



Valorisation of dragon fruit peel in functional squash

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Abstract:

Dragon fruit (*Hylocereus* spp.) peel is a waste product rich in bioactive components. This study developed and evaluated three experimental formulations of functional dragon peel squash with different acidulants, nutritional values, and sensory profiles. The acidulants were amla juice, citric acid, and lemon juice. The experimental samples were compared with the control sample and analyzed using standard methods, which included the proximate analysis, the Folin-Ciocalteu assay for phenolics, the DPPH assay for antioxidant activity, and a nine-point hedonic scale for sensory evaluation. The color degradation was evaluated over three successive one-week storage intervals. The proximate composition (wet basis) showed that the peel consisted of 92.81% moisture, 1.49% ash, 0.528% protein, 0.20% fat, and 4.9% carbohydrates. The squash showed 40–47°Brix of total soluble solids, pH 2.32–4.83, 0.18–1.5% titratable acidity, and ≤ 108 mg/100 mL ascorbic acid. The sample with amla juice possessed the highest phenolic content (5.20 mg GAE/100 g) and the control has highest antioxidant level ($IC_{50} = 0.725$ mg/mL), as well as the lowest microbial load (1.3×10^3 CFU/mL) after three weeks of storage. As for the sensory assessment, the amla juice sample was preferred for color and aroma, while the sample with lemon juice received a higher score for taste. The ANOVA test ($df = 2,4$) showed a stable L^* over 21 days, whereas the b^* values tended to increase in all four formulations, and the a^* value increased in the sample with lemon juice ($p < 0.05$). The significant change in b^* indicated poor storage stability, which is to be improved by reformulation with color stabilizers. In this research, dragon fruit peel was converted into a nutritious and organoleptically attractive squash. This functional beverage offers a sustainable strategy for valorizing agricultural waste.

Keywords: Squash, dragon fruit peel, pitaya, total polyphenol content, DPPH, sensory quality, storage stability

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INTRODUCTION

Dragon fruit, also known as pitaya or pitahaya, is a delicious fruit belonging to the *Cactaceae* family and two distinct genera: *Hylocereus* and *Selenicereus* [1, 2]. The most popular commercially cultivated variants are from the *Hylocereus* genus, which consists of 16 different species [3]. They are cultivated in about 20 countries, including Bangladesh, Japan, Malaysia, the Philippines, Taiwan, Vietnam, Thailand, Indonesia, the United States, and China [2].

Dragon fruit peel is an agricultural by-product in the fruit juice processing sector. Most often, it is utilized as fertilizer. Wastes discarded mostly by the beverage industry include 25–30% of peels, followed by seeds, cores, pulp, pomace, etc. However, all these materials have a good potential as natural functional food components [4–7]. Dragon fruit peels are rich in bio-

active substances. For instance, quercetin, gallic acid, and chlorogenic acid are known for anti-cancer, anti-hyperlipidemic, antidiabetic, and antioxidant properties. Other health-beneficial substances include phenolic compounds and betacyanins. As peel is primarily comprised of such antioxidants as pectin, betacyanin pigments, and dietary fiber, it has stronger phenolic and radical scavenging activity than pulp [8–11].

Squash is a concentrated fruit-flavored and non-alcoholic syrup prepared from fruit juice, water, and sugar or its substitute [12]. Fruit squashes, which contain around 25% of fruit juice, are gaining popularity over synthetic beverages due to their superior flavor, taste, nutritional value, and storage stability. As a result, squash has become a popular nutritious soft drink [13, 14].

Dragon fruit peel constitutes 20–22% of the whole fresh fruit, yet it is disregarded as waste, despite its

great health advantages. This research featured a new value-added dragon fruit squash made of underutilized peel waste and provided with detailed physiochemical, sensory, and storage profiles.

STUDY OBJECTS AND METHODS

Experimental site. The study was carried out in the laboratory of the Department of Food Engineering and Technology, Bangladesh Agricultural University (Mymensingh, Bangladesh).

Materials and equipment. The dragon fruits were purchased from a local market in Mymensingh, Bangladesh. The trays, knife, slicer, chopping board, balance, spatula, crucible, desiccator, and other tools came from the laboratory stock. The drying operation involved a cabinet dryer (Model No. 1816, Modern Laboratory Equipment, USA).

Formulation. Mature dragon fruits were washed and peeled to eliminate the scales on the outer layer. The pulp and inner peel, once separated, were finely chopped into small pieces. Seeds were extracted by pressing, followed by filtration through paper cloth. Amla juice, citric acid, or lemon juice were added to dragon fruit peel. Next, we added sugar syrup to those experimental samples and thoroughly mixed it with a spoon. The soluble solids content was adjusted to 40–50° in the concentrate resulted in a final drink with 10–15°Brix after dilution. The control sample did not include any acidifying agents. Figure 1 illustrates the method. Table 1 demonstrates the formulations of the squash under study.

Proximate analysis. The fresh dragon fruit peel was analyzed for moisture and protein (Kjeldahl method) as recommended by the Association of Official Agricultural Chemists (AOAC)¹. The fat and ash contents were determined by Ranganna's method [15] while the carbohydrate content was calculated using Pearson's test [16].

Physicochemical analysis. The physicochemical analysis for total soluble solids in the squash involved a hand refractometer (Model No. 8987, Puji Kuki, Japan) followed by AOAC (2012)². The pH, titratable acidity, and ascorbic acid were tested as recommended by AOAC (2005)³.

Table 1 Formulations of experimental dragon fruit peel squash

Ingredient	Sample			
	Control	Peel + amla juice	Peel + citric acid	Peel + lemon juice
Peel, g	70	70	70	70
Sugar, g	200	200	200	200
Water, g	730	580	715	580
Amla juice, mL	–	150	–	–
Citric acid, g	–	–	15	–
Lemon juice, mL	–	–	–	150
Total, g/mL	1,000	1,000	1,000	1,000

¹ Official methods of analysis of AOAC International. 19th ed. In: Horwitz W, Latimer GW, editors. Rockville: AOAC International; 2012.

² The same.

³ Official methods of analysis of AOAC International. 18th ed. Washington: AOAC International; 2005.

