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Physicochemical and Sensory Characteristics of Bread Substituted with Dragon Fruit Peels

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***Abstract*— Dragon fruit peel (DFP) which is typically discarded can provide a substantial amount of naturally occurring nutrients in low-fibre commercial white bread. The study evaluated physicochemical and sensory analysis of dragon fruit peel flour (DFPF) as a partial substitute for wheat flour in white bread formulations in following proportions: 0%, 3%, 6% and 9% (w/w). The measurements of the substituted breads involved crude fibre, ash, crude protein, fat, carbohydrate, moisture, volume, texture profile and colour profile along with sensory analysis. Based on chemical composition, DFPF was high in ash (11.60%), crude fibre (25.48%) and carbohydrate content (48.58%) however it was low in moisture (9.31%), fat (0.83%) and crude protein (5.15%). DFPF exhibits a brighter red colour due to the high values of L* and a*. As the DFPF level increased, the bread's ash and crude fibre content increased significantly, however the amount of carbohydrates decreased significantly. The bread's volume declined, while its moisture, density and hardness increased. Through sensory evaluation, the 6% DFPF was most favourable in terms of its appearance and texture. The addition of DFPF did not adversely affect the general appeal of the bread, indicating that it is a feasible way to increase the nutritious content of bread. In conclusion, DFPF can be used as a partial flour substitute to increase the nutritional value of white bread, particularly by increasing crude fiber content. The 6% substitution level provided the best balance of nutritional enhancement and consumer acceptance, indicating its potential for use in functional bakery goods.**

***Keywords*— Dragon fruit; peel; flour; bread; physicochemical**

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I. INTRODUCTION

Bread is a common food that is made from dough and considered as staple food in many countries. Bread is often made by fermenting sugars supplied from starch (most commonly wheat flour) and various components are employed in the bread-making process [1]. Foods with high levels of soluble dietary fibre are deemed to have a low glycaemic index [2] and help provide a more nutritionally balanced profile with additional fibre fortification [3]. In many cases, customers expect high-fibre bread (HFB) to have at least the same positive texture and tasty flavour qualities as regular white bread. Dietary fibre plays an essential part in the bread formulation in order to increase the nutrients and keep the identifiable taste of white bread, whether used alone or in combination [4].

Dragon fruit (*Hylocereus spp.*), also known as pitaya, produces a large amount of peel waste during processing, even though the peel contains valuable nutrients similar to the fruit's flesh. If not reused, this organic waste can cause environmental pollution due to its high nutrient content that promotes microbial growth [5]. Therefore, exploring its commercial value is important for reducing waste and improving sustainability. Studies have shown that many plant-based by-products can be turned into flour and used to develop healthier food products [6]. Dragon fruit peel is rich in dietary fibre, pectin, antioxidants such as phenolics and betacyanins, and has shown potential as a functional food ingredient [7]. Its fibre may help with digestion and blood sugar control, while antioxidants may reduce inflammation and oxidative stress [8].

Additionally, recent research has shown that the peel of the dragon fruit has a total dietary fibre content of 46.7%, including 12.6% insoluble dietary fibre and 34.3% soluble dietary fibre [9]. Along with other nutrients such as 3.2% protein, 0.7% fat, 19.3% ash, and 72.1% carbohydrate [10]. DFPF mainly contains non-starch polysaccharides, which are types of complex carbohydrates known as dietary fibre. These fibres

include insoluble types such as cellulose, hemicellulose, and lignin, and soluble types like pectin [5,11,12]. DFPF also contains small amounts of simple sugars and monosaccharides such as glucose, fructose, arabinose, xylose, galactose and rhamnose, which are part of the polysaccharides in the peel [13]. Although DFPF does not contain the same type of starch or gluten-forming proteins as wheat flour, its fibre content can still contribute significantly to bread-making. It enhances water retention, improves dough rheology, extends shelf life and increases the nutritional value of the bread by boosting its fibre content [14]. According to [15], fruit fibre works well as an ingredient in dough foods. Hence, dragon fruit peel has great potential to be used in dough-typed food production such as bread.

Since the peel makes up roughly 48% of the weight of the entire fruit, the food processing sector is concerned about the peel's substantial amount of waste and the associated financial burdens. The conversion of agro-industrial waste into food with added value can minimise production costs while also reducing environmental damage as a whole [16]. Previous research has investigated its incorporation into a variety of food products to improve their nutritional value and functional properties. For example, [17] showed that adding red dragon fruit puree to bread increased its dietary fibre content and antioxidant activity, albeit with changes in physicochemical characteristics. Similarly, [18] found that replacing wheat flour in cookies with pitaya peel powder improved their nutritional profile but affected texture and colour. Despite these developments, there is still a research gap regarding the ideal levels of DFPF in bread formulations to balance nutritional enhancement with sensory acceptability. Addressing this gap, the current study set out to evaluate the effects of varying DFPF concentrations (0%, 3%, 6%, and 9%) on the physicochemical and sensory properties of white bread, aiming to identify a formulation that offers improved health benefits without compromising consumer preferences. The findings of this study have significant implications for using fruit waste, specifically dragon fruit peel, as a more health-promoting resource in the production of value-added food products.

