jackfruit Turkish delight samples were placed into the platform where UV light standard illuminate type D65 was used. The light penetration was tested using a colourimeter. By clicking the button, the light penetrates the sample. After that, the L*, a*, and b* values were displayed on the screen of the instrument. Each sample was measured three times with three replications. ∆E (delta E) was calculated by using the formula (equation 1) below:

$$\Delta E = \sqrt{(L*2 - L*1) + (a*2 - a*1) + (b*2 - b*1)} \quad (1)$$

Where;
L^*_1 = Lightness of the control sample
L^*_2 = Lightness of sample
a^*_1 = Greenness and redness of control sample
a^*_2 = Greenness and redness of sample
b^*_1 = Blueness and yellowness of control sample
b^*_2 = Blueness and yellowness of sample
∆E = Total colour difference

Proximate Analysis

The proximate analysis of jackfruit Turkish delight involved several standard procedures. Moisture content was determined using the oven drying method, while ash content was measured using a muffle furnace at 550 °C for 24 hours (AOAC, 2005). Fat content was analyzed using the Labtec system, and protein content was determined by weighing 1.0 g of the pounded sample in a 250 ml digestion tube. For fibre analysis, an empty FibreBag was dried in an oven at 100–109 °C for 3 hours and weighed using an analytical balance (m1). Finally, total carbohydrate content was calculated as the last step in the proximate analysis of the Turkish delight.

Sensory Evaluation Test of Jackfruit Turkish Delight

Thirty untrained panellists were chosen randomly among University Malaysia Terengganu (UMT) students without specific priority in selection. The panellists evaluated the products using seven hedonic scales, where 1 indicates dislike extremely and 7 indicates like extremely. The evaluation was based on the Jackfruit Turkish delight's appearance, colour, flavour, texture, aroma, and overall acceptability. Each sample was packed individually and coded with a three-digit random number.

Statistical Analysis

All data obtained from the physicochemical analysis and sensory evaluation of Turkish delight were assessed using one-way analysis of variance (One-way ANOVA) with multiple comparisons, and significant differences among means (p<0.05) were determined by Fisher's LSD using the program MINITAB release 21 Statistical Software. All data represent the means of triplicate.

Results

Texture Profile

The texture profile analysis of jackfruit Turkish delight with the addition of jackfruit seed powder is shown in Table 2. Hardness decreased from 1483.20 ± 159.00 g in the control (100% corn starch, 0% jackfruit seed powder) to 376.30 ± 119.50 g in Formulation C (25% corn starch, 75% jackfruit seed powder). Adhesiveness increased in magnitude (more negative) with higher jackfruit seed powder levels, ranging from -96.60 ± 47.50 g·s in the control to -311.20 ± 59.40 g·s in Formulation C. Springiness slightly decreased as the proportion of jackfruit seed powder increased, with values from 0.99 ± 0.04 in the control to 0.88 ± 0.03 in Formulation C. Cohesiveness declined from 0.88 ± 0.01 in the control to 0.56 ± 0.04 in Formulation C. Gumminess and chewiness also decreased with higher jackfruit seed powder content, with gumminess ranging from 836.00 ± 111.20 g in the control to 260.50 ± 66.20 g in Formulation C, and chewiness ranging from 823.60 ± 84.50 g in the control to 229.30 ± 60.40 g in Formulation C. Values with different superscripts within each row were significantly different at $p<0.05$.

Table 2. Texture profile analysis of jackfruit Turkish Delight with the addition of jackfruit seed powder

Parameter	*Control*	*Formulation A*	*Formulation B*	*Formulation C*
Hardness (g)	1483.20 ±159.00^{a}	946.90 ±129.90^{b}	927.10 ±127.10^{b}	376.30 ±119.50^{c}
Adhesiveness (g.s)	-96.60 ±47.50^{a}	-192.80 ±37.80^{b}	-256.87 ±28.42^{c}	-311.20 ±59.40^{d}
Springiness	0.99 ±0.04^{a}	0.94 ±0.01^{b}	0.91 ±0.01^{b}	0.88 ±0.03^{c}
Cohesiveness	0.88 ±0.01^{a}	0.76 ±0.02^{b}	0.71 ±0.07^{c}	0.56 ±0.04^{d}
Gumminess(g)	836.00 ±111.20^{a}	812.30 ±112.00^{a}	716.60 ±82.70^{b}	260.50 ±66.20^{c}
Chewiness(g)	823.60 ±84.50^{a}	761.60 ±100.50^{a}	656.20 ±81.80^{b}	229.30 ±60.40^{c}