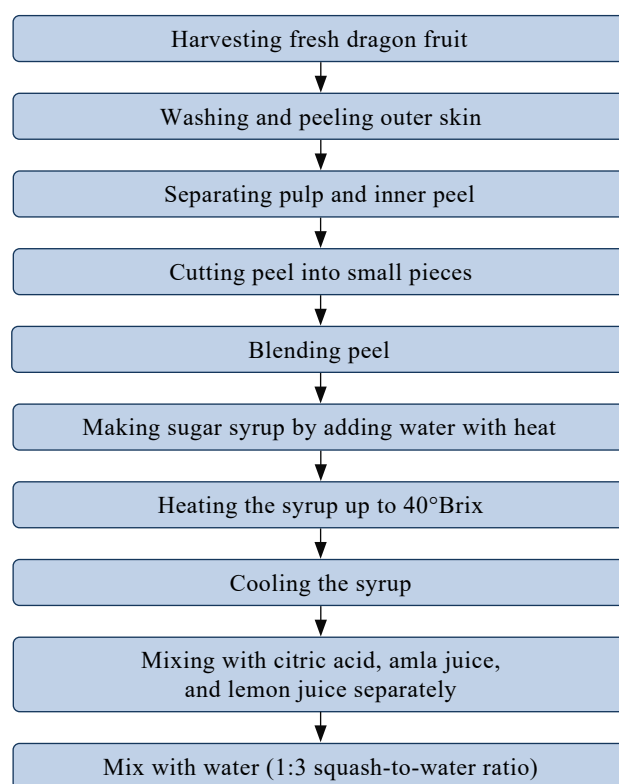


Figure 1 Scheme for preparing dragon fruit peel squash

Total phenolic content. To determine the total phenolic content, we applied the Folin-Ciocalteu reagent technique followed by Zahan *et al.* [17]. Gallic acid (GAE) served as reference during the colorimetric experiment. Briefly, we mixed 1 mL of extract solution with 5 mL of Folin-Ciocalteu's reagent for 2 min and added 4 mL of 7.5% (w/v) sodium carbonate. After a 15-s vortexing, the mix was allowed to stand for 30 min at room temperature for color development. The absorbance was measured at 765 nm with a Photolab 7600 spectrophotometer (UV-Vis, EU). Gallic acid was employed for calibration. The estimate was done in triplicate, and the findings were averaged before being expressed as GAE mg/g dry extract.

DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity. The DPPH radical is a stable free radical or oxidizing radical that is subsequently reduced by the antioxidant. It also serves as a reaction marker. We used DPPH to assess the ability of the extract to eliminate free radicals. The antioxidant activity of the powder was assessed as recommended by Nitisuk *et al.* [18]. A set of ethanol solutions with varying concentrations (60, 80, 100, 120, 140, and 160 µg/mL) were created by diluting while the control was conducted similarly but with ethanol. This experiment combined a 1 M DPPH solution with a 1 mL extract solution at various concentrations. The total volume was then adjusted to 10 mL using ethanol. After agitating the contents for 15 s, we placed the solutions in a lightless environment at an ambient temperature for 30 min to facilitate the chemical reaction. Subsequently, we measured the absorbance

at a wavelength of 517 nm using a single beam spectrophotometer (Photolab 7600, UV-Vis, EU) with a blank as reference. The capacity to scavenge DPPH radical was determined as in Eq. (1):

$$\text{DPPH radical} = \frac{A_0 - A}{A_0} \times 100 \quad (1)$$

where A_0 is the absorbance of the control solution, which contained the same reagents but no dragon fruit peel extract; A is the absorbance of the DPPH solution containing the dragon fruit peel extract. The DPPH radical scavenging activity, %, was plotted against the concentration of dragon fruit peel extract to determine the concentration necessary to decrease the DPPH radical scavenging by 50% (IC_{50}).

Storage conditions. The squash samples were stored at $4 \pm 1^\circ\text{C}$ in a refrigerator (RT28T3122S, Samsung Electronics, South Korea) for 21 days. Initially, the samples were evaluated immediately after preparation, and subsequent evaluations were performed at seven-day intervals.

Total plate count. To obtain the total plate count in the dragon fruit peel squash, we used the conventional plate count method⁴. The samples stored at $4 \pm 1^\circ\text{C}$ were aseptically collected (10 mL) on days 0, 7, 14, and 21, diluted in 90 mL of sterile 0.1% peptone water (1:10), and serially diluted (10^{-2} to 10^{-6}). Using pipette aids, we spread in triplicate 0.1 mL of each dilution onto plate count agar, incubated them at $35 \pm 1^\circ\text{C}$ for 48 ± 2 h, and counted colonies (25–250 per plate) to calculate the total plate count, CFU/mL, as in Eq. (2):

$$\text{Total plate count} = \frac{A_c}{D_f \times 0.1} \quad (2)$$

where A_c is the average colonies; D_f is the dilution factor.

Sensory evaluation during storage. The sensory evaluation was performed by a panel of ten faculty members, staff, and students of the Department of Food Engineering and Technology, Bangladesh Agricultural University (Mymensingh, Bangladesh). As in a study by Hasan *et al.* [19], the hedonic scale ranged from 1 to 9 and covered the color, aroma, taste, flavor, and overall acceptability of four squash samples, including the control (Fig. 2). The scale was arranged as follows: 9 – like extremely; 8 – like very much; 7 – like moderately; 6 – like slightly; 5 – neither like nor dislike; 4 – dislike slightly; 3 – dislike moderately; 2 – dislike very much; and 1 – dislike extremely.

Color parameters during storage. The color of squash powder was measured according to Khan *et al.* [20] using a CR-400/410 Chroma Meter (Konica Minolta, Japan). Using the Hunter L , a , b color scale, we conducted the measurements under illuminants $*C$ and D65. In Fig. 3, L^* , a^* , and b^* stand for greenness (–), blueness (–) or yellowness (+), and lightness (100:white, 0:black). The tests were conducted in duplicate.



Figure 2 Experimental dragon fruit peel squash samples for sensory evaluation: control (a); peel + amla juice (b); peel + citric acid (c); and peel + lemon juice (d)

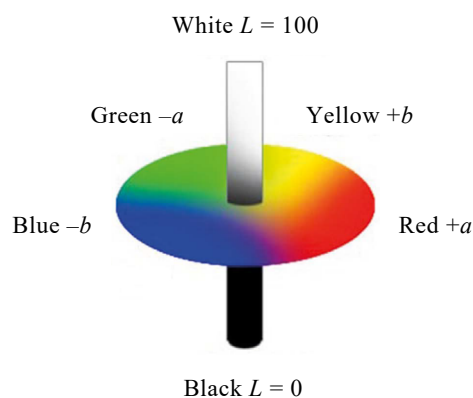


Figure 3 Hunter L , a , b color scale [23]

Statistical analysis. The statistical analysis was performed in Microsoft Excel 2019 and then exported into SPSS Version 27.0 software (SPSS Inc., USA), where we applied ANOVA to compare mean values among treatments. The Python programming (Python Software Foundation) made it possible to visualize the graph. The results were reported with 5% significance level.

RESULTS AND DISCUSSION

Proximate analysis. To determine the moisture content, ash, protein, fat, and carbohydrates in the dragon fruit peel, we applied a chemical analysis that involved both water content and dry weight (Table 2).