II. Material and Methods

A. Material

Dragon fruit was purchased from the CS Grocer Kajang Mewah in Selangor. The following ingredients were acquired from bakery shop (Bake with Yen) at Bandar Baru Bangi, Selangor: bread flour (Bake with Yen), sugar (Gula Prai, MSM Malaysia Holding Berhad), salt (Double Swallow, Seng Hin Brothers Enterprises Sdn. Bhd.), butter (Buttercup, DKSH Manufacturing Sdn. Bhd.), milk powder (Milkpro, House of Ingredients Sdn. Bhd.), water and instant yeast (Saf-instant, Société Industrielle Lesaffre).

B. Methods

Preparation of dragon fruit peel flour

The peels utilised in this study came from commercially available mature red dragon fruits (*Hylocereus polyrhizus*), which are frequently seen in local markets. Since pigment, fibre and moisture content might change depending on the stage of ripeness, only peels from completely matured fruits were chosen. Dragon fruit peel was prepared according to the method described by [19] with slight modification. The dragon fruit peel was made by peeling newly purchased dragon fruit and then washing them with tap water to remove any adhering dust and dirt particles. The peels were blanched for 5 minutes then chopped into small pieces (6 cm x 2 cm). The peel was placed on aluminium foil and laid out in thin layers in trays and dried in a cabinet dryer (FSD-380) at 60°C for 24 hours. The dried peels were next processed into powder form using a grinder (GM-800S1) [6], sieved through a 60-mesh sieve (0 to 250µ particle size) and was stored in airtight plastic bags.

TABLE 1
FORMULATION OF CONTROL AND DRAGON FRUIT PEEL FLOUR SUBSTITUTED INTO BREAD

Particulars	**Formulation for 286.7 g total ingredients of bread (g)**			
	Control (0%)	**F1 (3%)**	**F2 (6%)**	**F3 (9%)**
Dragon fruit peel flour	0	4.8	9.6	14.4
Wheat flour	160	155.2	150.4	145.6
Water (ml)	102	102	102	102
Yeast	2.2	2.2	2.2	2.2
Salt	2.2	2.2	2.2	2.2
Sugar	8	8	8	8
Butter	7.2	7.2	7.2	7.2
Milk powder	5.1	5.1	5.1	5.1

Preparation of bread

The preparation of the bread was made using a bread maker (Trio TBM-106). **Table 1** shows the preparation formulation for 160 g total flour. In the bread preparation, four dragon fruit peel powder/bread flour ratios of 0 (control), 3, 6 and 9% (w/w) were utilised. The substitution levels of DFPF were selected based on preliminary trials. Although levels exceeding 9% were tested, the bread produced was too hard and had an unsatisfactory texture. The study also concentrated on small-scale bread manufacture because of financial constraints and the limited supply of ingredients. Therefore, 3 to 9% was considered a practical and effective range to evaluate the potential of DFPF in bread formulation. For the control loaf, water (102 ml) was added first followed by butter (7.2 g) then dry material (160 g bread flour, 8 g sugar, 2.2 g salt, 5.1 g milk powder and 2.2 g instant yeast). Following that, the bread machine was set to programme 1, which produces basic bread with the colour set to light crust. After starting, the dough was

kneaded, proofed, and baked in the bread machine according to the time estimate. The baked bread was allowed to cool for 1 hour at room temperature before being packed in a plastic bag. Similar to this, substituted bread samples were made by combining composite flour (dragon fruit peel flour at 3%, 6% and 9% levels) with other ingredients.

Chemical analysis

Fat content

The Soxhlet extraction method was used to determine the fat content in the sample according to AOAC method 920.39 [15]. The fat content was measured by using the formula as follows:

$$\%\ Fat = \frac{Weight\ of\ fat\ in\ sample\ (g)}{Weight\ of\ sample\ taken\ (g)} \times 100 \quad \text{eq (1)}$$

Crude protein content

The crude protein of the bread was evaluated using the Kjeldahl method (manually titration) and AOAC method 920.87 [15]. The crude protein content was calculated using the following equation:

$$\%\ Crude\ protein = total\ nitrogen \times conversion\ factor\ of\ foodstuff\ analysed \quad \text{eq (2)}$$

Ash content

Ash content was evaluated using dry ashing AOAC method 923.03 [15]. The ash content was determined using the following formula:

$$\%\ Ash = \frac{Weight\ of\ ash\ (g)}{Weight\ of\ sample\ (g)} \times 100 \quad \text{eq (3)}$$

