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COMPARATIVE EVALUATION OF PROXIMATE COMPOSITION AND PHYTOCHEMICAL PROPERTIES OF BANANA, MANGO, AND PAPAYA PULP AND PEEL

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Abstract

This study evaluated the proximate composition and phytochemical properties of the pulp and peel of banana (Musa spp.), mango (Mangifera indica L.), and papaya (Carica papaya L.). Proximate parameters, including moisture, ash, fat, protein, and carbohydrates, along with functional characteristics based on total phenolic content (TPC), total flavonoid content (TFC), and antioxidant capacity measured by ferric reducing antioxidant power (FRAP), were analyzed in samples from local agri-food markets. Results showed significant differences between peel and pulp in both composition and functional properties, highlighting their nutritional and health potential. Antioxidant activity was consistently higher in peels than in pulps, with mango peel exhibiting the highest value (166.89 μM Fe^{2+}/g d.w.). TPC and TFC followed a similar trend, with peels showing higher concentrations than edible fractions. These findings suggest that fruit peels are rich sources of natural antioxidants and have potential as functional ingredients, supporting the sustainable valorization of fruit-processing by-products for food and nutraceutical applications.

Key words*: banana, mango and papaya, by-products, functional properties, peel and pulp, proximate composition.*

INTRODUCTION

Fruits play a fundamental role in human nutrition due to their rich content of essential nutrients and bioactive compounds, contributing significantly to the prevention of chronic diseases and the promotion of overall health. Among tropical fruits, banana (*Musa spp.*), mango (*Mangifera indica* L.), and papaya (*Carica papaya* L.) are widely cultivated and consumed worldwide, owing to their sensory attributes, nutritional value, and economic importance (FAO, 2022; Slavin et al., 2012). These fruits are commonly consumed fresh or processed into juices, purees, dried products, jams, and other value-added foods, generating substantial quantities of by-products, particularly peels, which are often discarded as waste.

Banana is one of the most consumed fruits globally and represents a major staple food in many developing countries. It is a valuable source of carbohydrates, dietary fiber, potassium, vitamins, and bioactive compounds that support digestive health, cardiovascular function, and energy metabolism (Anyasi et al., 2013; Wall, 2006).

Mango, commonly referred to as the "king of fruits," is appreciated for its pleasant flavor and aroma and is recognized for its high content of vitamins A and C, sugars, minerals, and phenolic compounds with antioxidant and anti-inflammatory activities (Masibo et al., 2009). Papaya is valued not only for its nutritional quality but also for its medicinal properties, being rich in vitamin C, carotenoids, dietary fiber, and proteolytic enzymes such as papain, which contribute to digestive health and anti-inflammatory effects (Aravind et al., 2013; Rivera-Pastrana et al., 2010).

The nutritional and functional properties of fruits are mainly attributed to their proximate composition (moisture, proteins, fats, carbohydrates, ash, and fiber) as well as their phytochemical constituents, including phenolic

acids, flavonoids, carotenoids, and other antioxidant compounds. Numerous studies have demonstrated that regular consumption of fruits rich in antioxidants is associated with a reduced risk of oxidative stress-related diseases, such as cardiovascular disorders, diabetes, cancer, and neurodegenerative conditions (Liu, 2013; Shahidi et al., 2015). As a result, there is growing scientific and industrial interest in identifying new natural sources of bioactive compounds that can be used in functional foods, nutraceuticals, and pharmaceutical products.

In recent years, attention has increasingly shifted toward fruit-processing by-products, particularly peels, which are produced in large quantities during industrial processing and household consumption. Fruit peels are often considered waste and disposed of, leading to environmental concerns and economic losses. However, emerging evidence suggests that these by-products contain significant amounts of valuable nutrients and phytochemicals, often in higher concentrations than the edible pulp (Ayala-Zavala et al., 2011; Ajila et al., 2010). The sustainable valorization of fruit peels aligns with the principles of circular economy and waste reduction, promoting the efficient use of natural resources while generating added-value products.

Banana peel, which accounts for approximately 30-40% of the total fruit weight, has been reported to contain appreciable levels of dietary fiber, starch, proteins, essential minerals, and phenolic compounds with strong antioxidant activity (Emaga et al., 2008; Emaga et al., 2011). Studies have shown that banana peel extracts exhibit antioxidant, antimicrobial, and anti-inflammatory properties, supporting their potential use as functional ingredients in food formulations and animal feed (Vu et al., 2018; Pereira et al., 2015).

