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PHYSICO-FUNCTIONAL, CHEMICAL, NUTRITIONAL AND ANTIOXIDANT PROPERTIES OF FLOUR FROM THREE VARIETIES OF UNRIPE BANANA (*MUSA* SP.) CULTIVATED IN SRI LANKA

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ABSTRACT

Banana, scientifically known as *Musa acuminate* L., is a valuable source of nutrients and widely grown in tropical and subtropical regions. They can be consumed either in their natural state or after undergoing various processing methods. Green banana flour is an excellent alternative to keep the nutritional value of fresh bananas while minimizing post-harvest losses. The present study aimed to evaluate the physico-functional, chemical, nutritional, and antioxidant properties of flour obtained from three different banana varieties (*Seeni* banana, *Ambul* banana, and Cavendish banana) grown abundantly in Sri Lanka. Different properties of banana flour from selected banana varieties were measured using standard methods. Green banana flours showed significant differences ($p<0.05$) in colour parameters (CIE L*a*b*), swelling capacity, transparency, gelatinization temperature, pH, and titratable acidity, with no significant difference ($p>0.05$) in bulk, and tapped densities, water holding, oil holding and foaming capacities. There was no significant difference ($p>0.05$) in the amount of crude fiber content among all three flour types, while *Seeni* banana flour showed a significant amount of carbohydrate (88.65±0.39 g per 100 g wet weight), polyphenols (31.41±0.61 mg GAE/100 g of sample) and flavonoids content (337.7±31.11 mg QE/100 g of sample). Cavendish banana flour showed the highest antioxidant activity (576±0.028 mg of TE/g of the dried sample) compared to the other two banana varieties. The obtained results confirmed that green banana flour is a good source of nutrients and can be effectively used in developing value added products.

1. Introduction

Banana is one among the most produced, traded, and consumed fruits in the world. Bananas are classified under genus Musa of the family Musaceae. More than 1000 varieties of banana are produced worldwide and Cavendish reached about the 45% of the global market due to its high production and tolerance to mechanical damages than other varieties. There have been recorded to be 29 banana cultivars in Sri Lanka, along with two wild species (Department of Agriculture Sri lanka, 2012). Five of these species can be used for cooking, while all the others, with the exception of two wild species, are eaten as desert. In Sri Lanka, banana production is estimated to be 780,000 metric tons per year, with an average yield of 13 Mt/ha (Department of Census and Statistics, 2014). The banana can be grown and harvested throughout the year without seasonal barriers, so there is an abundance of bananas available throughout the year.

A banana is one of the most popular fruits among consumers due to its affordability, abundance, and nutritional value. A single 100 g serving of dessert banana contains 368 kilojoules of calories, while the same amount of plantain provides 556 kilojoules (Ranjha et al., 2022). The firm and fleshy banana fruit is packed with antioxidants, minerals such as iron, magnesium, manganese, and phosphorus, and vitamins such as vitamin B1, B2, B3, choline, vitamin C (Nadeeshani et al., 2021). Unripe banana contain resistant starch that supports digestive health and can serve as a healthy option for individuals with non-communicable diseases such as diabetes and obesity. Unripe banana flour offers several health benefits that are not found in wheat flour, making it a nutritious and beneficial alternative. Green banana flour is a gluten-free substitute that is ideal for patients with celiac disease. Besides their nutritional value, bananas offer several medicinal benefits such as lowering the risk of high blood pressure, restoring normal bowel activity, protecting against ulcers, reducing cholesterol levels, maintaining kidney health, boosting immunity, and promoting weight loss. Compared to wheat flour (GI- between 56 and 69), unripe banana flour has a lower glycemic index (around 30) and can be considered as good alternative food to regulate blood sugar levels and reduce the risk of diabetes (Gómez *et al.*, 2020).

Bananas are highly perishable and decay quickly due to their high moisture content and rapid metabolic activity that continues after harvest. Therefore, harvested banana become overripe and senescent before being delivered to markets due to unavoidable transportation delays, inadequate post-harvest technologies, and fluctuating market demand. However, it is possible to reduce postharvest losses by converting them into forms with a lower moisture content as it can lengthen the shelf-life and prevent a significant amount of post-harvest loss (Falade & Oyeyinka, 2015). Among the different types of bananas highly consumed by Sri Lankans, the post-harvest loss of *Ambul* and *Seeni* bananas are high compared to the other types. Cavendish banana is one of the main cultivars of banana grown in Sri Lanka targeting the export market. A significant amount of Cavendish bananas that do not meet the export standards are wasted. Therefore, this has prompted research into the processing and application of mature green bananas of *Seeni*, *Ambul*, and Cavendish to diversify the uses while minimizing the post-harvest loss.

Therefore, the objective of this research was to evaluate and compare the physico-functional, chemical, nutritional, and antioxidant properties of banana flours obtained from most abundant three banana varieties grown in Sri Lanka in order to determine their potential for further application in processed food industry.