The peel demonstrated a high moisture content of 92.81% (wet basis). The protein content was 0.528% wet basis and 7.350% dry basis, while the fat content was relatively low at 0.20% wet basis and 2.78% dry basis. The ash contents were 1.49% wet basis and 20.72% dry basis, reflecting the presence of essential minerals. The content of carbohydrates, which contributed to the energy status of the experimental beverage, accounted for 4.90% wet basis and 68.15% dry basis. Thus, we

⁴ Zhang G, Ferguson M, Blodgett RJ. Bacteriological analytical manual. Chapter 3: Aerobic Plate Count. May 2025 ed. Silver Spring: FDA; 2025, pp. 2–13.

Table 2 Proximate composition of fresh dragon fruit peel

Parameter	Wet basis	Dry basis
Moisture content, %	92.81 ± 0.42 ^p	–
Protein, %	0.528 ± 0.080 ^p	7.350 ± 0.310 ^q
Ash, %	1.49 ± 0.11 ^p	20.72 ± 0.95 ^p
Fat, %	0.20 ± 0.03 ^p	2.78 ± 0.14 ^q
Carbohydrate, %	4.90 ± 0.01 ^p	68.15 ± 1.03 ^q
Total phenolic content, mg GAE/100 g	3.20	–
IC ₅₀ , mg/mL	0.729	–

The values are presented as mean ± standard deviation. The values with same superscripts in the same row are not significantly different ($p < 0.05$)

confirmed the nutritional potential of dragon fruit peel, supporting its application in value-added food products.

In this particular research, the moisture content in dragon fruit peel was 92.81% (wet basis) (Table 2). This aligns almost perfectly with Nur *et al.* [22] and Alam *et al.* [23], who reported a moisture content of 86.95 and 92.24% (wet basis), respectively. Meanwhile, Qalbi *et al.* [24] reported a much lower water content of 9.73% in dragon fruit peel powder (dry weight). The variation might be due to the differences in the drying methods, stage of maturity, environmental effects, or post-harvest handling.

In our case, the protein content in dragon fruit peel was 0.528% wet basis and 7.350% dry basis (Table 2), which exceeded the crude protein (4.35%) in dried peel powder [25]. Nur *et al.* [22] (dragon fruit peel) and Arivalagan *et al.* [26] (dragon fruit) reported lower protein contents. Other sources give a higher protein range of 13.07 to 15.18% (dry basis), indicating that the composition depends, to some extent, on the species or sample processing method [24]. A complimentary feed of soybean and fish paste with added dragon fruit peels demonstrated a higher protein content (16.28–20.60% dry basis) [27]. However, the protein percentage was lower than the results published by Alam *et al.* [23] and Yasmin *et al.* [28].

The amount of ash in a food product is the leftover inorganic material that remains after organic matter [29]. In this research, the ash content was 1.49% wet basis and 20.72% dry basis for fresh dragon fruit peel. Our results were very close to the 15.91% reported by Chumroenvidhayakul *et al.* [30]. In Rosiana *et al.* [27], the ash content also ranged from 4.28 to 5.05%. Thus, dragon fruit peel is extremely rich in minerals. Another study, however, reported as low as 3.56% (wet basis) of ash content in dragon fruit peel [23]. These variations across the studies can be due to the differences in soil, plant variety, and processing conditions.

The fat content in this study was relatively low, measuring 0.20% wet basis and 2.78% dry basis. Our finding agreed with the value (0.76 %) in Prasad's research [31] on carrot squash drink but was much lower than in [22]. However, Rosiana *et al.* [27] detected a much higher fat content, ranging from 15.51 to 15.60% in complementary

feeding from soybeans and dragon fruit peels. Due to the antioxidant effect, a lower fat content in dragon fruit peel helped keep the produce fresh for a longer period [32].

In terms of bioactive compounds and antioxidant activity, the dragon peel had 3.2 mg GAE/100 g (wet basis) of total phenolic content. Its IC₅₀ value was 0.729 mg/mL (wet basis), indicating a moderate radical scavenging ability (Table 2). However, Madane *et al.* [32] reported 36–39 mg GAE/100 g in dragon fruit peel, accompanied by good radical scavenging activity. Another study showed an IC₅₀ value of 0.112 mg/mL in aqueous dragon fruit extract, which was below our findings [11]. In our case, the total phenolic content was relatively low while the IC₅₀ was high, which could be due to the fresh state of peel and the extraction methods.

Fruits are rich in carbohydrates, but the exact content depends on the type of fruit, ripeness, and origin. Carbohydrates in fruit juices are a crucial source of energy for recovering patients [33]. The carbohydrate contents of dragon fruit peel in this study were 4.9% wet basis and 68.15% dry basis (Table 2), which was compatible with Rosiana *et al.* [27]. Qalbi *et al.* [24] observed a comparably lower carbohydrate content in the range of 34.99 to 39.49% (dry basis) in dragon fruit peel powder, whereas Chumroenvidhayakul *et al.* [30] documented a slightly higher carbohydrate content in dragon fruit peel than in the current study. The high carbohydrate content suggests that dragon fruit peel could be a valuable source of dietary fiber and other polysaccharides.

Physicochemical analysis. Table 3 summarizes the physicochemical properties of different parts of two dragon fruit species. The physicochemical properties differed across the formulations, depending on the type of acidulants used, i.e., amla juice, lemon juice, and citric acid. The total soluble solids ranged from 40.30 to 47.00°Brix, the pH values were between 2.32 and 4.83, the titratable acidity was 0.15–1.50%, and the content of ascorbic acid (Vitamin C) ranged from 0.40 to 108.00 mg/100 mL (Table 3). The sample with amla juice showed the highest contents of total soluble solids (47.00°Brix) and ascorbic acid (108.00 mg/100 mL), indicating excellent nutritional and sensory quality. The control sample showed the highest pH (4.83) and the lowest total soluble solids (40.30°Brix) and titratable acidity (0.15%), compared to other formulations (Table 3).

Our total soluble solids were higher than those previously reported for fresh dragon fruit peels and pulp, which generally ranged between 7.03 and 10.78°Brix [22], or equaled 8.73°Brix for white flesh dragon fruit [23]. Our results also exceeded the values found in cucumber and summer squash fruits [34] but were quite comparable to squash products fortified with lime (41–45°Brix), mango (47.91°Brix), and dragon fruit (48.5°Brix) [12, 14, 35]. Apparently, the product demonstrated good sweetness and concentration.