Similarly, mango peel represents about 15–20% of the fruit weight and is considered a rich source of polyphenols, flavonoids, carotenoids, and dietary fiber, often surpassing the pulp in antioxidant capacity (Ajila et al., 2010; Berardini et al., 2005). Mango peel extracts have demonstrated strong free radical scavenging activity and have been proposed for use as natural antioxidants and colorants in food and cosmetic industries (Macedo et al., 2022).

Papaya peel, though less extensively studied than banana and mango peels, has also been identified as a promising source of bioactive compounds. Research indicates that papaya peel contains phenolic compounds, flavonoids, carotenoids, and dietary fiber, contributing to its antioxidant and antimicrobial properties (Calvache et al., 2016; Nwofia et al., 2012). The presence of these compounds suggests that papaya peel may be exploited as a functional ingredient or as a raw material for the extraction of nutraceutical compounds.

The chemical composition and bioactive potential of fruit pulps and peels can vary significantly depending on species, cultivar, maturity stage, climatic conditions, soil type, agricultural practices, and post-harvest handling (Kader, 2008). Moreover, differences between pulp and peel composition highlight the importance of comparative evaluations to fully understand the nutritional and functional potential of each fruit fraction.

Several studies have reported that fruit peels generally contain higher concentrations of total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activity compared to pulps, emphasizing their underutilized value (Ayala-Zavala et al., 2011; Shahidi et al., 2015). Despite increasing evidence on the nutritional richness of fruit peels, their utilization in food systems remains limited, mainly due to a lack of comprehensive compositional data, consumer acceptance issues, and technological challenges. Comparative studies that simultaneously assess proximate composition and phytochemical properties of both pulp and peel across different fruit species are essential to support their effective valorization. Such studies provide scientific justification for incorporating fruit by-products into functional foods, dietary supplements, and natural antioxidant formulations.

In this context, the present study aims to comparatively evaluate the proximate composition and phytochemical properties of the pulp and peel of banana (*Musa* spp.), mango (*Mangifera indica* L.), and papaya (*Carica papaya* L.) collected from local agri-food markets. The analysis focuses on key nutritional parameters, including moisture, ash, fat, protein, and carbohydrate content, as well as functional characteristics based on total phenolic content, total flavonoid content, and antioxidant capacity assessed by ferric reducing antioxidant power (FRAP).

By highlighting the differences between edible and non-edible fractions, this study seeks to contribute to the growing body of knowledge supporting the sustainable utilization of fruit-processing by-products as valuable sources of natural antioxidants and functional ingredients for food and nutraceutical applications.

MATERIALS AND METHODS

Three types of tropical fruit: banana (*Musa* spp.), mango (*Mangifera indica* L.), and papaya (*Carica papaya* L.) were collected from various local agri-food markets (Timisoara, Romania), in three batches, two weeks apart between collections. For further analysis, banana, mango, and papaya were coded as B, M, and P, respectively.

The ripe fruits were washed in tap water, dried with paper towel, and subsequently separated into peels, pulps, and seeds. The pulp and raw peel of each fruit variety were vacuum-sealed in separate polyethylene bags and stored at -18°C pending analysis. These samples were used for proximate analysis (moisture, ash content, fat, protein, and carbohydrates) and for determining phytochemical properties (total phenolic content – TPC, expressed as gallic acid equivalents, total flavonoid content – TFC, expressed as quercetin equivalents, and antioxidant capacity assessed by ferric reducing antioxidant power, FRAP).

All reagents used for the chemical analyses were of analytical grade and were purchased from three primary suppliers: Merck (Darmstadt, Germany) for the Folin-Ciocalteu reagent and sodium carbonate; Sigma-Aldrich (Taufkirchen, Germany) for antioxidant standards (gallic acid, quercitin, trolox), and inorganic reagents; and Amex-Lab (Bucharest, Romania) for 70% ethanol. To ensure statistical reliability, all measurements were performed in triplicate for every sampling interval.

Proximate analysis

Proximate composition was determined in accordance with the protocols established by the Association of Official Analytical Chemists (AOAC, 2000). Thus, samples were dried at 103±2°C to a constant weight to evaluate moisture content, while ash content was determined by incinerating samples in a muffle furnace at 550°C for about 4-hour duration.