Note: Data values are expressed as mean ± standard deviation of triplicates (n=3). Values with different superscripts within the row are significantly different at ($p<0.05$); Control: 100% Corn starch, 0% JSP; Formulation A: 75% Corn starch, 25% JSP; Formulation B: 50% Corn starch, 50% JSP; Formulation C: 25% Corn starch, 75% JSP.

Colour Profile

The colour profile analysis of jackfruit Turkish delight with the addition of jackfruit seed powder is presented in Table 3. The lightness (L*) values decreased as the proportion of jackfruit seed powder increased, ranging from 40.30 ± 0.53 in the control (100% corn starch, 0% jackfruit seed powder) to 34.44 ± 0.33 in Formulation C (25% corn starch, 75% jackfruit seed powder). The a* values shifted from -1.21 ± 0.25 in the control to 1.89 ± 0.40 in Formulation C, indicating a gradual change from green to red tones. Similarly, b* values increased from 11.27 ± 0.54 in the control to 18.84 ± 2.52 in Formulation C, showing a trend toward a more yellow hue. The total colour difference (ΔE) ranged from 1.38 ± 0.37 in Formulation A to 2.05 ± 0.83 in Formulation C, with significant differences observed between formulations ($p<0.05$). These results indicate that increasing jackfruit seed powder resulted in a darker and more intensely coloured Turkish delight.

Table 3. Colour profile analysis of jackfruit Turkish Delight with the addition of jackfruit seed powder

Formulation	*L**	*a**	*b**	*ΔE*
Control	40.30 ±0.53^{a}	-1.21 ±0.25^{d}	11.27 ±0.54^{d}	-
A	38.35 ±0.74^{b}	-0.76 ±0.25^{c}	14.79 ±0.59^{c}	1.38 ±0.37^{b}
B	36.06 ±0.53^{c}	0.67 ±0.12^{b}	16.41 ±0.52^{b}	1.65 ±0.26^{ab}
C	34.44 ±0.33^{d}	1.89 ±0.40^{a}	18.84 ±2.52^{a}	2.05 ±0.83^{a}

Note: Data values are expressed as mean ± standard deviation of triplicates (n=3). Values with different superscripts within the column are significantly different at ($p<0.05$); Control: 100% Corn starch, 0% JSP; Formulation A: 75% Corn starch, 25% JSP; Formulation B: 50% Corn starch, 50% JSP; Formulation C: 25% Corn starch, 75% JSP.

Proximate Composition

The proximate composition of jackfruit Turkish delight with the addition of jackfruit seed powder is shown in Table 4. Moisture content remained relatively constant across all formulations, ranging from 11.37 ± 0.19% in the control (100% corn starch, 0% jackfruit seed powder) to 11.16 ± 0.37% in Formulation C (25% corn starch, 75% jackfruit seed powder). Ash content slightly increased from 0.46 ± 0.05% in the control to 0.54 ± 0.04% in Formulation C, while fat content ranged from 0.49 ± 0.05% to 0.53 ± 0.04% across the formulations. Protein content increased significantly with higher levels of jackfruit seed powder, from 0.48 ± 0.12% in the control to 1.59 ± 0.05% in Formulation C. Similarly, fibre content rose from 0.20 ± 0.06% in the control to 0.96 ± 0.10% in Formulation C. Carbohydrate content decreased slightly with increasing jackfruit seed powder, ranging from 87.00 ± 0.38% in the control to 85.22 ± 0.49% in Formulation C. Values with different superscripts within each row were significantly different at $p<0.05$.