Crude fibre analysis

The acid and alkali digestion technique were used to analyse crude fibre content. 2 g ± 0.0001 (W1) of dried ground sample was weighed into a 600 ml beaker. 200 ml warm 0.255 N H_2SO_4 was added and boiled for 30 minutes. The hot contents were filtered through muslin cloth. The insoluble material was transferred into the original beaker. 200 ml warm 0.313 N NaOH was added and boiled for 30 minutes. Contents were filtered and washed with hot water, then with 15 ml of 1% hydrochloric acid twice. The insoluble material was transferred into a weighted crucible and dried in an oven at 105°C overnight to a constant weight. The weight of residue and crucible (W2) was recorded. The residue in a muffle furnace was ignited at 550°C for 4 hours. The crucible in the desiccator was cooled and weighed. The weight of ash and crucible (W3) was recorded. The loss in weight on ignition represented the weight of crude fibre.

$$\%\ Crude\ fibre = \frac{W2-W3}{w1} \times 100 \quad \text{eq (4)}$$

Where,
W1 = weight in gram of sample taken (g)
W2 = weight in gram of weight of crucible + dried residue (g)
W3 = weight in gram of weight of crucible + ash (g)

Carbohydrate Content

The carbohydrate content was calculated using a different method. Total carbohydrate percentage was estimated by subtracting the percentages of protein, fat, and ash from 100% as described by [20].

$$\%\ Carbohydrate = 100 - (\%moisture + \%protein + \%ash + \%fat + \%fibre) \quad \text{eq (4)}$$

Physical analysis

Moisture content

Moisture content was evaluated by drying the sample to constant mass at 160°C for 15 minutes in a moisture analyser (A&D MX-50, Japan) according to [21].

Determination of loaf volume, loaf specific volume and density measurements of bread

The rapeseed displacement method was used to determine the volume of the loaves according to procedure by [22] with a slight modification.

$$Loaf\ specific\ volume\ (cm^3/g) = \frac{Loaf\ volume\ (cm^3)}{Weight\ of\ bread\ (g)} \quad \text{eq (5)}$$

$$Loaf\ density\ (g/cm^3) = \frac{Weight\ of\ bread\ (g)}{Loaf\ volume\ (cm^3)} \quad \text{eq (6)}$$

Texture Profile Analysis

The texture analyser (TA-XT2i, Stable Micro Systems, UK) was used to conduct the textural profile analysis (TPA) of the crumb of bread samples [4]. The textural parameters studied were hardness, springiness, cohesiveness and chewiness. The centre portion of the loaf was then carefully sliced into 2 cm x 2 cm x 2 cm squares with a thickness of 25 mm. The sample was then placed on the analyser's base. The analyser was fitted with a cylinder probe (P/75) placed above the base.

Colour Profile analysis

The colour profiles of the bread samples (crumb and crust) were determined using a chromameter (CR400, Konica Minolta, Japan). The illuminant used was D25. Colour profiles were expressed using CIE L*, a*, and b*. The L* value denotes the intensity of light. The degree of red-green colour is indicated by the a* value, with a larger positive a* values indicating redness (+a) and (-a) represent green hue. The degree of yellow-blue hue is indicated by the b* value, with a larger positive b* value suggesting yellowness (+b) while blueness is (-b) [20,23].

Sensory evaluation

The sensory evaluation was conducted following ethical guidelines reviewed and approved by the supervising lecturer in charge of the study. All panellists were informed about the purpose and procedures of the evaluation and provided written informed consent before participating, ensuring voluntary and confidential involvement. The nine-point hedonic scale was applied for the sensory evaluation of bread by judges based on their appearance, colour, texture, taste, aroma and overall

acceptability. The samples were sliced to a standard size of 30 x 15 x 30 mm [6]. All samples were coded with 3-digit codes and permuted. The judges were given the samples with plain water to rinse their mouths in between evaluating the sample [20].

Statistical analysis

All data was scientifically evaluated with the Statistical Package for Social Science 21 (IBM SPSS version 21). Analysis of Variance (ANOVA) was used to assess the data from the sensory evaluation test and the physicochemical analysis as well as to determine the significant differences in means. The means was compared using Duncan's test at $p<0.05$. The Least Significant Differences (LSD) test was used at a 95% confidence level ($p<0.05$) to determine the differences between property ranges [20,24].

III. Result and Discussion

A. Physicochemical analysis of dragon fruit peel flour

The result indicates that the dragon fruit peel contains a low level of moisture (9.31%) and the moisture was in between 10 to 14% flour requirement in usable storage [25,26]. [8] also stated low moisture content (5.81%). The low moisture level demonstrated strongest resistance against fungal development while being stored. As a result, the flour's microbiological activity is significantly reduced hence increasing the flour quality and shelf life [27]. Based on **Table 2**, the fat content of dragon fruit peel was 0.83% which is generally low. Even with low crude fat content, numerous analyses have demonstrated that the peel of the red dragon fruit contains important lipids such butanoic acid, propanoic acid, docosanoic acid, stearic acid, and pentenoic acid [28]. Low fat also adds to the powder's extended shelf life and stability [29].