Additionally, crude protein and fat content were measured using the Kjeldahl and Soxhlet extraction (using petroleum ether) methods, respectively.

The total carbohydrate content was derived by difference using the following formula:

Carbohydrate (%) = 100 – (% moisture + % crude protein + % ash + % crude fat)

The energy value was computed using the methodology of Das et al. (2019), considering that 1 g of fat provides 9 calories, 1 g of carbohydrates provides 4 calories and 1 g of protein provides 4 calories.

Energy value (kcal/100 g) = carbohydrates (%) x 4 + lipids (%) x 9 + proteins (%) x 4

Preparation of the antioxidant extracts

2 g of ground sample were treated with 20 mL 70% (v/v) ethanol for 120 minutes in a constant temperature chamber (25°C) under continuous stirring using a Heidolph Promax 1020 (Germany) shaker. After extraction, the samples were filtered and the extract was used to determine the total phenolic content – TPC (expressed as gallic acid equivalents), total flavonoid content – TFC (expressed as quercetin equivalents), and antioxidant capacity assessed by ferric reducing antioxidant power, FRAP.

Evaluation of total phenolic content (TPC)

Total phenolic content – TPC was quantified via the Folin-Ciocalteu assay. Extracts were first diluted (1:10 v/v) in distilled water; subsequently, 0.5 mL of the sample was reacted with 2.5 mL of Folin-Ciocalteu reagent (1:10 v/v) and 2 mL of 7.5% sodium carbonate. After incubating for 30 minutes at 50°C, the absorbance at 750 nm was measured. A gallic acid standard curve (prepared using standard solutions with concentrations ranging from 0.1 to 1.0 µM GAE/mL) was used to calculate TPC, which was reported as mg GAE/100 g d.w. for both pulp and peel samples.

Evaluation of total flavonoid content (TFC)

Total flavonoids were measured using the aluminum nitrate colorimetric method. The reaction involved sequential additions of 0.3% sodium nitrite, 10% aluminum nitrate, and 4%

sodium hydroxide to the sample extract. Following volume adjustment to 25.0 mL and a 15-minute stabilized reaction period, the absorbance was read at 510 nm (UV-VIS spectrophotometer). Results were normalized to dry weight (mg QE/100 g d.w.) based on a quercetin calibration curve prepared using standard solutions with concentrations ranging from 0.5 to 50 µg/mL.

Assessment of antioxidant activity by ferric-reducing antioxidant power (FRAP) assay

Antioxidant capacity was determined by the FRAP method, based on the electron-donating ability of the extracts to reduce Fe^{3+} to Fe^{2+}. The working reagent consisted of acetate buffer (300 mM, pH 3.6), 10 mM tripyridyltriazine (TPTZ), and 20 mM ferric chloride in a 10:1:1 (v/v/v) ratio. Aliquots of the 1:10 (v/v) diluted extracts (0.5 mL) were mixed with 2.5 mL of the FRAP solution and incubated at 37°C for 30 minutes. The chromogenic reaction was monitored at 593 nm using UV-VIS spectrophotometer. Antioxidant activity was quantified using a ferrous sulfate standard curve and normalized to the dry weight of the pulp and peel samples. Results were calculated as µM Fe^{2+}/g d.w.

Statistical analysis

Data were collected from three independent batches, each performed in triplicate. Results are presented as the mean ± standard deviation (SD). Statistical evaluation was performed using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test for multiple comparisons and Levene's test to assess variance equality. Variations in the evaluated parameters among the three fruit types were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSIONS

Proximate composition of banana, mango and papaya pulp and peel

Table 1 presents the proximate composition and calculated energy value of banana (B), mango (M) and papaya (P) pulp and peel. Significant differences ($p < 0.05$) were observed among fruits within each group (pulp or peel), indicating distinct compositional characteristics between species and anatomical fractions.