Table 4. Proximate analysis of jackfruit Turkish Delight with the addition of jackfruit seed powder

Parameter	*Control*	*Formulation A*	*Formulation B*	*Formulation C*
Moisture (%)	11.37 ±0.19^{a}	11.29 ±0.49^{a}	11.25 ±0.40^{a}	11.16 ±0.37^{a}
Ash (%)	0.46 ±0.05^{a}	0.49 ±0.03^{a}	0.51 ±0.06^{a}	0.54 ±0.04^{a}
Fat (%)	0.49 ±0.05^{a}	0.50 ±0.03^{a}	0.51 ±0.01^{a}	0.53 ±0.04^{a}
Protein (%)	0.48 ±0.12^{c}	0.69 ±0.19^{c}	0.98 ±0.18^{b}	1.59 ±0.05^{a}
Fibre (%)	0.20 ±0.06^{c}	0.32 ±0.04^{c}	0.61 ±0.05^{b}	0.96 ±0.10^{a}
Carbohydrate (%)	87.00 ±0.38^{a}	86.80 ±0.64^{ab}	86.14 ±0.57^{ab}	85.22 ±0.49^{b}

Note: Data values are expressed as mean ± standard deviation of triplicates (n=3). Values with different superscripts within the row are significantly different at ($p<0.05$); Control: 100% Corn starch, 0% JSP; Formulation A: 75% Corn starch, 25% JSP; Formulation B: 50% Corn starch, 50% JSP; Formulation C: 25% Corn starch, 75% JSP.

Sensory Acceptance

The sensory evaluation of jackfruit Turkish delight with the addition of jackfruit seed powder is shown in Table 5. The mean scores and percentage of acceptance (%Ac.) were recorded for appearance, colour, aroma, chewiness, texture, sweetness, taste, aftertaste, and overall evaluation. Overall, Formulation B (50% corn starch, 50% jackfruit seed powder) received the highest acceptability among the JSP-enriched samples, with an overall mean score of 6.13 ± 0.47 and 96.67% acceptance, while Formulation C (25% corn starch, 75% JSP) received the lowest scores and acceptance, with an overall mean of 4.97 ± 1.05 and 53.33% acceptance. Control samples (100% corn starch, 0% JSP) received high mean scores for overall evaluation (6.37 ± 0.67) with 93.33% acceptance. Individual attributes followed similar trends; appearance, colour, aroma, chewiness, texture, sweetness, taste, and aftertaste scores were highest in the control and Formulation B and lowest in Formulation C. Values with different superscripts within each row were significantly different at p<0.05.

Table 5. Mean scores and % of acceptances of jackfruit Turkish Delight with the addition of jackfruit seed powder

Attribute	*Control*	*%Ac.*	*A*	*%Ac.*	*B*	*%Ac.*	*C*	*%Ac.*
Appearance	6.17 ±0.80^{a}	96.67	6.13 ±1.31^{a}	73.33	6.12 ±0.52^{a}	90.00	5.43 ±0.98^{b}	66.67
Colour	6.23 ±0.69^{a}	93.33	6.15 ±0.59^{a}	80.00	6.05 ±0.42^{a}	93.33	5.22 ±0.97^{b}	56.67
Aroma	6.20 ±0.52^{a}	90.00	6.12 ±0.82^{a}	66.67	5.95 ±0.42^{a}	83.33	5.17 ±1.06^{b}	56.67
Chewiness	6.07 ±0.58^{a}	90.00	5.97 ±0.75^{a}	56.67	5.82 ±0.65^{a}	86.67	4.72 ±1.22^{b}	46.67
Texture	6.28 ±0.54^{a}	93.33	6.12 ±0.75^{a}	66.67	5.93 ±0.55^{a}	90.00	4.33 ±1.59^{b}	36.67
Sweetness	5.82 ±1.49^{a}	80.00	5.80 ±0.91^{a}	60.00	5.72 ±0.61^{a}	83.33	4.62 ±1.41^{b}	40.00
Taste	6.23 ±0.83^{a}	83.33	6.20 ±0.74^{a}	66.67	6.08 ±0.77^{a}	90.00	4.97 ±1.11^{b}	50.00
Aftertaste	5.92 ±0.84^{a}	93.33	5.80 ±0.98^{a}	70.00	5.78 ±0.54^{a}	86.67	4.73 ±1.17^{b}	43.33
Overall evaluation	6.37 ±0.67^{a}	93.33	6.20 ±0.73^{a}	70.00	6.13 ±0.47^{a}	96.67	4.97 ±1.05^{b}	53.33

Note: Data values are expressed as mean ± standard deviation (n=30). Values with different superscripts within the row are significantly different at (p<0.05); Control: 100% Corn starch, 0% JSP; Formulation A: 75% Corn starch, 25% JSP; Formulation B: 50% Corn starch, 50% JSP; Formulation C: 25% Corn starch, 75% JSP. %Ac.; Percentage of Acceptance.