2. Materials and methods

2.1. Materials

In this study, three banana varieties, namely *Ambul*, *Seeni* and Cavendish were selected considering the abundance and popularity. Banana in first stage of ripening process which has green peel and sharp edges were chosen. Hard green (unripe) *Seeni* and *Ambul* banana fruits were purchased from the village market located in Kamburupitiya, Matara, Sri Lanka and Cavendish banana from Ambalanthota, Sri Lanka.

2.2. Production of Banana flour

The banana flour was prepared according to the method described by Fatemeh *et al.* (2012) with some modifications. Bunch of matured (green peel and sharp edges) banana fruits were separated into individual fingers and their weight was taken, Banana fingers were washed and dipped in 0.5% (w/w) citric acid solution for 5 min. Then individual banana fingers were peeled and cut in to 2 mm thickness slices and the cut pieces were dipped in citric acid solution. After draining, the pieces were dried at 60 ± 2 °C for eight hours to obtain the dried chips, and they were grounded using a home scale grinder to obtain the banana flour. Finally, banana flour was sieved (60 Mesh) and packed in impermeable plastic bags and stored under room temperature (30 ± 2 °C) until further use.

2.3. Evaluation of the physico-functional properties of banana flour

Prepared banana flour was separately subjected to examination of functional properties such as bulk and tapped densities, compressibility index, Hausner ratio, water absorption and oil absorption capacity, swelling capacity, transparency, foaming capacity, gelatinization temperature, colour parameters, and all the readings were taken in triplicates.

2.3.1. Bulk and Tapped Densities

The bulk and tapped densities of the banana flour were measured using the methods described by Okaka & Potter, (1977). The banana flour samples (50 g) were weighted and gently poured through a glass funnel into a 100 mL cylinder separately. The volume occupied by each sample was recorded, and the bulk density (Bd) was calculated. Then, the measuring cylinders with powders were tapped on a wooden surface until a constant volume was observed, and the tapped density (Td) was calculated. The Bd and the Td were calculated as the volume (mL) per unit weight of a sample.

2.3.2. Compressibility Index (CI) and Hausner Ratio (HR)

The values of bulk (Bd) and tapped densities (Td) were used to calculate the compressibility index (equation 1) and the Hausner ratio (equation 2) of the flour samples according to the method described by Olayemi *et al.,* (2008).

$$\text{Hausner ratio (HR)} = Td / Bd \qquad (1)$$

$$CI = [(Td - Bd)/ Td] \times 100 \qquad (2)$$

2.3.3.Water Absorption Capacity (WAC) and oil absorption Capacity (OAC)

Water absorption and oil absorption capacities of banana flour were examined using the method described by Sosulski *et al.* (1976). In order to measure the WAC and OAC, one gram of flour sample was mixed with 10 mL of distilled water and coconut oil respectively. Then, the mixtures wer allowed to stand for settling at 30 ± 2 °C for 30 min and it was centrifuged at 2000 rpm for 30 min. The weight of water/ oil absorbed by the flour was measured using the difference of the final weight of the sample after centrifuging and the orginal sample weight. WAC and OACs were expressed as grams of water/oil bound per gram of flour.

2.3.4. Swelling Capacity

The swelling capacity of each flour sample was measured as described by Okaka & Potter (1977). The flour samples were filled in a graduated cylinder separately, and water was added and mixed. The volume occupied by the sample was recorded after 30 min.

2.3.5. Transparency

Transparency of banana flour samples were measured using the method described by Wang *et al.,* (2017) where an aqueous flour solution was prepared, heated and cooled to room temperature. The transparency was measured at 620 nm using the spectrophotometer (CT-8600 double beam spectrophotometer, Spain).

2.3.6. Foaming capacity

Foaming capacity of banana flour was determined according to the method described by Chandra & Samsher, (2013) which involves adding 1 g of flour into 50 mL of distilled water, shaking for 5 min and measuring the volume.

2.3.7. Gelatinization temperature

Gelatinization temperature of the flour samples were measured using the method described by Chandra & Samsher, (2013) where 1 g of flour sample with water was heated slowly in a water bath until a solid gel formed and the temperature at the point of complete gel formation was recorded.

2.3.8. Color Parameters

The CIE tristimulus L*, a*, and b* parameters were determined using colorimeter (BCM-200, China). Chroma (ΔC), hue angle, Yellowness index and whiteness index were calculated according the formulas described by Falade & Oyeyinka (2015).

2.4. Evaluation of the Proximate Composition of banana Flour

Proximate analysis was conducted to determine the amount of moisture, ash, crude fiber, crude protein, and crude fat according to the AOAC methods (2000) while carbohydrate content was determined by the difference method (Pearson, 1970).

2.5. Evaluation of the chemical properties of banana flour

2.5.1. Titratable acidity and pH

The titrimetric method described by Falade & Oyeyinka, (2015) was used to measure the titratable acidity of the banana flour samples while the pH values of the banana flour were determined using a pH meter (Model AD 132, Romania).