TABLE 2
THE PHYSICOCHEMICAL ANALYSIS OF DRAGON FRUIT PEELS FLOUR

Parameters	Dragon fruit peel flour
Moisture content (%)	9.31 ± 0.56
Fat content (%)	0.83 ± 0.07
Ash content (%)	11.60 ± 0.05
Crude fibre content (%)	25.48 ± 1.81
Crude protein (%)	5.15 ± 0.05
Carbohydrate (%)	48.58 ± 0.32
L*	54.11 ± 1.12
a*	29.01 ± 0.85
b*	5.55 ± 0.24

Note: Data were presented in mean ± standard deviation (n=3).

The total ash level of the dragon fruit peel flour (DFPF) was found to be 11.60%. The peel powder's high ash content indicates that it contains a significant number of minerals, hence it is highly nutritious and might be worth using in food production. According to the analysis results on **Table 2**, it was found that DFPF was rich in crude fibre (25.48%). This might be due to high fibre content in dragon fruit peels as stated by [30] and [28] that pitaya peels are a source of dietary fibre as they exhibit high quantities of soluble and insoluble fibre. The crude protein content of DFPF is relatively low (5.15%) while carbohydrate content is high (48.58%) using the difference method. In contrast, [31] reported slightly higher carbohydrate (50.74%) and crude fibre (26.22%) contents in DFPF, while the protein content (5.08%) was slightly lower than in this study. Similarly, [8] found higher values for carbohydrate (70.85%), ash (15.91%), and fat (1.06%) compared to this study, along with a slightly higher protein content (6.37%).

Although this study did not quantify individual carbohydrate fractions, previous research indicates that the major carbohydrates in DFPF are primarily dietary fibres, including cellulose, hemicellulose and pectin [12,32]. [12] also reported high cellulose content (34.35%) and low lignin content (6.73%) in *Hylocereus polyrhizus* peel. [32] extracted pectin from dragon fruit peel, with yields ranging from 10.93% to 20.22%, mainly composed of galacturonic acid and rhamnose. [13] further identified monosaccharides such as glucose (12.53%), galactose (11.47%), rhamnose (9.24%), arabinose (4.26%), fructose (3.57%) and xylose (1.79%) in the polysaccharide content of DFP. Additionally, [33] reported a total dietary fibre content of 59.83% in DFPF, comprising 50.41% insoluble and 9.42% soluble fibre. These findings confirm that the main carbohydrate components in DFPF are dietary fibres, which contribute valuable nutritional and functional properties in bread-making. Pitaya peel flour exhibited a high redness value ($a^* = 29.01$) and lightness ($L^* = 54.11$) but low value of yellowness ($b^* = 5.55$). The presence of betacyanin pigments in the peels of the dragon fruit peel is responsible for the red colour [8,34,35]. Dragon fruit peel also contains other types of betalains such as betaxanthins that give yellow pigment colour to the dragon fruit peel but mostly undergo degradation due to heat during the drying process [36].

B. Chemical analysis of bread

There was no substantial variation ($p>0.05$) in the fat content of the loaves as it is ranging from 2.82% to 2.95% as displayed in **Table 3**. This is due to low fat content in DFPF (0.83%) causing the bread's crude fat content to remain mostly unchanged even after adding up to 9% DFPF. [6] observed a similar range of fat content (2.63% to 2.90%) for bread combined with Melon Manis Terengganu peel powder (MMTPP), with no significant difference in fat content as the amount of MMTPP increased. The Malaysian Adult Nutrition Survey (MANS) 2014 indicated that the current median total fat intake is projected to be 46g/day, or 29% total energy intake (TEI) [37]. However, the crude fat percentage of all the bread formulations in this study was lower than the recommended total fat intake. The results revealed that the ash content of bread significantly increased as the concentration of DFPF increased due to high concentration of ash in DFPF (11.60%). [38] claimed that the product may become a rich source of minerals due to the rise in ash content. Previous studies showed result of the ash content in bread samples incorporated with different types of fruit peel falls within the range 1.18-2.75% [4].

TABLE 3
THE CHEMICAL COMPOSITION OF BREAD SUBSTITUTED WITH DIFFERENT LEVELS OF DRAGON FRUIT PEEL FLOUR

Composition (%)	Control (0%)	F1 (3%)	F2 (6%)	F3 (9%)
Fat content	2.88 ± 0.21[a]	2.95 ± 0.25[a]	2.82 ± 0.26[a]	2.87 ± 0.19[a]
Ash content	1.44 ± 0.02[d]	1.68 ± 0.07[c]	1.84 ± 0.06[b]	2.00 ± 0.03[a]
Crude fibre	-	0.45 ± 0.03[c]	1.04 ± 0.08[b]	1.52 ± 0.11[a]
Crude protein	14.69 ± 0.25[a]	15.02 ± 0.67[a]	13.96 ± 0.18[a]	14.69 ± 1.37[a]
Carbohydrate	49.30 ± 0.17[c]	52.96 ± 0.08[a]	51.76 ± 0.12[b]	48.04 ± 0.74[d]

Note: Data were presented in mean ± standard deviation (n=3). Means values with different superscript letters in the same row had significant differences ($p < 0.05$) between samples. Control: bread with 100% wheat flour; F1: bread with 97% wheat flour and 3% DFPF; F2: bread with 94% wheat flour and 6% DFPF; F3: bread with 91% wheat flour and 9% DFPF.