Discussion

Texture Profile

Table 2 presents the texture profile of jackfruit Turkish delight formulated with varying levels of JSP. This analysis provides insights into how the incorporation of JSP influences the texture properties of jackfruit Turkish delight. Hardness, the force required to compress the Turkish delight, showed a significant reduction (p<0.05) as the level of JSP increased. The control formulation, prepared with 100% corn starch, recorded the highest hardness value (1483.20 ±159.00 g), indicating a firmer texture. In contrast, Formulation C, with 75% JSP substitution, exhibited the lowest hardness value (376.30 ±119.50 g). The decreasing trend suggests that incorporating JSP weakens the structural matrix, reducing the firmness of the product. This significant difference highlights the influence of JSP on the texture of the Turkish delight. Lower starch levels lead to a softer texture because starch granules contribute to the gel matrix's firmness and stability (Dey, 2017).

Adhesiveness, defined as the work required to overcome the attractive forces between the product and a surface, increased significantly (p<0.05) with higher levels of JSP. The control formulation exhibited the lowest adhesiveness (-96.60 ±47.50), while Formulation C showed the highest magnitude of adhesiveness (-311.20 ±59.40). This significant increase is likely due to JSP's hydrophilic properties, which enhance moisture retention, making the Turkish delight stickier. The increased adhesiveness may impact the product’s handling and consumer experience, as it becomes more challenging to manage during packaging and consumption. Jackfruit seed flour has been shown to exhibit adhesive properties, which can enhance the binding in products. This is likely due to the presence of polysaccharides and proteins that create a sticky matrix upon hydration (Mufarikha et al., 2021).

Springiness, the measure of a product's ability to recover its shape after deformation, decreased significantly ($p<0.05$) with increased JSP content. The control formulation showed the highest springiness (0.99 ±0.04), indicating a more elastic texture, while Formulation C, with 75% JSP substitution, recorded the lowest springiness (0.88 ±0.03). This significant reduction suggests that JSP disrupts the starch network, resulting in a denser and less elastic product. Lower springiness may affect the sensory perception of Turkish delight by reducing its bounciness and elasticity. Jackfruit seed powder is known for its fibrous and dense texture, which can compact the structure of the food product. This compaction reduces the amount of air pockets that contribute to springiness, leading to a less elastic texture (Ibrahim et al., 2022).

Cohesiveness, which indicates the strength of internal bonds within the product, showed a significant decrease ($p<0.05$) with increased JSP levels. The control formulation had the highest cohesiveness (0.88 ±0.01), reflecting stronger structural integrity, while Formulation C recorded the lowest cohesiveness (0.56 ±0.04). The significant reduction indicates that JSP incorporation weakens the internal bonds, likely due to its lower binding properties compared to corn starch. Reduced cohesiveness may compromise the stability and structural integrity of the jackfruit Turkish delight. Higher levels of JSP may alter the moisture content and the interaction between the ingredients, leading to a weaker binding matrix. Studies have shown that as the concentration of a binder increases, it can sometimes disrupt the cohesive forces among other components, resulting in decreased cohesiveness (Barbosa et al., 2023).

Chewiness, which represents the energy needed to chew the product until it is ready for swallowing, significantly decreased ($p<0.05$) with increasing JSP levels. The control formulation had the highest chewiness value (823.60 ±84.50), reflecting a firmer and more elastic texture, while Formulation C recorded the lowest chewiness (229.30 ±60.40). The significant reduction in chewiness is a result of decreased gumminess and springiness in JSP-enriched formulations. This softer texture may enhance the product's appeal for consumers who prefer easier-to-chew confectionery items. This reduction in chewiness was attributed to the softer texture imparted by JSP, which altered the structural integrity of the confectionery matrix (Achinna et al., 2024).