2.6. Evaluation of the nutritional and antioxidant properties of the banana flour

2.6.1. Determination of Vitamin C content

Two grams of banana flour was weighed and mixed with 100 mL of distilled water in a conical flask. The mixture was filtered, and 5 mL of the filtrate was taken and volumed up to 100 mL with distilled water. Five drops of phenolphthalein indicator was added, and the mixture was titrated with 0.01 N NaOH until the color of the solution turned into pink. The vitamin C content present in 100 g of the sample was calculated using formula presented by Ndayambaje *et al.*,(2019).

$$\text{Vit. C} = \text{Vol. of NaOH} \times 0.01\ \text{N} \times 100\ \text{ml} \times 100\ \text{g}/2 \times 176.13 \times 10^{-3} \qquad (3)$$

2.6.2. Determination of Total polyphenol content

The total polyphenol content of the prepared banana flour was measured using the method given by Singleton *et al.*, (1999) with some modifications. The banana flour extracts using 95% (v/v) ethanol (400 μL) were mixed with 2 mL of Folin-Ciocalteu reagent which has been diluted (ten-fold) using distilled water. After a period of one minute, 2 mL of 7.5% (w/v) sodium bicarbonate solution was added to stop the reaction. Then the mixture was volumed up to 10 mL using distilled water. This mixture was placed at dark for 120 min, and the absorbance was measured at 760 nm. Results were expressed as mg of Gallic acid equivalents per 100 g of the sample (mg GAE/100 g) using the equation obtained by linear regression of Gallic acid standard curve prepared by serially diluted Gallic acid solutions.

2.6.3. Determination of total flavonoid content

The aluminum chloride colorimetric method was used for the determination of the total flavonoid content of the sample according to the methods described by Zhishen *et al.*, (1999) and Chang *et al.*(2020) with some modifications using quercetin as the standard. One milliliter from properly diluted methanolic fractions of the samples or quercetin standard solutions or (water or methanol) the blank solution was added to 10 mL volumetric flask. Then 4 mL of distilled water was added to the solution followed by 0.3 mL of 5% $NaNO_2$ at the beginning, and 0.3 mL of 10% $AlCl_3$ after 5 min. At the sixth minute, 2 mL of 1 M NaOH was added, and the solution was volumed up to 10 mL with distilled water, and the mixture was mixed well. After a period of 15 min, the absorbance was measured at 510 nm. The total flavonoid content was expressed as milligrams of quercetin equivalent per 100 g of the sample.

2.6.4. Determination of DPPH Radical Scavenging Activity

DPPH radical scavenging activity was assessed by using the method suggested by Petlevski *et al.*, (2013) with some modifications. A control sample was prepared by mixing 4 mL of DPPH solution in 0.4 mL of methanol to obtain an absorbance at 517 nm using UV-Vis Spectrophotometer. Initially, 4 mL of 0.1 mM DPPH methanolic solution was added to 0.4 mL methanolic sample and mixed well using the vortex. Samples were kept in the dark for 30 min and the absorbance was taken at 517 nm using a spectrophotometer. The results were expressed as Trolox equivalent (TE) in milligrams per g of dried sample.

2.7. Data analysis

All the experiments were conducted in triplicate and data are presented in mean ± standard deviation. One-way ANOVA with Tukey's post hoc test was applied to determine the statistical significance among the three banana varieties at $p < 0.05$.

3.Results and discussions

3.1. Physico-functional properties of the banana flour

The results of physico-functional properties of flour from three different banana varieties (*Ambul*, *Seeni* and Cavendish) are summarized in Table 1.

Table 1 Physico-functional properties of the banana flour

Functional property	***Ambul***	***Seeni***	**Cavendish**
Bulk density (g/mL)	0.51± 0.00[a]	0.51±0.01 [a]	0.51±0.01 [a]
Tapped density (g/mL)	0.72± 0.01 [a]	0.74±0.01 [a]	0.70±0.01 [a]
Compressibility index	29.83 ± 1.78 [a]	31.28 ± 1.62 [a]	28.56 ± 1.44 [a]
Hausner ratio	1.43 ± 0.04 [a]	1.46 ± 0.03 [a]	1.40 ± 0.03 [a]
Swelling capacity (mL)	27.25± 0.31 [b]	20.50±2.12 [a]	24.00±0.00 [ab]
Transparency	84.00± 0.21 [b]	71.70±0.00 [a]	89.60±0.00 [c]
Water Absorption Capacity (%)	302.00± 8.49 [a]	298.50±2.12 [a]	279.50±0.71 [a]
Oil Absorption Capacity (%)	267.00±1.41 [a]	143.00±1.41 [a]	152.50±3.54 [a]
Foaming capacity	7.00± 1.41 [a]	1.00±0.00 [a]	11.00±1.41 [a]
Gelatinization temperature (˚C)	74.10± 0.01 [a]	75.00±0.00 [b]	75.30±0.00 [b]
Color parameters			
Color – L*	69.64±0.13 [b]	72.18±0.50 [c]	60.40±0.13 [a]
a*	3.33±0.18 [a]	3.15±0.35 [a]	3.55±0.07 [a]
b*	26.90±0.57 [a]	27.26±1.05 [a]	27.88±0.32 [a]
Hue angle	1.45±0.01 [a]	1.46±0.01 [a]	1.44±0.00 [a]
Yellowness index	55.18±0.89 [a]	53.94±1.90 [a]	65.94±0.82 [b]
Whiteness index	59.26±0.10 [b]	60.92±0.59 [c]	51.44±0.02 [a]
Chroma c	27.11±0.54 [a]	27.44±1.09 [a]	28.10±0.31 [a]