The pH value was at its maximum in the control sample (4.83) ($p < 0.05$), but the other formulations had almost the same values (2.90, 2.32, and 2.42) (Table 3). These results coincided with the findings for various

Table 3 Physicochemical profile of experimental dragon fruit peel squash

Parameter	Sample			
	Control	Peel + amla juice	Peel + citric acid	Peel + lemon juice
Total soluble solid, °Brix	40.30 ± 0.27 ^r	47.00 ± 0.58 ^p	41.00 ± 0.32 ^r	46.00 ± 0.51 ^q
pH	4.83 ± 0.05 ^p	2.90 ± 0.02 ^q	2.32 ± 0.06 ^q	2.41 ± 0.07 ^q
Titrateable acidity, %	0.15 ± 0.02 ^r	0.18 ± 0.01 ^r	1.50 ± 0.23 ^p	0.90 ± 0.11 ^q
Ascorbic acid, mg/100 mL	4.70 ± 1.25 ^q	108.00 ± 1.25 ^q	0.40 ± 0.02 ^r	9.50 ± 0.45 ^p

The values are presented as mean ± standard deviation. The values with different superscripts in the same row are significantly different ($p < 0.05$)

squash products, e.g., tamarind squash (2.60) [36] or mango and guava blended squash (2.70–2.82) [13]. However, they were comparatively lower than those reported for dragon fruit peel squash (3.40) [14], mango squash (3.30–3.45) [22], or carrot squash (6.0) [31]. Another study detected a higher pH value in a refined squash peel extract [37]. The low pH in our squash samples suggested higher acidity and potentially better microbial stability.

In terms of titrateable acidity, the maximal level belonged to the combination of dragon peel with citric acid (Table 3). The titrateable acidity values of the samples with citric acid and lemon juice aligned well with those in peach squash (1.52%) [31] and carrot squash (1%) [38]. This acidity level suggested better taste and preservation.

High levels of vitamin C boost antioxidant capacity [27]. For ascorbic acid, the maximal recorded value was (108.00 mg/100 mL) in the sample with amla juice, compared to the control (4.70 mg/100 mL), the sample with citric acid (0.40 mg/100 mL), and the sample with lemon juice (9.50 mg/100 mL) ($p < 0.05$), which exceeded the values reported for dragon fruit peel (9.81 mg/100 g) in [22], tamarind squash (46.75 mg/mL) [36], and mango and guava blended squash (33.05–39.30 mg/100 mL) [13]. Even carrot squash had a much lower range of ascorbic acid, which was quite comparable with the sample with citric acid [31]. The high vitamin C content in the sample with amla juice was likely due to its exceptional ascorbic acid concentration.

Total phenolic content levels. In functional foods, phenolics are responsible for antioxidant properties associated with scavenging free radicals and chelating metal ions. In humans, they react against bacteria, inflammation, and oxidation [39, 40]. In our study, the concentration vs. absorbance curve for gallic acid was as in Fig. 4, which led to the following regression Eq. (3):

$$y = 0.0011x + 0.2758 \quad (3)$$

$$R^2 = 0.9961$$

where y is the absorbance at 765 nm; x is the amount of gallic acid.

The absorbance increased proportionally with the concentration of gallic acid in dragon fruit peel (Fig. 3). The regression equation yielded a total polyphenol content of 3.20 mg GAE/100 g (Table 2).

The total phenolic content across the dragon fruit peel squash formulations in this study ranged from 2.89

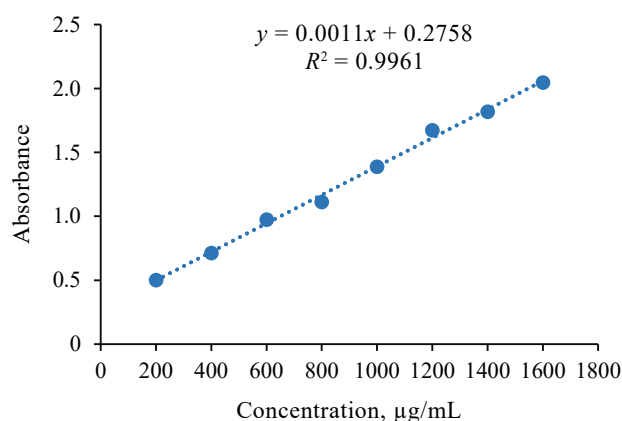

Figure 4 Concentration vs. absorbance (765 nm) curve of gallic acid in dragon fruit peel

Table 4 Total phenolic content and DPPH radical scavenging activity in experimental dragon fruit peel squash

Sample	Total phenolics, mg GAE/100 g	IC ₅₀ , mg/mL
Control	2.89 ± 0.10 ⁿ	0.725 ± 0.020 ^s
Peel + amla juice	5.20 ± 0.12 ^m	0.633 ± 0.015 ^p
Peel + citric acid	3.41 ± 0.43 ^l	0.711 ± 0.101 ^q
Peel + lemon juice	4.24 ± 0.14 ^m	0.691 ± 0.021 ^r

The values are presented as mean ± standard deviation. The values with different superscripts in the same column are significantly different ($p < 0.05$)

to 5.20 mg GAE/100 g, with sample 1 (amla juice) exhibiting the maximum (Table 4). These values were modest but consistent with those reported for other experimental processed fruit beverages. For instance, the total phenolic contents in dragon fruit peel extracts and powders were significantly higher, e.g., 454.79 mg GAE/g powder [30] and 35.81 mg/g dry basis [41], which could be attributed to the concentrated nature of those samples.

Other studies on dragon fruit peel and squash-like products report similar total phenolics [42]. In general, our results validated that the squash from dragon fruit peel retained its functional phenolic content, thus confirming its values as a health-beneficial beverage and a way for sustainable utilization of fruit waste.

DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity. The antioxidant capacity depends on the ability of the substance to neutralize stable organic

Table 5 Total plate count during storage

Sample	Total plate count, CFU/mL, during storage, day			
	0	7	14	21
Control	$1.8 \times 10^2 \pm 25^{aD}$	$5.2 \times 10^3 \pm 300^{aC}$	$3.1 \times 10^5 \pm 4,500^{aB}$	$8.7 \times 10^6 \pm 95,000^{aA}$
Peel + amla juice	$1.5 \times 10^2 \pm 20^{aC}$	$2.8 \times 10^2 \pm 35^{cC}$	$6.0 \times 10^2 \pm 80^{cB}$	$1.3 \times 10^3 \pm 150^{cA}$
Peel + citric acid	$2.1 \times 10^2 \pm 30^{aD}$	$1.1 \times 10^3 \pm 150^{bC}$	$4.5 \times 10^3 \pm 500^{bB}$	$2.2 \times 10^4 \pm 2,500^{bA}$
Peel + lemon juice	$1.9 \times 10^2 \pm 25^{aC}$	$3.5 \times 10^2 \pm 40^{cC}$	$7.8 \times 10^2 \pm 90^{dB}$	$1.8 \times 10^3 \pm 200^{cA}$

The results are given as means $\pm$ standard deviation. Lowercase letters in the same column (same storage time) indicate significant differences across samples (Tukey's HSD, $p < 0.05$). Uppercase letters in the same row (same sample) indicate significant differences across storage times (Tukey's HSD, $p < 0.05$).

free radicals. The inhibitory function or DPPH (2,2-diphenyl-1-picrylhydrazyl) scavenging activity, in our case, increased with the extract concentration (Table 4). The IC_{50} values represent the concentration needed to eliminate 50% of DPPH free radicals [43]. Greater DPPH radical scavenging percentage and lower IC_{50} value suggest higher antioxidant ability [24].