Colour Profile

Table 3 presents the mean values of colour profile parameters (L*, a*, and b*) for jackfruit Turkish delight formulated with varying amounts of JSP. The colour attributes, L*, a*, and b*, were analysed to determine how the inclusion of JSP affects the colour of the product. The L* values, which represent the lightness or darkness of the formulations, ranged from 34.44 to 40.30. The control formulation (100% corn starch) exhibited the highest lightness at 40.30 ±0.53, indicating it had the brightest colour. Formulation C (25% corn starch: 75% JSP) showed the lowest lightness with a value of 34.44 ±0.33, indicating that the addition of JSP resulted in a darker product. Significant differences were observed across all formulations ($p<0.05$), with the lightness decreasing as the percentage of JSP increased. When additional jackfruit seed flour was added, the colour changed from light brown to dark brown (Hossain, 2014).

The a* values, indicating the redness or greenness of the formulations, showed a significant increase as the JSP content increased. The control formulation had the lowest a* value of -1.21 ±0.25, indicating a greener hue. However, as JSP was added, the a* values became more positive, showing a shift towards a redder hue. Formulation C had the highest a* value of 1.89 ±0.40, indicating the most pronounced red tint. Significant differences were observed among all formulations ($p<0.05$), with Formulation C showing the greatest redness compared to the control, which was the least red. The drying process alters the chemical composition of the seeds, leading to a more intense colour that can contribute to increased redness in the final product (Lien et al., 2024).

The b* values, which represent the degree of yellowness or blueness, ranged from 11.27 ±0.54 to 18.84 ±2.52. The control formulation had the lowest b* value of 11.27 ±0.54, indicating a less yellow colour. As the JSP concentration increased, the b* value also increased, with Formulation C showing the highest value of 18.84 ±2.52, indicating the most yellow hue. Significant differences were found between all formulations ($p<0.05$), with Formulation C being the most yellow compared to the control. Jackfruit seed powder typically has a yellowish hue, which can enhance the b* value of food products (Ravindran et al., 2020).

The ΔE values, indicating the total colour difference from the control, were calculated for Formulations A, B, and C. Formulation A (75% corn starch: 25% JSP) had a ΔE of 1.38 ±0.37, followed by Formulation B (50% corn starch: 50% JSP) with a ΔE of 1.65 ±0.26. The highest ΔE was observed in Formulation C (25% corn starch: 75% JSP), with a value of 2.05 ±0.83. Significant differences in ΔE were observed among the formulations ($p<0.05$), with increasing JSP content leading to a greater colour change from the control. The use of JSP in various formulations has shown that it can maintain or even improve total colour difference when combined with other ingredients effectively (Achinna et al., 2024).

Proximate Composition

Table 4 shows the proximate composition of jackfruit Turkish delight with varying levels of JSP incorporated into the formulation. The moisture content of the jackfruit Turkish delight was not significantly influenced ($p>0.05$) by the incorporation of jackfruit seed powder (JSP), ranging from 11.16% to 11.37% across all formulations (Table 5). The consistent values suggest that JSP does not markedly alter the water retention capacity of the product, a valuable property for its potential use as a functional ingredient (Swami et al., 2012). Although Formulation C (25% corn starch: 75% JSP) recorded a slightly lower value (11.16%) compared to the control (11.37%), the overall stability in moisture levels indicates that product shelf life would not be heavily impacted by JSP incorporation.

Ash content showed a gradual increase with the inclusion of JSP, rising from 0.46% in the control to 0.54% in Formulation C. Although the differences were not statistically significant ($p>0.05$), this upward trend reflects the inherent mineral contribution of JSP, as jackfruit seeds are known to be a source of minerals such as potassium, calcium, and magnesium (Ocloo et al., 2010). The findings suggest that JSP can modestly enhance the mineral composition of Turkish delight without negatively affecting its fundamental properties.