Data are expressed in mean ± SD of three independent measurements. Values with different superscripts within the same row are significantly different at $p<0.05$.

The bulk density of flour obtained from all three banana varieties was 0.51±0.01 g/mL and it was in the range (0.459 g/mL to 0.67 g/mL) which reported in literature (Falade & Oyeyinka, 2015 and Pragati *et al.*, 2014). The bulk density of banana flour of the present study showed slightly higher value compared to the bulk density of wheat flour (0.49 g/mL) reported by Amankwah *et al.,* (2022). Bulk density of flours is mainly influenced by their initial moisture content and particle size (Chandra & Samsher, 2013) where it decreases along with the increase of maturity of fresh material. The bulk density is a good indicator of heaviness of the flour (Ocloo *et al.*, 2010) and it is important to decide the package specifications, material handling, and application in wet processing in the food industry. Flour with lower bulk density occupies more space than a denser product of the same weight, which can affect the amount of packaging material required, and the overall size and weight of the package (Anderson, & Atnip, 2013).

Tapped density is another important physical parameter of flours to determine its powder characterization such as compressibility index and Hausner ratio due to its simplicity and rapidity of measurement. The results of the present study showed that Cavendish banana flour had the lowest tapped density (0.7±0.014 g/mL), while *Seeni* banana flour showed the highest tapped density (0.74±0.01 g/mL). Tapped density for *Ambul* banana flour was about 2.7% lower than for *Seeni* banana flour. Tapped density of wheat flour (0.74 g/mL) obtained from Kumasi-Ashanti region, Ghana was reported as 0.74 g/mL (Amankwah *et al*., 2022), and the tapped densities of banana flour of the present study were also in the same range. The tapped density of flour plays a significant role in its flowability, compressibility, and bulk volume. When the tapped density is lower, it indicates that the particles are loosely packed and have a higher volume, which can result in more dusting and settling during storage and transport. In contrast, higher tapped density indicates tightly packed particles with lower volume, which reduces dusting and settling during storage and transport but also leads to decreased flowability (Rosell & Collar, 2012).

Compressibility index and Hausner ratio are two other important indicators which showing the significance of inter-particulate interactions and important to forecast the propensity of a given powdered sample to be compressed (SherVington & Sherrington, 1998). The relationship among compressibility index, Hausner ratio and flowability of flour is shown in Table 2 (Carr, 1965).

Table 2. The relationship among Compressibility index, Hausner ratio, and flowability of flour

Compressibility index %	Flow character	Hausner ratio
≤10	Excellent	1.00 - 1.11
11-15	Good	1.12 - 1.18
16-20	Fair	1.19 - 1.25
21-25	Passable	1.26 - 1.34
26-31	Poor	1.35 - 1.45
32-37	Very poor	1.46 - 1.59
>38	Very very poor	>1.60

Source : Carr, (1965)

The above-mentioned scale in Table 2 is widely used by researchers to determine and compare the flow characters of flours used in the bakery industry. Highest compressibility index (31.28 ± 1.62) and Hausner ratio (1.46 ± 0.03) recorded from *Seeni* banana flour compared to the other two banana flour types. However, the banana flours of the present study showed very poor flow properties according to the given scale (Table 2). The study conducted by Thanyapanich *et al*., (2021) reported that the compressibility indexes of banana flour from *Musa acuminata* L. (Musa AAA; Hom Khieo) and *Musa sapientum* L. (Musa ABB; Namwa) were 31.70 ± 2.13 and 34.84 ± 1.59, respectively, and the Hausner ratios of those varieties as 1.47 ± 0.05 and 1.54 ± 0.04, respectively which are in line with the results of the present study. The reason for showing very poor flow characters may be due to the fine particle size distribution of flour. Fine particle size can lead to poor flow characteristics in flour and other powders due to increased inter-particle friction and cohesion. Small particles tend to stick together, forming clumps that impede flow. The irregular shapes and surface features of fine particles can also contribute to increased cohesion. Poor flow can negatively impact the handling and processing of powders (mixing, blending or dispersing of ingredients), leading to downtime, waste, or inconsistent product quality (Vredenburgh, 2017).