We studied the DPPH radical scavenging activity of dragon fruit peel extract at different concentrations. By plotting the absorbance of gallic acid against concentration in linear graph paper, we obtained a regression line and a regression Eq. (4):

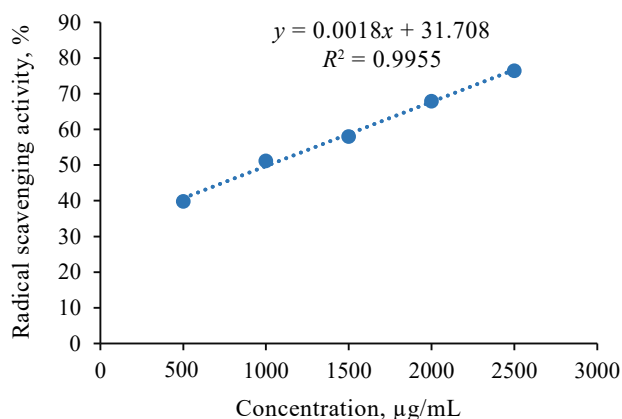
$$y = 0.0018x + 31.708 \quad (4)$$

$$R^2 = 0.9955$$

where y is the absorbance at 765 nm; x is the concentration of gallic acid, $\mu\text{g/mL}$.

As the concentration increased, the percentage of radical scavenging activity rose from 39.86 to 76.51% (Fig. 5), highlighting a clear concentration-dependent antioxidant effect. The IC_{50} value was 0.715 mg/mL (Table 2).

The formulated squash showed IC_{50} values from 0.633 to 0.725 mg/mL, which were higher than those reported for other varieties of dragon fruit [28]. However, dragon fruit peel powders showed the highest antioxidant activity [24]. Another study on dragon fruit peel found good antioxidant activity consistent with the current results [41]. All in all, our experimental squash demonstrated powerful antioxidant activity.


Figure 5 DPPH scavenging activity of dragon fruit peel

Total plate count during storage. Microbial safety is an essential quality factor when it comes to assessing the shelf-life and acceptability of fruit beverages [44, 45]. According to the Bangladesh Food Safety Authority, ready-to-drink fruit beverages must not exceed a total plate count of 1×10^4 CFU/mL to be considered microbiologically safe; otherwise, the beverage may cause potential health risks and spoilage⁵. In this study, the total plate count was monitored on storage days 0, 7, 14, and 21 across all formulations (Table 5).

The control sample experienced a significant increase in microbial load, jumping from 1.8×10^2 to 8.7×10^6 CFU/mL by day 21 (Table 5). This phenomenon indicated the susceptibility of untreated fruit-based beverages to microbial contamination over time, consistent with previous findings in unprocessed dragon fruit pulp and juice [46, 47]. In contrast, the sample with amla juice demonstrated the most effective microbial control, with only 1.3×10^3 CFU/mL at the end of storage (Table 5). This reduction was likely due to the natural antibacterial properties of amla juice, which contained a lot of polyphenols and ascorbic acid (Tables 3 and 4), which are known to suppress microbial growth in fortified herbal beverages [44, 48].

The sample with citric acid showed moderate microbial control, with the value rising to 2.2×10^4 CFU/mL after 21 days (Table 5). The acidic environment created by citric acid may have contributed to the microbial inhibition, aligning with other studies that reported the preservative effects of such acidulants as ascorbic and citric acid in dragon fruit products [46, 49].

The sample with lemon juice included vitamin C, which effectively limited the microbial growth from 1.9×10^2 to 1.8×10^3 CFU/mL (Table 5). Our results were comparable to the antimicrobial activities of lemon juice observed in sugarcane juice [50]. Therefore, the samples with amla and lemon juice demonstrated more acceptable microbial limits throughout the storage period, which meant a more extended shelf-life and a safer consumption than in the other samples.

Sensory evaluation. The current trends in functional beverages are towards the favor of fruit squashes over synthetic beverages. Due to their taste, flavor, nutritive value, and storage stability, squash drinks have really

⁵ Food Safety (Determination and Control of microbiological contaminants) Regulations. Dhaka: Bangladesh Food Safety Authority; 2023.

Table 6 Sensory evaluation of experimental dragon fruit peel squash during storage

Sensory characteristic	Sample	Storage time, day			
		0	7	14	21
Color	Control	6.80 ± 0.15 ^{ca}	6.20 ± 0.13 ^{cb}	5.50 ± 0.19 ^{cc}	4.10 ± 0.21 ^{cd}
	Peel + amla juice	7.40 ± 0.12 ^{aa}	7.00 ± 0.35 ^{aa}	6.50 ± 0.13 ^{ab}	5.80 ± 0.22 ^{ac}
	Peel + citric acid	6.20 ± 0.20 ^{ba}	5.80 ± 0.11 ^{bb}	5.30 ± 0.22 ^{bc}	4.80 ± 0.21 ^{bd}
	Peel + lemon juice	5.30 ± 0.21 ^{da}	4.80 ± 0.27 ^{db}	4.20 ± 0.30 ^{dc}	3.60 ± 0.24 ^{dd}
Aroma	Control	5.80 ± 0.20 ^{da}	5.30 ± 0.24 ^{db}	4.90 ± 0.29 ^{dc}	4.00 ± 0.33 ^{dd}
	Peel + amla juice	7.00 ± 0.25 ^{aa}	6.60 ± 0.31 ^{ab}	6.20 ± 0.22 ^{ac}	5.70 ± 0.15 ^{ad}
	Peel + citric acid	6.50 ± 0.28 ^{ba}	6.10 ± 0.74 ^{ba}	5.60 ± 0.35 ^{bb}	5.10 ± 0.38 ^{bc}
	Peel + lemon juice	6.70 ± 0.26 ^{ca}	6.30 ± 0.46 ^{ca}	5.80 ± 0.54 ^{cb}	5.30 ± 0.67 ^{cc}
Taste	Control	5.50 ± 0.22 ^{ca}	5.10 ± 0.16 ^{da}	4.30 ± 0.31 ^{db}	3.10 ± 0.26 ^{dc}
	Peel + amla juice	6.70 ± 0.23 ^{ba}	6.30 ± 0.21 ^{bb}	5.80 ± 0.23 ^{bc}	5.30 ± 0.27 ^{bd}
	Peel + citric acid	6.70 ± 0.24 ^{ba}	6.30 ± 0.23 ^{ba}	5.80 ± 0.14 ^{bb}	5.30 ± 0.64 ^{bc}
	Peel + lemon juice	7.30 ± 0.33 ^{aa}	6.90 ± 0.42 ^{aa}	6.40 ± 0.38 ^{ab}	5.90 ± 0.13 ^{ac}
Flavor	Control	5.20 ± 0.30 ^{ca}	4.90 ± 0.26 ^{cb}	4.40 ± 0.31 ^{cc}	3.00 ± 0.27 ^{cd}
	Peel + amla juice	6.70 ± 0.42 ^{aa}	6.20 ± 0.20 ^{ab}	5.70 ± 0.42 ^{ac}	5.20 ± 0.42 ^{ad}
	Peel + citric acid	6.00 ± 0.50 ^{ba}	5.60 ± 0.34 ^{bb}	5.10 ± 0.65 ^{bc}	4.60 ± 0.52 ^{bd}
	Peel + lemon juice	6.00 ± 0.48 ^{ba}	5.50 ± 0.23 ^{bb}	5.00 ± 0.46 ^{bc}	4.50 ± 0.83 ^{bd}
Overall acceptability	Control	5.50 ± 0.25 ^{ca}	5.10 ± 0.19 ^{cb}	4.40 ± 0.41 ^{cc}	3.30 ± 0.54 ^{cd}
	Peel + amla juice	6.50 ± 0.21 ^{aa}	6.10 ± 0.24 ^{ab}	5.60 ± 0.61 ^{ac}	5.00 ± 0.29 ^{ad}
	Peel + citric acid	6.50 ± 0.23 ^{aa}	5.90 ± 0.42 ^{ab}	5.30 ± 0.55 ^{ac}	4.70 ± 0.44 ^{bd}
	Peel + lemon juice	6.20 ± 0.24 ^{ba}	5.70 ± 0.14 ^{bb}	5.20 ± 0.63 ^{bc}	4.60 ± 0.25 ^{bd}