The crude fibre content increased significantly ($p<0.05$) with increasing levels of DFPF substituted in bread. Similar results were found for the crude fibre content of bread using MMTPP, which similarly showed a significant difference as the level of substitution increased [6]. This is due to the high amount of crude fibre (25.48%) in DFPF. However, the crude fibre content of the control bread was not detected because there are less fibrous components in wheat flour considering that it does not contain macronutrients of the wheat's bran and germ like whole wheat flour [39]. DFPF substituted bread has a considerably higher water-holding capacity than control bread because polysaccharide chains in fibre contain a large number of hydrophilic groups, such as hydroxyl groups, which may interact with water molecules [40].

The crude protein level of the bread samples ranged from 13.96% to 15.02% demonstrates no significant difference ($p>0.05$) as the proportion of DFPF substituted increased. This is due to lower protein content in DFPF (5.15%). A similar trend was observed by [6], who reported a decrease in protein content in bread incorporated with MMTPP. This reduction may be attributed to the higher protein content in wheat flour (9%) compared to that of MMTPP (7.53%). The protein content is a crucial factor in determining the quality of bread that is produced because gluten protein, which is made up of gliadin and glutenin, gives bread its strength and structure [41]. The bread samples' carbohydrate contents reduced significantly ($p<0.05$) as more DFPF was included into the bread. Nevertheless, F3 bread has lower carbohydrate content than control bread because of the considerable increases in moisture, ash content and crude fibre content of F3 bread [18]. Similar research by [42], who found that Balada flatbread made with banana peel flour had a substantial ($p<0.05$) lower carbohydrate load due to its higher crude fibre content.

C. Physical analysis of bread

Determination of Moisture Content, Loaf Volume, Loaf Specific Volume and Density Measurements of Bread

The moisture content in this study increased with higher levels of DFPF, showing a similar trend to bread incorporated with MMTPP, where moisture content also increased as the MMTPP level increased. The reason for the bread's increasing moisture content as the percentage of DFPF increased could be attributed to the crude fibre content. Fibre has a tendency to absorb more water, hence this will increase dough's capacity to bind with water, which causes the gluten structure to inflate and moisture to be gained [43]. The moisture content of the control bread (31.26%) falls within the same range as F3 bread (31.45%) as it can be seen on **Table 4**.

TABLE 4
MOISTURE CONTENT, VOLUME, SPECIFIC VOLUME AND DENSITY OF BREAD SUBSTITUTED WITH DRAGON FRUIT PEEL FLOUR

Parameters	Control (0%)	F1 (3%)	F2 (6%)	F3 (9%)
Moisture content (%)	31.26 ± 1.04[a]	26.96 ± 0.38[c]	28.77 ± 1.23[b]	31.45 ± 0.83[a]
Volume (cm^3)	785.00 ± 49.24[a]	660.00 ± 10.00[b]	628.33 ± 40.42[b]	565.00 ± 40.93[b]
Specific volume (cm^3/g)	3.19 ± 0.20[a]	2.67 ± 0.02[b]	2.53 ± 0.18[b]	2.44 ± 0.03[b]
Density (g/cm^3)	0.31 ± 0.02[b]	0.38 ± 0.01[a]	0.40 ± 0.03[a]	0.41 ± 0.00[a]

Note: Data were presented in mean ± standard deviation (n=3). Means values with different superscript letters in the same row had significant differences ($p < 0.05$) between samples. Control: bread with 100% wheat flour; F1: bread with 97% wheat flour and 3% DFPF; F2: bread with 94% wheat flour and 6% DFPF; F3: bread with 91% wheat flour and 9% DFPF.

Wheat flour has a high content of starch ranging from 70 to 75% [44] and starch is known for its high water absorption capacity [45]. Although the wheat flour used in this study was not directly analysed, it is generally reported to contain 9–18% protein [46,47]. Its fine particle size, commonly achieved through industrial milling for commercialisation, enhances protein functionality and water absorption. The protein content and particle size can influence swelling behaviour, as higher protein increases gluten formation and smaller particles provide more surface area for water uptake [48,49]. These characteristics likely contributed to the higher moisture retention observed in the control bread. This suggests that the wheat flour's natural protein and hydration properties may have balanced the lower protein content introduced by DFPF substitution. [50] state that the acceptable range for bread's usual moisture content for day one storage is between 35% to

45%. As a result, the current study's bread samples were all at an appropriate moisture content.