The fat content of the Turkish delight remained relatively stable across all formulations, ranging between 0.49% and 0.53%, with no significant differences detected ($p>0.05$) as shown in Table 5. This indicates that the incorporation of jackfruit seed powder (JSP) does not markedly influence the fat profile of the final product. The observed stability aligns with the known composition of jackfruit seeds, which are characterized by their low fat content, thereby positioning JSP as a suitable low-fat ingredient for developing healthier confectionery options (Cheng et al., 2022).

In contrast to the stable fat content, the protein content increased significantly ($p<0.05$) with higher levels of JSP incorporation (Table 5). The protein value rose from 0.48% in the control to 1.59% in Formulation C, with Formulation B (0.98%) showing nearly double the protein content of the control. This dramatic increase highlights the direct nutritional benefit of replacing corn starch with JSP. The results are a direct reflection of the inherently high protein content of jackfruit seeds, confirming that JSP is a valuable ingredient for significantly improving the protein quality of confectionery products (Swami et al., 2012).

Fibre content exhibited the most notable increase, rising from 0.20% in the control to 0.96% in Formulation C ($p<0.05$). This dramatic enhancement confirms the suitability of JSP as an excellent functional ingredient for boosting dietary fibre intake in enriched foods (Ranasinghe et al., 2019). The considerable improvement seen even in Formulation B (0.61%) presents a balanced option for enhancing nutritional value while likely maintaining desirable sensory attributes.

The carbohydrate content exhibited a decreasing trend, falling significantly ($p<0.05$) from 87.00% in the control to 85.22% in Formulation C (Table 5). This reduction is a direct nutritional benefit of partially replacing refined corn starch with JSP, which contributes higher levels of protein and fibre instead of simple carbohydrates. This shift aligns with current food science strategies to create healthier confectionery options by incorporating fruit and vegetable by-products to improve their nutritional profile (Gómez & Martínez, 2018), catering to health-conscious consumers seeking lower-carbohydrate alternatives.

Sensory Acceptance

Table 5 presents the mean sensory acceptance scores for the attributes of jackfruit Turkish delight with varying levels of JSP incorporation. Sensory attributes such as appearance, colour, aroma, chewiness, texture, sweetness, taste, aftertaste, and overall evaluation were evaluated. The data provides insight into how the inclusion of JSP impacts the sensory characteristics. The appearance scores ranged from 5.43 to 6.17, with no significant differences ($p>0.05$) observed between the control and the formulations A and B. However, formulation C, with the highest proportion of JSP (75%), exhibited the lowest appearance score of 5.43, significantly different from the other formulations ($p<0.05$). This may be attributed to the higher amount of JSP, which could impart a more opaque and less visually appealing appearance compared to the translucent control, as the incorporation of alternative flours often alters the surface properties and light transmission of gels (Jan et al., 2018).

Colour scores ranged from 5.22 to 6.23, with the control formulation scoring the highest (6.23) and formulation C scoring the lowest (5.22). While there were no significant differences between the control, formulations A, and B ($p>0.05$), the addition of JSP in formulation C caused a significant reduction in the colour score ($p<0.05$). This can be directly attributed to the natural, often darker, colour of jackfruit seed powder, which alters the product's overall colour when incorporated at high concentrations, leading to a less bright and desirable hue compared to the control made with pure corn starch (Waghmare et al., 2019).

The aroma scores ranged from 5.17 to 6.20, with the control formulation having the highest score of 6.20. Similar to colour, the control formulation was rated higher for aroma, while formulation C had the lowest score (5.17). No significant differences were observed between the control and other formulations except for formulation C ($p<0.05$). The decrease in aroma score for formulation C is likely due to the distinct and potentially strong aroma imparted by JSP, which might overpower the delicate, pleasant aromas typically expected from a traditional Turkish delight, a phenomenon observed when strong-flavoured novel ingredients are used at high levels (Ngwere & Mongi, 2021).

Chewiness scores showed a range from 4.72 to 6.07, with formulation C receiving the lowest score (4.72), which was significantly different from all other formulations ($p<0.05$). The control formulation, along with formulations A and B, scored higher in chewiness, indicating that the addition of JSP at higher levels may alter the texture of the product, making it less chewy. This is likely because JSP dilutes the corn starch network responsible for the characteristic chewy, elastic texture of Turkish delight, as the functional properties of composite flours directly influence the final product's texture (Mukprasirt & Sajjaanantakul, 2004).