The results are given as means ± standard deviation. Lowercase letters in the same column (same storage time) indicate significant differences for that sensory characteristic across samples (Tukey's HSD, $p < 0.05$). Uppercase letters in the same row (same sample) indicate significant differences across storage times for that sensory characteristic (Tukey's HSD, $p < 0.05$)

taken the market across the globe as an important nutritious drink [5, 6]. The expert panel evaluated the experimental dragon fruit peel squash in terms of color, aroma, taste, flavor, and general acceptance (Table 6).

Color. Food color is a crucial factor in establishing the first visual impression; typically, bright and striking colors have more appeal for consumers [51]. The sensory evaluation revealed a distinct ranking across the samples regarding color preferences at storage time up to 21 days. The sample with amla juice received the highest score of 7.40 (“like moderately”), followed by the control (6.80, “like slightly”) and the sample with citric acid (6.20, “like slightly”). The sample with lemon juice received the lowest score (5.30), indicating the least preferred color (Table 6). The initial value in the control sample dropped to 4.10 by day 21, showing the poorest color retention, while the sample with amla juice consistently scored highest for color, starting at 7.40 (day 0) and declining to 5.80 (day 21). It maintained its visual appeal despite a significant decrease over time ($p < 0.05$). The color score in the samples with citric acid and lemon juice decreased from 6.20 and 5.30 to 4.80 and 3.60, respectively, after 21 days (Table 6). A similar color degradation pattern was reported for mango squash during eight weeks of storage [14] and dragon fruit pulp during three months [44].

The superior color retention in the sample with amla juice was likely due to the antioxidant properties of ascorbic acid in amla juice, which stabilized betacyanin pigments in dragon fruit. Ascorbic acid had a similar

protective effect on betalains [52]. Color preference often collaborates with visual appeal [51]. Obiloma *et al.* [33], who also studied fruit drinks, reported similar appearance scores of 5.30–8.35, which aligned with the color score in the current study. In another study, dragon fruit squash scored higher in color and appearance, i.e., consumers tend to prefer colored products [35]. Thus, the visual appeal of the sample was positively received.

Aroma. Aroma influences consumer preference and product quality. The samples from this study scored impressively, with an aroma score ranging from 4 to 7 across samples under different storage times. In the control, the initial value of 5.80 fell to 4.00 at the end of experimental storage ($p < 0.05$). The sample with amla juice achieved the highest initial aroma score of 7.00, which declined to 5.70 by day 21 ($p < 0.05$). The samples with citric acid and lemon juice initially scored 6.50 and 6.70, respectively, dropping significantly to 5.10 and 5.30 ($p < 0.05$) (Table 6).

Our values were comparable to those detected in lemongrass fruit squash, where the aroma score ranged from 6.40 to 8.20 [52]. Obiloma & Afam-Anene [33], however, provided a higher aroma score in fruit drinks. The high initial aroma score in the sample with amla juice may be attributed to the aromatic compounds in amla juice, which enhanced the sensory appeal, as seen in [44], where ascorbic acid-treated pulp maintained favorable aroma. The relatively high aroma score in the sample with lemon juice may stem from the volatile compounds in lemon juice, which provided a fresh citrus note, align-

ing with other findings for herbal beverages [53]. Overall, the experimental dragon fruit peel squash scored quite satisfactory for aroma.

Taste. Taste is often the most influential sensory attribute [51]. Following the taste evaluation, the control sample scored the lowest, falling from 5.50 to 3.10 during experimental storage (21 days), while the samples with amla juice and citric acid both exhibited similar reduction values (from 6.70 to 5.30). The sample with lemon juice scored highest at 7.30 at day 0, decreasing to 5.90 by day 21, indicating better taste retention compared to others ($p < 0.05$) (Table 6). A report on dragon fruit pulp displayed a decreasing trend with storage time up to three months [44]. Other studies also exhibited a similar decreasing behavior of consumer taste preference profile for prepared fruit squash during storage [14, 52]. The moderate taste score in the sample with amla juice was less preferred than in the sample with lemon juice. Obiloma & Afam-Anene [33] obtained similar taste scores (6.20–9.00) for other fruit drinks. However, Archana *et al.* [35] obtained a taste score of 8 for dragon fruit squash, which was slightly higher than in the current study. All in all, our samples received good taste scores with moderate sweetness, therefore supporting that carefully adjusted ratios and processing control lead to optimal taste profiles.

Flavor. Flavor is a mix of various sensations derived from foods [54]. The control sample showed the lowest score range (5.20–3.00) for flavor preference. The sample with amla juice displayed the highest score (6.70) at the initial stage, falling to 5.20 on day 21, followed by the samples with citric acid (6.00–4.60) and lemon juice (6.00–4.50) (Table 6). The poor flavor retention in the control sample aligned with [44], where untreated pulp showed significant flavor loss after three months of storage.

The present result is positively comparable with other studies. Archana *et al.* [35] reported a very similar flavor score in dragon fruit value-added products. In [14], the flavor score dropped from 5.93 to 6.78 for mango squash after eight weeks, which was in concurrence with our dragon fruit peel squash after 21 days of storage. The experts in the current research confirmed that the flavors were well-balanced and within an acceptable limit.