The volume of bread showed a decreasing trend as the DFPF level substituted in bread increased. Increase in DFPF did not have a significant effect on bread samples volume. The control loaf volume was significantly greater ($p<0.05$) than the volumes of those substituted with 3%, 6%, and 9% DFPF. The specific volume of the fibre bread significantly reduced with increasing amount of DFPF (from 0 to 9%) but there was no significant difference ($p>0.05$) in the loaf specific volume among the substituted samples referring to the data in **Table 4**. A similar study by [6] reported that the loaf volume and specific volume of bread decreased with increasing levels of MMTPP with some of the changes were not statistically significant ($p > 0.05$). The density of the substituted bread samples was significantly ($p<0.05$) higher than that of the control sample. These results were mostly attributed to DFPF's higher fibre content than control bread. A higher fibre content in the formulation can reduce the specific volume and increase the density of the bread. The smaller protein network forms with increased fibre incorporation are due to the weak interaction between gluten and starch. This high fibre level may reduce the effectiveness of the gluten and interfere with the efficient development of the gluten matrix during mixing, fermentation, and baking [4]. As stated by [49], gluten is necessary for dough's ability to retain gas. Hence, the combination of gluten and fibre will lessen the development of gluten and reduce the volume of F1, F2 and F3 bread. As a result, it cannot rise and extend [51].

Texture Profile Analysis

The hardness of bread which had been substituted with DFPF ranging from 0% to 9% was significantly proportional ($p<0.05$) to the DFPF content. The trend of increasing hardness observed in this study was consistent with findings by [6], where the hardness of bread increased with higher levels of MMTPP incorporation. [52] revealed that the hardness of bread was significantly influenced by fibre and gluten content. Fibre component in DFPF has strong water holding capacity that causes dilution of gluten and altered its viscoelastic properties [53]. These phenomena will prevent gluten formation and change the texture of breads [54,55]. Undeveloped gluten network will decrease the dough's inflation and gas cell stability throughout the dough proofing phase causing the dough's gas cell expansions to be limited. As a result, the amount of gluten network development in the bread will be decreased by raising the percentage of DFPF (3, 6 and 9%) thus increasing their hardness. The moisture content was also correlated with the hardness of bread. The moisture content of bread will add to the hardness and typically results in low elasticity [56].

TABLE 5
TEXTURE PROPERTIES OF BREAD SUBSTITUTED WITH DRAGON FRUIT PEEL FLOUR

Parameters	Control (0%)	F1 (3%)	F2 (6%)	F3 (9%)
Hardness (g)	465.75 ± 4.81^{d}	533.36 ± 2.60^{c}	650.48 ± 41.32^{b}	1051.74 ± 29.25^{a}
Springiness	0.97 ± 0.00^{a}	0.96 ± 0.01^{b}	0.95 ± 0.01^{b}	0.94 ± 0.00^{c}
Cohesiveness	0.84 ± 0.01^{a}	0.78 ± 0.03^{b}	0.78 ± 0.03^{b}	0.77 ± 0.05^{b}
Chewiness	365.37 ± 7.25^{c}	391.95 ± 12.39^{c}	468.50 ± 39.86^{b}	772.59 ± 26.18^{a}

Note: Data were presented in mean ± standard deviation (n=3). Means values with different superscript letters in the same row had significant differences ($p < 0.05$) between samples. Control: bread with 100% wheat flour; F1: bread with 97% wheat flour and 3% DFPF; F2: bread with 94% wheat flour and 6% DFPF; F3: bread with 91% wheat flour and 9% DFPF.

Table 5 demonstrates that when DFPF was added, the bread's springiness showed a declining trend. The measured springiness for the control bread (0.97%) was the highest and the lowest for F3 bread (0.94%). A similar range of springiness was reported by [6], where the addition of MMTPP to bread resulted in a decreasing trend in springiness. When wheat flour was replaced with DFPF, some of the gluten was lost, which may have contributed to the lesser springiness in F3 bread since gluten production in the bread is responsible for its high springiness [41]. The control bread had the highest cohesiveness (0.84) and it differed significantly from the other breads. However, there is no significant difference in cohesiveness from 3 to 9% substituted DFPF. This might be because commercial wheat flour has a finer particle than DFPF. Fine-particle flour has the ability to absorb a significant amount of water during mixing due to its higher surface area, which results in a more cohesive dough [57]. The decreased cohesiveness of F1 to F3 breads implied that its resistance to the deformation of the bread structure in the mouth was lower than control bread. A low cohesiveness rating in bread suggests that the crumb is more prone to rupture [58]. The chewiness of the bread followed a similar trend to hardness, with F3 bread exhibiting the highest chewiness value. Similarly, [4] reported that bread with the highest level of corncob powder substitution exhibited the greatest chewiness. However, the control bread showed no significant difference ($p > 0.05$) compared to F1 bread and recorded the lowest chewiness value. Chewiness is directly related to hardness and is defined as the energy required to chew solid food to the point of readiness for swallowing [59]. The findings indicate a positive correlation between chewiness and hardness when DFPF is added into the bread.