The texture scores ranged from 4.33 to 6.28, with the control formulation scoring the highest (6.28) and formulation C the lowest (4.33) of texture. Significant differences were observed between the control and the other formulations ($p<0.05$), with formulation C exhibiting the softest texture. The incorporation of higher levels of JSP may have reduced the product's firmness, likely due to the lower gelatinising ability and different starch and fibre composition of JSP compared to pure corn starch, which is critical for forming the firm, yet tender gel structure of a high-quality Turkish delight (Gómez & Martínez, 2018).

Sweetness scores ranged from 4.62 to 5.82, with the control formulation receiving the highest score (5.82) and formulation C the lowest (4.62). The data revealed no significant differences between the control and the other formulations in terms of sweetness ($p>0.05$). This indicates that the sweetness level was primarily governed by the added sucrose in the recipe, which is a potent sweetener that can mask minor variations in flavour contributed by other ingredients (Gómez & Martínez, 2018). The stability of the sweetness score across formulations is a positive finding, as it suggests that JSP can be added without creating an undesirable sweet or non-sweet taste imbalance.

Taste scores ranged from 4.97 to 6.23, with the control formulation again scoring the highest (6.23) and formulation C scoring the lowest (4.97). There were no significant differences in taste between the control, formulation A, and formulation B ($p>0.05$), but formulation C exhibited a significant difference ($p<0.05$). This reduction is likely due to the inherent flavour of JSP, which can introduce distinct, and at high concentrations, less preferred taste notes that alter the clean, sweet profile of the traditional product (Ranasinghe et al., 2019). This demonstrates that while moderate levels of JSP are acceptable, high levels can detrimentally affect the primary flavour.

Aftertaste scores ranged from 4.73 to 5.92, with formulation C receiving the lowest score (4.73) and the control formulation scoring the highest (5.92). Similar to taste, there was no significant difference between the control, formulation A, and formulation B ($p>0.05$), while formulation C showed a significant difference ($p<0.05$). This suggests that the compounds responsible for the distinct flavour of JSP persist in the mouth, creating a lingering sensation that overshadows the clean finish of the control. The presence of such persistent off-flavours or astringent notes is a common sensory challenge when incorporating seed-based flours into refined confectionery products (Ngwere & Mongi, 2021).

The overall acceptance scores ranged from 4.97 to 6.37, with the control formulation scoring the highest (6.37) and formulation C the lowest (4.97). Significant differences were observed between the control and formulation C ($p<0.05$). The overall acceptance of the jackfruit Turkish delight was most positively affected by colour, aroma, and texture, with the control formulation scoring the highest in these attributes. Formulation C, which contained the highest level of JSP, was the least accepted, likely due to the negative effects of JSP on texture, aftertaste, and overall flavour balance. The incorporation of jackfruit seed flour at the optimum concentration aided in improving the sensory properties of various products (Waghmare et al., 2019).

Conclusion

The incorporation of jackfruit seed powder in Turkish delight significantly enhanced its nutritional profile by increasing protein and fibre content, resulting in a more stable and healthier product. Among the formulations tested, Formulation B (50% corn starch and 50% jackfruit seed powder) was the most preferred by the sensory panel due to its balanced texture, flavour, and overall acceptability, demonstrating that nutritional improvement can be achieved without compromising product quality. These findings highlight the potential of jackfruit seed powder as a valuable functional ingredient in confectionery products. For future research, studies on antioxidant activity and total phenolic content are recommended to further explore its functional benefits, along with shelf-life and microbial stability evaluations to determine storage suitability and commercial viability.

Declarations

Ethical Approval Certificate

This study did not involve human participants or animals, and all experimental procedures were limited to food product development; therefore, formal ethical approval was not required.

Author Contribution Statement

Nur Ariff Aiman Bin Mohd Salleh: Data collection, investigation, formal analysis, and writing the original draft.

Fisal Ahmad: Project administration, supervision, conceptualisation, methodology, review, and editing.

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Conflict of Interest

Please The authors have declared that no conflict of interest exists.

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