Overall acceptability. Overall acceptability integrates all sensory attributes. The control sample scored the lowest range (5.50–3.30), while the samples with amla juice and citric acid received the same scores (6.50) at day 0, which reduced to 5.00 and 4.70, respectively, over 21 days of storage (Table 6). The high acceptability of the sample with amla juice stemmed from its superior color and aroma, aligning with the higher acceptability range for dragon fruit juice beverages [53]. The acceptance score for leh berry fruit squash corroborated with our findings [52]. Archana *et al.* [35] revealed a higher acceptance score of 8.20 whereas mango squash and mixed fruit drinks had similar scores [14, 33].

Products featuring dragon fruit or other tropical fruits tend to gain high consumer approval due to their

appealing sensory combinations [35]. For instance, an ice cream with pumpkin and dragon fruit (50:50) was also top-rated [51]. Well-balanced formulations lead to greater acceptability [42]. These observations together back up the idea that the formulation took the best route in ingredient pairing, which led to its high marks for sensory parameters, and it is degraded with prolonged storage may be due to chemical changes and microbial acceleration. All in all, the current formulated product mirrored the successful trends seen across multiple studies, and its scores ensured its position as a strong contender in consumer preference.

Color parameters during storage. The color attributes of dragon fruit peel squash are crucial in determining consumer acceptability and overall product quality. In the present study, the color values of the dragon fruit peel squash samples were recorded in terms of lightness (L^*), redness (a^*), and yellowness (b^*), and were evaluated during 1, 2, and 3 weeks of storage (Fig. 6–8).

Lightness (L^*) reflected distinct trends across the formulations. The control showed a gradual increase in L^* from 17.01 to 17.83, likely attributable to the sedimentation of suspended particles. Thermally treated fruit juices stabilize color and cloudiness by inactivating enzymes and coagulating proteins [55]. The sample with amla juice displayed fluctuating L^* values, increasing from 17.05 to 17.33 during week 2, then dropping to 16.70 by week 3. This pattern suggested an initial stabilizing effect of ascorbic acid that diminished over time [56]. The sample with citric acid was more acidic (pH 2.32). It displayed a consistent L^* increase from 14.48 to 16.23. Citric acid was reported to stabilize anthocyanins and reduce enzymatic browning [57, 58]. The sample with lemon juice had the brightest lightness at 21.40 in week 2, but then it fell to 16.66 by week 3, indicating unstable interactions between lemon juice components and peel pigments (Fig. 6).

Archana *et al.* [35] recorded L^* value for dragon fruit squash, which stood at 20.51. In contrast, Qalbi *et al.* [24] reported L^* values for dried peel powder that ranged

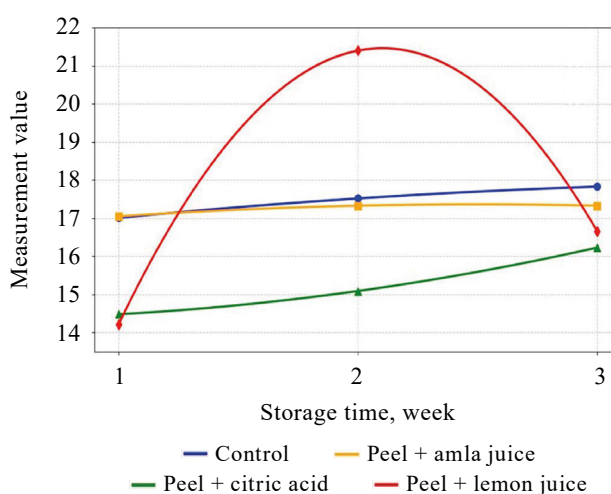


Figure 6 Lightness (L^*) in dragon fruit peel squash during storage

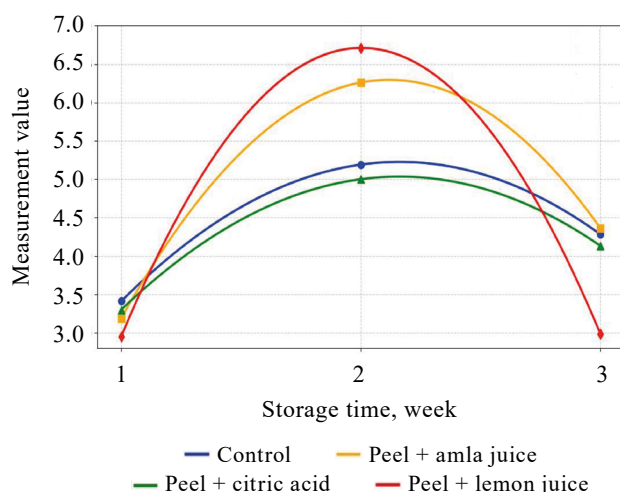


Figure 7 Redness/greenness (a^*) in dragon fruit peel squash during storage

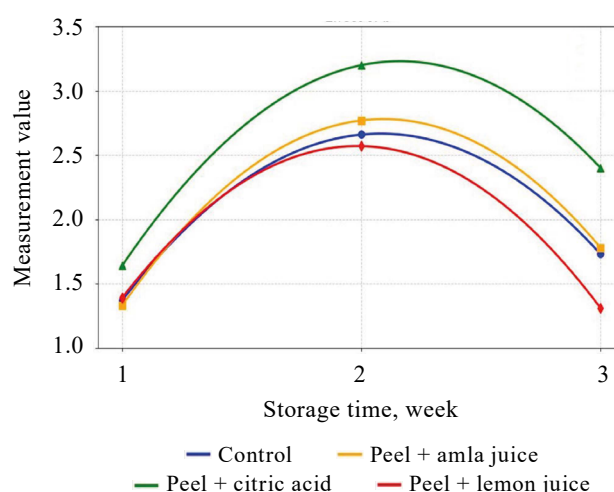


Figure 8 Yellowness/blueness (b^*) in dragon fruit peel squash during storage

Table 6 ANOVA results for color parameters during storage

Sample	Color parameter	Storage time, week			F-value	Significance
		1	2	3		
Control	L^*	17.01	17.52	17.83	0.073	n.s.
	a^*	3.41	5.19	4.28	1.649	n.s.
	b^*	1.37	2.66	1.73	11.823	*
Peel + amla juice	L^*	17.05	17.33	16.70	0.006	n.s.
	a^*	3.19	6.26	4.36	4.07	n.s.
	b^*	1.33	2.77	1.78	12.056	*
Peel + citric acid	L^*	14.48	15.09	16.23	0.1778	n.s.
	a^*	3.30	5.00	4.13	1.225	n.s.
	b^*	1.64	3.2	2.4	13.467	*
Peel + lemon juice	L^*	14.21	21.4	16.66	3.069	n.s.
	a^*	2.95	6.71	2.98	7.87	*
	b^*	1.39	2.57	1.31	10.989	*

n.s. – not significant ($p \geq 0.05$, $F \leq 6.944$); * – significant ($p < 0.05$; $F > 6.944$)

from 29.68 to 30.23, indicating a lighter appearance compared to the product in this study. This difference might be due to more browning reactions occurring in the current samples. Nurhadi *et al.* [59] observed a discernible pattern of betacyanin pigment in dragon fruit peel powder with storage time in dragon fruit-based beverages, which correlated with our L^* values due to the state of pigment polymerization and browning reactions. Additionally, the dragon fruit peel showed a wider range of L^* values, from 32.43 to 45.47, which were notably higher than the recent findings [42]. Interestingly, even non-red fruits, like butternut squash [60], displayed much higher lightness values with the emphasis of the darker natural pigment profile of dragon fruit peel products. The lower L^* values observed in this study could be linked to pigment degradation during storage or specific characteristics of formulations in the samples, which could reduce light reflectance.