Colour Profile Analysis

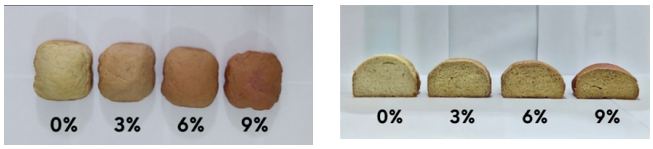
The values of L*, a* and b* of the crust and crumb of the breads are shown in **Table 6**. The crust and crumb of control bread had the highest value of L* (70.10 and 63.72 respectively)

indicating that it was lighter in colour but the lowest values of a* (1.85 and -0.55 respectively). The result demonstrates that as the DFPF level in the bread formulation grew, the L* of the bread crust and crumb decreased. The greatest value of L* was found in control bread may be due to its high percentage of gluten as study conducted by [60] on the quality of bread revealed that the brilliant colour of bread is probably correlated with its high protein (gluten) content. The findings showed that the bread's crumb and crust redness (a*) had significantly increased ($p<0.05$) with the increase of DFPF levels in bread. These results followed a similar pattern to [34], who reported that incorporating pitaya peel flour resulted in a darker surface on cookies with decreasing value of L* and increasing value of a*. From **Figure 1**, it can be seen that the crumb and crust's hue changed from lighter yellow for the control bread to a darker pink for F3 bread. In comparison to the crumb, the crust's L* and a* were darker and redder. The hue was influenced by the temperature during baking, as heat is first transferred to the bread's surface (crust) through convection from the heating medium and radiation from the oven walls, followed by conduction that moves the heat from the crust into the centre of the bread [61].

TABLE 6
COLOUR PROPERTIES OF BREAD SUBSTITUTED WITH DRAGON FRUIT PEEL FLOUR

Parameters	Control (0%)	F1 (3%)	F2 (6%)	F3 (9%)
Crumb				
L*	63.72 ± 0.36^{a}	59.46 ± 0.80^{b}	57.23 ± 0.61^{c}	55.53 ± 0.27^{d}
a*	-0.55 ± 0.03^{d}	0.22 ± 0.02^{c}	1.29 ± 0.09^{b}	4.46 ± 0.37^{a}
b*	19.58 ± 0.52^{a}	19.57 ± 0.34^{a}	18.31 ± 1.62^{a}	17.84 ± 0.67^{a}
Crust				
L*	70.10 ± 2.18^{a}	62.31 ± 0.33^{b}	59.37 ± 0.17^{c}	56.49 ± 0.12^{d}
a*	1.85 ± 0.08^{d}	11.27 ± 0.80^{c}	16.46 ± 0.93^{b}	22.18 ± 0.66^{a}
b*	24.24 ± 0.76^{a}	24.96 ± 0.60^{a}	24.65 ± 0.56^{a}	23.76 ± 0.61^{a}

Note: Data were presented in mean ± standard deviation (n=3). Means values with different superscript letters in the same row had significant differences ($p < 0.05$) between samples. Control: bread with 100% wheat flour; F1: bread with 97% wheat flour and 3% DFPF; F2: bread with 94% wheat flour and 6% DFPF; F3: bread with 91% wheat flour and 9% DFPF.



(a) (b)

Fig. 1 The (a) crust and (b) crumb of breads substituted with different ratios of DFPF.

The differences observed in L*, a*, and b* values in this study can be attributed to browning reactions during baking, as supported by previous research. According to [62], the L* values for bread crumb are consistently higher than those of the crust, indicating that the crumb is lighter in colour. This difference arises because the crust is directly exposed to high temperatures during baking, causing it to undergo browning reactions, while the crumb is shielded from direct heat and retains a lighter shade. Additionally, a* and b* values are typically higher in the crust than in the crumb due to Maillard reactions and caramelization, which intensify colour development on the bread's surface [63,64]. These reactions are triggered by the rapid evaporation of water from the dough's outer layer and prolonged exposure to elevated temperatures, resulting in the formation of melanoidin pigments that darken the crust [65,66]. [67] further explained that these browning reactions are initiated by interactions between reducing sugars and amino acids or wheat proteins, influenced by the dough's internal moisture distribution. At higher DFPF substitution levels, the browning effect becomes more intense, contributing to the darker crust and crumb coloration.

In the case of red DFPF, the presence of betalains, particularly betacyanins, contributes to a reddish-violet hue in the crumb and crust. These anthocyanin-related pigments are responsible for the vivid coloration observed with increasing DFPF levels [68]. The hue angle values confirm that the colour of DFPF breads shifts towards the red-purple spectrum, while higher chroma values indicate increased colour saturation with higher DFPF content [15]. The higher dietary fibre content in DFPF may also contribute to the browning of the crust as more DFPF is substituted into the bread. Conversely, the b* values of the samples fell within the yellow-blue colour spectrum, with the crust showing slightly higher b* values than the crumb, indicating a marginally more yellow hue. However, there were no significant differences ($p > 0.05$) in b* values among the control and DFPF-substituted breads (F1, F2, F3). This could be attributed to the relatively low amount of betaxanthins, the yellow pigments present in DFPF, resulting in a consistent yellow coloration across all bread samples.