The Hausner ratio of the wheat flour (1.53), which were obtained from Kumasi-Ashanti region, Ghana (Amankwah *et al*., 2022), is slightly higher than the Hausner ratio values reported by the banana flour in the present study (1.40-1.46). This may be due to the lower bulk density of wheat flour than the banana flour. The Hausner ratio is directly related to the bulk density of flour and increase in bulk density usually results a higher Hausner ratio. This is due to the decrease of space between particles and the particles become more tightly packed, making it more difficult for them to flow. Therefore, a material with a higher bulk density is likely to have a higher Hausner ratio, indicating poorer flowability. However, the relationship between Hausner ratio and bulk density may not always be straightforward, as other factors such as particle size, shape, and surface properties can also affect for the flowability.

The swelling capacity of flour is directly related to their binding ability (Lawal *et al.*, 2011). *Seeni* banana flour showed the lowest swelling capacity while *Ambul* banana flour showed the highest swelling capacity. Further, there was a significant difference ($p<0.05$) between the swelling capacities of *Ambul* and *Seeni* banana flour. However, swelling capacity of both flour types were not significantly difference ($p<0.05$) from that of Cavendish banana flour. The study conducted by Ocheme *et al.* (2018) reported that wheat flour has 12.71% swelling capacity and the banana flour of the present study showed around 1.8 times higher swelling capacity than the wheat flour. The reason of showing higher swelling capacity could be the presence of high amount of protein and carbohydrate in the banana flour (Gull *et al*., 2015). In addition, swelling capacity of flours can be depend on the size of particles, types of variety and types of processing methods or unit operations (Chandra & Samsher, 2013).

The transparency of the banana flour from three tested varieties was found to be varied in the sequence of Cavendish > *Ambul* > *Seeni*, and a significant difference ($p<0.05$) was observed among the varieties. Measuring the transparency of flour is important because it can provide information about the quality and purity of the flour, which can affect the final product. Transparency can be influenced by several factors, including the particle size distribution, protein content, and ash content of the flour (AACC International., 2010; Giraldo & Aguilera, 2017).

The highest Water Absorption Capacity (WAC) was showed by the *Ambul* banana flour and the lowest by the Cavendish banana flour. Banana flour showed a higher WAC compared to that of wheat flour (140%) which was reported by Chandra *et al*., (2015). Further, these findings showed that addition of banana flour to wheat flour will be affected on the water holding capacity of the composite flour mixture. Water absorption capacity of banana flour is greatly depend on the starch concentration, composition, granule shape and temperature (Falade and Oyeyinka, 2015). According to Pragati *et al*., (2014) and Falade & Oyeyinka, (2015), WAC of unripe banana flour was greater than ripe banana flour as unripe banana has higher starch content that increase the water absorption capacity. Water absorption capacity of flour affects the texture and quality of the bakery products. Flour with high WAC can absorb more water, resulting in stickier and more elastic dough that can be difficult to handle and shape. Furthermore, a low WAC results in dry and crumbly dough that can be tough and hard to chew. The increase or decrease of WAC can have both beneficial and detrimental effects on the bakery industry.

The Oil Absorption Capacity (OAC) of three types of banana flour ranged between 143 to 267% and there was no significant difference ($p>0.05$) among the flours from three varieties. As compared to wheat flour (146%) (Chandra *et al*., 2015), *Ambul* and Cavendish banana flour showed higher OACs while *Seeni* banana flour showed a lower OAC. This may be due to the composition and granule shape of the flours. OAC is an important parameter in flour quality assessment, with a significant impact on the texture, volume, and overall quality of baked goods. Flours with higher OACs tend to produce more moist, tender, and fine-textured products, while flours with lower OACs can result in dry, crumbly products.

The gelatinization of starch is a critical process in the production of baked goods, as it provides the structure and texture of the final product. The gelatinization temperature of flour determines how easily the starch can be gelatinized, and therefore, affects the final texture and quality of the baked goods. The temperature at which the starch granules rapidly swell and yield a thickened paste, depends upon the water content, type of starch and the ratio of amylose and amylopectin present in the flour. In the present study, Cavendish banana showed the highest gelatinization temperature (75.30 °C) while *Ambul* banana showed the lowest gelatinization temperature (74.10 °C). The results were in agreement with a previous study that found the gelatinization temperatures of banana flour which was in a range of 70–79 °C (Bello-Pérez *et al.*, 2005; De la Torre-Gutiérrez *et al*., 2008 and Utrilla-Coello *et al.*, 2014). According to the Matsuki *et al.*, (2003), the peak gelatinization temperatures of wheat flour varieties (Norin 3, Norin 29, Haruhikari, and Haruyutaka) at daytime temperature (30 °C) was 60.2 °C, 59.7 °C, 59.8 °C, and 60.0 °C, respectively. Those values are around 20% lower than the gelatinization temperatures of banana flour varieties used in the present study (74.10 - 75.30 °C). This may be due to the variation in stable crystalline structure and length of amylopectin chains between these two flour types (wheat and banana) (Matsuki *et al.*, 2003). Baked goods made from flour with a lower gelatinization temperature tend to have a softer and moister crumb while extremely higher gelatinization temperature may lead to a firmer or drier texture in baked products (Aguilera & Kruger, 2001; Zhang *et al*., 2008).