Redness/greenness (a^*). Redness (a^*) is the most critical parameter for betalains stability and visual appeal. Its value shows the range from red to green, with red being positive and green being negative of the sam-

ple [24]. In this study, it rose in all samples between week 1 and 2 and dropped during week 3. This trend indicated initial color enhancement of red pigment, perhaps, via enhanced extraction or stabilization followed by degradation. In the control sample, a^* increased from 3.41 to 5.19 and then decreased to 4.28. the sample with amla juice showed a more pronounced increase (3.19 to 6.26), maybe, because of the protective action of ascorbic acid on pigment [61], before declining to 4.36. In the sample with citric acid, the value of a^* rose from 3.30 to 5.00, then dropped to 4.13 with its low pH (2.32) by 21 days. This result closely corroborated the study where maximum betalains deteriorated in pH 2.0 [62], potentially accelerating degradation. The sample with lemon juice also peaked as 6.71 in week 2 but dropped to 2.98 by week 3, showing that lemon juice deteriorated long-term redness stability (Fig. 7).

Archana *et al.* [35] reported an a^* value of 22.18, which indicated a much stronger reddish tone compared to our experimental product. Additionally, Martínez *et al.* [60] highlighted very high a^* values in butternut squash hydrocolloids. Other investigations into dried peel prod-

ucts revealed slightly elevated redness values [24, 42]. Hence, the existing previous values showed very reddish squashes, especially when the squashes were ripe and the acidity was adjusted to maintain pigmentation. The relatively lower redness observed in the current samples (Fig. 7) could be attributed to the gradual degradation of such natural red pigments as betalains or lower initial concentrations of these pigments in the sample matrix.

Yellowness/blueness (b^*). The yellowness (b^*) showed the same pattern, rising from week 1 to 2 and decreasing during week 3 across all the samples, indicating a temporary production and a breakdown of yellow pigments. This phenomenon occurs when betalains degrade into betalamic acid, which contains yellow betaxanthins [63]. In the control sample, the value of b^* rose from 1.37 to 2.66 and dropped to 1.73. The sample with amla juice was 2.77 in week 2, possibly as a result of the amla juice effect. The sample with citric acid was 3.2, likely owing to its high acidity accelerating degradation. The sample with lemon juice increased to 2.57 during week 2 before decreasing to 1.31, which indicated rapid color shifts towards yellow colors.

Our values were considerably below those documented in other publications. Qalbi *et al.* [24] observed the b^* values in dried peel powders between 15.20 and 16.53, which tended to drop as the drying time increased; yet, their results remained significantly higher than ours. Raj & Dash [42] also registered much higher b^* values (23.97–28.33) in dragon fruit peel, likely due to the color concentration through drying. Martínez *et al.* [60], who studied butternut squash peels, found even more pronounced b^* values. Therefore, the lower b^* values in the current study suggested either minimal yellow pigment presence or substantial degradation during storage. These results are expected to reflect betacyanin-rich compositions with yellows but not overly predominant.

ANOVA test for color parameters during storage.

Table 6 presents the color parameter values (L^* , a^* , b^*) for dragon fruit peel squash formulations across samples during weeks 1 (7 days), 2 (14 days), and 3 (21 days), with F -values testing the effect of storage time within each sample. Twoway ANOVA ($D_f = 2,4$; critical $F = 6.944$) involved a common MSE ($L^* = 4.3575$; $a^* = 0.590$; $b^* = 0.045$). The lightness (L^*) did not vary significantly with storage time in any sample ($F < 6.944$, ns); the redness (a^*) increased significantly only in the sample with lemon juice ($F = 7.87$, $p < 0.05$), and the yellowness (b^*) changed significantly in all four formulations.

The L^* values started to alter in just over 21 days, showing good overall lightness retention; however, the values of a^* and b^* increased considerably, showing difficulty in retaining the normal red–pink color under storage conditions. Compared to [24] with L^* 29.68–30.23 in dried peel powder and L^* 32.43–45.47 in dragon fruit

peel, our experimental squash showed poorer color stability, most probably as a result of the greater pigment breakdown in the aqueous matrix. For enhanced shelf life and consumer acceptability, future studies would need to investigate formulation adjustments (e.g., natural color stabilizers) and storage optimization (light-protected, antioxidant-supplemented packaging) to reduce the existing a^* and b^* drift.

CONCLUSION

This study demonstrated the feasibility of utilizing dragon fruit peel for the production of functional squash. Conventionally regarded as waste, dragon fruit peel proved to be a highly valued functional ingredient. The chemical analysis revealed 92.81% of moisture content, 1.49% ash, 0.528% protein, 0.20% fat, and 4.90% carbohydrate (wet basis). The formulated squash samples were within the acceptable microbial range and possessed favorable physicochemical properties, especially total soluble solids, which ranged from 45.00 to 47.00°Brix. The low pH and sufficient acidity guaranteed safety and palatability. The samples fortified with amla juice and citric acid tied in overall acceptability (6.50), with oversteps in color (7.40) and aroma (7.00). The sample with with lemon juice was ahead in taste (7.30). The formulation with amla juice showed a superior ascorbic acid content (108.00 mg/100 mL) and antioxidant activity ($IC_{50} = 0.633$ mg/mL). The ANOVA result revealed storage time effects on redness (a^* , $p < 0.05$), as well as storage time and sample type effects on yellowness (b^* , $p < 0.05$), indicating pigment breakdown after three weeks of storage. In general, the dragon fruit peel squash proved to be a healthy drink with a good commercial potential, but it requires optimized storage conditions or natural stabilizers to maintain color qualities that are significant to consumer acceptance.

CONTRIBUTION

M.A. Alim was responsible for the research concept, methodology, formal analysis, and original draft; I. Hossain wrote the original draft, performed the analysis, and worked with the software; T. Yesmin wrote the original draft, performed the analysis, and conducted the data curation; M.T. Islam was responsible for the review, proofreading, validation, software, and research concept; R. Zaman was responsible for the review, proofreading, validation, and data curation; M.M. Khan supervised the research, developed the concept, designed the methodology, wrote the review, and proofread the manuscript.

CONFLICT OF INTEREST

The authors declared no conflict of interest regarding the publication of this research.

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