Sensory evaluation

The sensory evaluation scores for the bread samples were summarised in **Table 7**. Panellists favoured F2 bread (6.94) based solely on appearance as it has the highest score compared to F3 bread (6.26). The taste and aroma of the DFPF loaves had no significant level ($p>0.05$) with control bread, therefore all the breads tasted and smelled the same as the control bread. The addition of DFPF does not have an impact on the finished product's scent and still contributes to the favourable taste of bread. The colour was becoming less vibrant as the DFPF level increased. However, the panellists rated control bread which has the vibrant colour, the lowest but showed no significant difference with F3 bread because panellists' dislike of the colour, which was excessively white for control and too dark for F3 bread. The texture of F3 bread (5.77) has the lowest rating and shows a significance with others as it was less

appealing to the panellist due to bread's extreme firmness. This is because bread with a higher fibre content would make the bread's crumb texture denser and more compact, making it harder for panellist to chew. [6] reported a similar finding where the bread with 12% MMTPP substitution exhibited the highest hardness and was the least acceptable formulation among panellists. Meanwhile, the texture of the F1 (6.49) and F2 (6.70) bread was rated the same as the control bread (6.45) at $p>0.05$. This indicates that consumers prefer bread that are not too hard and not too soft.

F1, F2 and F3 breads' overall acceptability score was not significant with control breads at $p>0.05$. According to [4], a bread sample must have an overall acceptability score greater than five in order to be deemed acceptable. Since the overall acceptability score in this sensory test was greater than 5, all bread samples were deemed acceptable. This finding aligns with the study by [69], which reported that cookie samples enriched with pitaya peel powder were deemed acceptable as their overall acceptability scores also surpassed the five-point threshold, however, higher levels of fibre-rich ingredients can negatively impact sensory attributes. Similar trends were reported in studies involving cookies fortified with pomegranate peel powder [70] and purple passion fruit epicarp [71], where increasing levels of fibre additives led to lower sensory scores. This is consistent with the present study, where the F3 bread sample, which contained the highest level of DFPF, received the lowest acceptability rating. Thus, F2 bread appeared to have a good possibility of competing in the current bread market based on the sensory evaluation results.

TABLE 7
SENSORY EVALUATION OF BREAD SUBSTITUTED WITH DRAGON FRUIT PEEL FLOUR

Parameters	Control (0%)	F1 (3%)	F2 (6%)	F3 (9%)
Appearance	6.38 ± 1.63^{ab}	6.68 ± 1.41^{ab}	6.94 ± 1.63^{a}	6.26 ± 1.40^{b}
Aroma	6.55 ± 1.26^{a}	6.34 ± 1.41^{a}	6.53 ± 1.75^{a}	6.30 ± 1.46^{a}
Taste	6.38 ± 1.48^{a}	6.19 ± 1.73^{a}	6.64 ± 1.72^{a}	6.17 ± 1.66^{a}
Colour	6.02 ± 1.61^{b}	6.68 ± 1.42^{a}	6.91 ± 1.54^{a}	6.57 ± 1.29^{ab}
Texture	6.45 ± 1.46^{a}	6.49 ± 1.96^{a}	6.70 ± 1.71^{a}	5.77 ± 1.92^{b}
Overall acceptability	6.34 ± 1.37^{a}	6.49 ± 1.61^{a}	6.89 ± 1.60^{a}	6.28 ± 1.45^{a}

Note: Data were presented in mean ± standard deviation (n=3). Means values with different superscript letters in the same row had significant differences ($p < 0.05$) between samples. Control: bread with 100% wheat flour; F1: bread with 97% wheat flour and 3% DFPF; F2: bread with 94% wheat flour and 6% DFPF; F3: bread with 91% wheat flour and 9% DFPF.

IV. CONCLUSION

In conclusion, although dragon fruit peel is often discarded, it still offers numerous health benefits that can be transformed into important food resource. This study aimed to investigate the effect of substituting wheat flour with DFPF on the quality of bread. The substitution approach worked well and was in line with the hypothesis, which proposed that incorporating DFPF would improve the nutritional value of bread without significantly affecting its acceptability. The addition of DFPF increased the bread's crude fibre, ash, and moisture content, while slightly reducing volume, specific volume, and carbohydrate content. Textural changes included increased hardness and chewiness, with reduced springiness and cohesiveness. Colour analysis showed darker bread with higher DFPF levels, particularly in redness (a*), while b* values remained relatively stable. Sensory evaluation confirmed that bread with 6% DFPF (F2) had good overall acceptance, especially in appearance and texture. Therefore, incorporating DFPF at appropriate levels can serve as a complementary strategy to enhance dietary fibre and functional value in bread without compromising consumer preference.

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CONFLICT OF INTEREST

The authors declare no conflict of interest to disclose.

During the preparation of this manuscript, generative AI tools (Grammarly, Quillbot, MS Office AI, and OpenAI) were used to improve the clarity, grammar, and overall readability of the text. The use of these tools was conducted under complete human oversight, and all intellectual and scientific content, data interpretation, and conclusions are entirely the responsibility of the authors. No generative AI tool was used to generate or analyze scientific data, and AI tools are not listed as authors or co-authors.

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