A particle made up of numerous gas bubbles that have been trapped in a liquid or solid is known as a foam (Fennama, 1996). The foaming capacity of flour is important to evaluate the flours capacity for foaming, which depends on the availability of flexible protein molecules that reduce the surface tension of water (Asif-Ul-Alam *et al.*, 2014). Foam capacities of tested banana flours were found to be varied from 7 mL to 11 mL where the highest foam capacity was observed from Cavendish banana flour (11 mL) while lowest from *Ambul* banana flour (7 mL). However, the foam capacities of banana flour were lower than the reported foam capacity of the wheat flour (12.92%) (Akubor & Badifu, 2004). This may be due to the differences in available flexible protein molecules in wheat flour and banana flour. Further, reduced or negative foam capacities may affect the shelf-life of the flour (Kaushal *et al*., 2012).

The Commission on Illumination (CIE) L*, a* and b* color parameters and the calculated Whiteness index, Chroma C, Hue angle and Yellowness index of the three different banana flour are summarized in Table 1. The L* value shows the lightness parameter which ranged from 0 to 100 (0 is black and 100 is white) whereas a* and b* values shows color direction from green to red and blue to yellow, respectively. There was a significant difference ($p<0.05$) among banana flours for the L* parameter while there was no significant difference ($p>0.05$) for a* and b* values. Wheat flour (variety Khadija) showed higher L* value (94.8) than banana flour while, banana flour had higher a*(3.15-3.55) and b*(26.90-27.88) value ranges than wheat flour (a*-0.54, b*-8.66) (Bouhlal *et al.,* 2019). These changes are probably due to the presence of different degree of colour pigments such as carotenoids in the banana flour.

The whiteness index (WI) represents the degree of whiteness of the product, which is susceptible to change during storage. As a result, materials with a lower level of whiteness are regarded as neutral, greyish, or creamier (yellowish), and materials with a higher level of whiteness are perceived as having bluish tones. According to the results of present study, there were significant differences ($p<0.05$) of whiteness index of flour obtained from three different banana varieties. This may be due to the degree of color pigments present in banana variety, astringency level and the level of controlling browning effect. The study conducted by Bouhlal *et al*., (2019) reported that wheat flour (variety Khadija) had a whiteness index of 89.89 which was higher than the whiteness index of the banana flour varieties (51.44 – 60.92) used in the present study.

Color parameters of flour especially the CIE L*, a* and b* values were greatly affected by the drying method, variety and the maturity of the banana fingers (Falade & Oyeyinka, 2015). Generally, dried banana samples showed higher L* value and lower a* and b* values than the fresh banana samples (Chandra *et al*., 2015). Moreover, use of pretreatment methods such as adding ascorbic acid, mixed with water or apply lime juice or salt water to unripe banana before processing into flour may help to reduce the effect of enzymatic browning and improve the color quality (Anyasi *et al*., 2014).

3.2 Chemical properties of the banana flour

The comparison of the results of chemical properties of flour from three different banana varieties is shown in Table 3.

Table 3 Chemical properties of the banana flour

Chemical property	*Ambul*	*Seeni*	Cavendish
pH	5.32±0.01 ^{c}	4.97±0.01 ^{a}	5.08±0.02 ^{b}
Titratable acidity	0.007±0.00 ^{b}	0.005±0.00 ^{a}	0.01±0.00 ^{b}

Data are expressed in mean ± SD of three independent measurements. Values with different superscripts within the same row are significantly different at $p<0.05$.

Table 4 Nutritional and antioxidant properties of the banana flour

Nutritional property	*Ambul*	*Seeni*	Cavendish
Proximate composition of banana flour (g per 100 g Wet Basis (Wb))			
Moisture content	7.10 ± 0.42 ^{a}	7.20 ± 0.00 ^{a}	7.90 ± 0.14 ^{a}
Ash content	2.80 ± 0.28 ^{a}	2.50 ± 0.14 ^{a}	4.60 ± 0.00 ^{b}
Crude fat	0.50 ± 0.23 ^{a}	0.83 ± 0.24 ^{a}	0.66 ± 0.00 ^{a}
Crude protein	0.97 ± 0.01 ^{b}	0.82 ± 0.03 ^{a}	0.97 ± 0.04 ^{bc}
Crude fiber	1.17 ± 0.23 ^{a}	0.67 ± 0.00 ^{a}	0.84 ± 0.23 ^{a}
Carbohydrate	88.64 ± 0.39 ^{b}	88.65 ± 0.39 ^{bc}	85.87 ± 0.39 ^{a}
Antioxidant properties of banana flour			
Total flavanoid content mg QE/100 g	162.20 ±16.26 ^{a}	337.70 ± 31.11 ^{b}	180.70 ± 18.39 ^{a}
Total polyphenol content mg GAE /100 g	30.45 ±0.22 ^{b}	31.41 ± 0.61 ^{b}	14.02 ± 0.26 ^{a}
DPPH radical scavenging activity (mg TE/g)	476.00 ±0.06 ^{ab}	324.00 ±0.04 ^{a}	576.00 ± 0.03 ^{b}
Vitamin C (mg per 100 g sample)	11.20 ± 0.75 ^{a}	10.83 ± 0.12 ^{a}	10.44 ± 0.06 ^{a}

Data are expressed in mean ± SD of three independent measurements. Values with different superscripts within the same row are significantly different at $p<0.05$.

The Organic acids such as malic, citric, and oxalic are the titratable acids found in banana. As per the results in Table 3, Cavendish banana flour had the highest titratable acidity while *Seeni* banana flour had the lowest value. Titratable acidity of flour is important in several baking operations, including leavening, flavor development and product formulation (Cauvain, 2015).

pH is another important parameter which decide the physical and chemical quality of the flour. The water absorption rate, dough formation, and texture of the final product can be influenced by the pH of flour. Flour with a low pH is more acidic, and thus tends to absorb less water, resulting in firmer and drier dough. Conversely, flour with a high pH is more alkaline, and tends to absorb more water, resulting in softer and stickier dough (Hoseney, 1994). Results of the present study confirmed the above-mentioned statement showing that the *Ambul* banana flour had highest pH value as well as higher water absorption capacity. There was a significant difference ($p<0.05$) among pH values of different banana varieties and the results of the present study are in agreement with the previously reported pH values of banana flour, where it ranged between 5.79–6.18 (Bakar *et al*., 2018). Moreover, the study conducted by Bakar *et al*., (2018) showed that the pH levels of banana flour was affected by the stage of ripeness. The pH of banana flour (4.97 ±0.01 - 5.32 ±0.01) was slightly lower than that of reported pH value of wheat flour (6.00 ± 0.00) (Zhang *et al.*, 2021).

3.3. Nutritional and antioxidant properties of the banana flour

The proximate composition and the antioxidant properties of the flour from three banana varieties were also compared and the obtained results are summarized in the Table 4.

3.3.1. Proximate composition of banana flour

The moisture level of food products has a significant impact on the textural quality, chemical and biochemical responses, shelf-life as well as the rates of microbial development (Aurore *et al.*, 2009). The moisture content of banana flours studied in the present study were within the acceptable limits of moisture (<20.0%) to reach a stable shelf-life (Amarasinghe *et al.*, 2021). Further, moisture content of the banana flour in the present study (7.1-7.9%) was lower than the moisture content of wheat flour (10%) in Kumasi-Ashanti region, Ghana (Amankwah *et al.*, 2022) and the moisture content of wheat flour Golden Penny (9.1%) obtained from Minna, Niger (Ocheme *et al.*, 2018). According to Codex Alimentarius standards if the moisture content of a flour is less than 14%, it can resist microbial growth and contribute to longer storage life (Mahloko *et al.*, 2019).

The fat content of the banana flour was ranged in 0.5-0.83 g per 100 g Wb and it is considerably low when compared to that of other common legumes and flours such as pearl millet (7.6%), quinoa (6.3%) (Oshodi *et al*., 1999), pigeon pea flour (1.80%) (Okpala & Mamah, 2001), and wheat flour (3.10%) (Akubor & Badifu, 2004).

Measurement of ash content aims to determine the amount of mineral matter which include in the three different banana varieties. The highest ash content (4.60 g per 100 g Wb) was recorded from Cavendish banana flour while *Seeni* banana flour showed the lowest ash content (2.50 g per 100 g Wb). The deviations between ash contents of banana flour may be due to the differences in the variety and the location. Banana flour showed higher amount of ash content compared to the reported ash content of wheat flour (0.45%) in Kumasi-Ashanti region-Ghana (Amankwah *et al*., 2022).

Considering the crude protein content, both *Ambul* and Cavendish banana flour showed 0.97 g per 100 g Wb protein content while *Seeni* banana flour showed 0.82 g per 100 g Wb protein content. However, the result of the present study was lower than the crude protein content (3.8 - 4.1%) reported by Morton, (1987) for banana flour. The varietal differences, fruit maturation, and environmental factors could be the reasons for showing different crude protein content in different studies. The crude protein content of the wheat flour which were obtained from Kumasi-Ashanti region, Ghana was 10.67% (Amankwah *et al*., 2022), and it was higher compared to the crude protein content of green banana flour.

The highest crude fiber content was showed by *Ambul* banana flour followed by Cavendish and *Seeni* banana flours. The results of present study was lower than the reported value of crude fiber content (4.2 g per 100 g Wb) by Asif-Ul-Alam *et al.*, (2014) for flour obtained from *Musa sapientum*. The disparity may be due to the differences in variety and location. The fiber content of the banana flour was ranged in 0.67-1.11 g per 100 g Wb and it is considerably high amount when compared to the crude fiber content of wheat flour (0.49%), obtained from Kumasi-Ashanti region, Ghana (Amankwah *et al.*, 2022).

The major component of the flour was carbohydrate, and the values obtained from the present study were in a range of 85.87-88.65 g per 100 g Wb. These values are comparably high to those reported by Morton, (1987) which was 79.6% for green banana flour. When comparing the carbohydrate contents of banana flour and wheat flour, banana flour had higher carbohydrate content (85.87- 88.65 g per 100 g Wb) than wheat flour (76.51%), obtained from Kumasi-Ashanti region, Ghana (Amankwah *et al.*, 2022), and wheat flour - Golden Penny (72.73%) which was obtained from Minna, Niger (Ocheme *et al.*, 2018). The high carbohydrate content of banana flour suggests that it is a suitable source of energy for humans to consume, particularly in breakfast and weaning formulas.

3.3.2. Antioxidant properties of banana flour

Antioxidants are indispensable to protect the human cells from the negative health effects such as cancer, inflammation, diabetic, and cardiovascular disease (Sulastri *et al.*, 2018). Phenols are one of the most common phyto-constituents of different fruits and vegetables which directly related to their antioxidant properties. Free radicals can be scavenged by phenolic compounds, which can serve as hydrogen donors and reducing agents (Phuyal *et al.*, 2020). The total polyphenol content (TPC) of the tested banana flours were ranged from 14.02 to 31.41 mg GAE/100 g of dry matter (Table 4). The TPC indicated significant variations across all samples ($p<0.05$). The study conducted by Fatemeh *et al.*, (2012) reported that dream banana flour showed 94.25 mg CEQ/100 g TPC value. These results are slightly higher than the results of TPC of banana flours in the present study which could be due to the difference in variety, maturity stage, growing conditions, and climate variations.

The total flavonoid content (TFC) of different types of banana flour exhibit significant difference ($p<0.05$) where the *Seeni* banana flour had the highest TFC (337.70 mg QE/100 g), while the *Ambul* banana flour had the lowest TFC (162.20 mg QE/100 g). The primary flavonoids that can be found in bananas are quercetin, myricetin, and kaempferol (Amarasinghe *et al.*, 2021). Some studies have shown that the banana flour had higher TFC compared to wheat flour (Amarasinghe *et al.*, 2021).

The results of the DPPH radical scavenging activity showed that there were significant differences ($p<0.05$) among the antioxidant activity of different types of banana flour (Table 4). The Cavendish banana flour had the highest DPPH radical scavenging activity (576 ± 0.03 TE mg/g), while the *Seeni* banana flour had the lowest (324 ± 0.04 TE mg/g). Studies by Pasko *et al.*, (2009) and Kim *et al.*, (2013) have investigated the DPPH radical scavenging activity of different types of wheat flour and reported that it was ranged from 0.50 to 2.8 TE mg/g depending on the variety. Further, Kim *et al*. (2013) found that red wheat flour had DPPH activity ranged from 2.2 to 5.5 TE mg/g. The results of the present study showed that green banana flour had a higher antioxidant activity compared to wheat flour. Moreover, Mahloko *et al.* (2019) stated that antioxidant capacity of flour may decrease, during baking due to reactions such as polymerization. However, they mentioned that the microwave roasting and baking both can improve the antioxidant activity of baked goods.

Vitamin C is one of the abundant nutrients present in banana. It is a thermal sensitive vitamin and can be easily destroyed by any heat treatment. Generally, edible bananas contain 11 mg of vitamin C per 100 g of the fresh sample (Ndayambaje *et al*., 2019). In the present study, vitamin C content of green banana flour range in 10.44 to 11.20 mg/100 g Wb of sample. The vitamin C content in wheat flour (Golden penny) was reported as 0.0924 mg/g (Abdulkadir, 2014) and green banana flour showed comparatively higher amount of vitamin C content than wheat flour. The highest vitamin C content showed by *Ambul* banana flour (11.20 mg/100 g Wb) while the lowest vitamin C content showed by Cavendish banana flour (10.44 mg/100 g Wb). Mallawaarchchi *et al*., (2021) reported that the vitamin C content of ripen *Seeni* banana was 3.13 mg/100 g, and it was lower than the vitamin C content of raw *Seeni* banana flour (10.83 mg/100 g) found in the present study.

4. Conclusions

The present study aims to characterize the physico-functional, chemical, nutritional and antioxidant properties of green banana flour. The green banana flour has good potential to be developed as an alternative to wheat flour and successful way of minimizing the post-harvest losses. It can be concluded that the green banana flour is an excellent source of antioxidants and good source of carbohydrates. *Seeni* banana flour had the highest polyphenol and flavonoid content while Cavendish banana flour had the highest antioxidant content. Comparing the three different banana flours, *Ambul* banana showed the highest nutritional properties and antioxidant activity. Bulk density and tapped density of banana flours were quite similar to that of the wheat flours. The present study revealed that banana flour has a greater potential to be used as a functional ingredient in food formulations especially in bakery industry.

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