Table 1. Proximate composition and energy value of the investigated fruit pulp and peel samples

Sample	Moisture (%)	Ash (%)	Crude protein (%)	Crude fat (%)	Carbohydrates (%)	Energy value (kcal/100 g)
B pulp	73.212 ± 0.011 ^{c}	1.980 ± 0.010 ^{a}	1.172 ± 0.013 ^{b}	0.440 ± 0.011 ^{a}	23.196±0.012^{a}	101.432 ± 0.030 ^{a}
M pulp	87.090 ± 0.023 ^{b}	0.330 ± 0.011 ^{c}	1.255 ± 0.015 ^{a}	0.074 ± 0.012 ^{c}	11.251±0.019^{b}	50.690 ± 0.095 ^{b}
P pulp	88.693 ± 0.044 ^{a}	0.430 ± 0.028 ^{b}	0.736 ± 0.011 ^{c}	0.162 ± 0.010 ^{b}	9.979±0.065^{c}	44.318 ± 0.032 ^{c}
B peel	88.156 ± 0.013 ^{a}	1.700 ± 0.012 ^{a}	1.127 ± 0.010 ^{c}	0.643 ± 0.011 ^{b}	8.374±0.013^{c}	43.791 ± 0.096 ^{c}
M peel	81.151 ± 0.041 ^{b}	0.901 ± 0.018 ^{c}	1.634 ± 0.019 ^{b}	2.466 ± 0.012 ^{a}	13.848±0.115 ^{b}	84.122 ± 0.013 ^{b}
P peel	77.260 ± 0.059 ^{c}	1.493 ± 0.012 ^{b}	4.592 ± 0.055 ^{a}	0.518 ± 0.010 ^{c}	16.237 ± 0.103 ^{a}	87.578 ± 0.044 ^{a}

B: banana; M: mango; P: papaya. Data are expressed as mean ± standard deviation of three independent analyses (n = 3). Within each column group (pulp or peel), values followed by different letters are significantly different among fruits (one-way ANOVA, $p < 0.05$)

Among pulps, papaya showed the highest moisture content (88.693%), followed by mango (87.090%) and banana (73.212%).

The lower moisture content of banana pulp may be associated with its higher carbohydrate accumulation during ripening, which contributes to a denser matrix and greater dry matter content.

The pulp moisture values are consistent with those reported in food composition databases such as TACO, which indicate moisture contents of approximately 73-75% for banana, 85-88% for mango and 88-90% for papaya pulps. Similar values were also reported by Morais et al. (2017) and Forster et al. (2003) for banana pulp (73.6%), respectively (71.94%). Papaya pulp humidity values determined in this experiment are comparable to those determined by Morais et al. (2017) (87.8%), confirming the reliability of the present results. For peels, banana peel exhibited the highest moisture content (88.156%), followed by mango (81.151%) and papaya (77.260%). These findings agree with Emaga et al. (2008), who reported high moisture content levels in banana peel (~85-90%). High moisture levels in peels indicate susceptibility to microbial spoilage,

reinforcing the need for drying or stabilization processes before industrial application.

Ash values, which reflect total mineral content, were significantly different among samples. In pulps, banana presented the highest ash content (1.980%), while mango (0.330%) and papaya (0.430%) showed lower values.

These values are comparable to those reported in the literature for banana pulp (1.18-3.89%) (Nadeeshani et al., 2021), mango pulp (0.31-0.66%) (Ubwa et al., 2014), and papaya pulp (0.31-0.61%) (Nwofia et al., 2012), where banana pulp typically contains higher mineral concentrations than mango and papaya pulps.

In peels, banana (1.7%) and papaya (1.493%) exhibited higher ash contents compared to mango peel (0.901%). Similar observations have been reported by Emaga et al. (2008) for banana peel and by other researchers evaluating mango and papaya processing residues. The relatively elevated ash content in peels suggests their potential as mineral-rich ingredients for food fortification or animal feed applications.

Protein levels in pulps were generally low, as expected for fruits. Mango pulp showed the highest protein content (1.255%), followed by banana (1.172%) and papaya (0.736%). These values are consistent with previously reported ranges: 0.5-1.4% for banana, 0.5-1.0% for papaya, and approximately 0.8-1.3% for mango pulp.

In contrast, peels, particularly papaya peel, presented higher protein levels. Papaya peel contained 4.592% protein, significantly higher than mango (1.634%) and banana (1.127%) peels.

Comparable findings have been reported for papaya peel by several authors, who described protein values ranging between 3-11%, namely 3.5% (Akintunde et al., 2022), 6.1% (Maisarah et al., 2014), and 10.51% (Mukta et al., 2025).

This indicates that papaya peel may represent a more promising protein source among the evaluated by-products.

Fat content in pulps was low, ranging from 0.074% (mango) to 0.440% (banana), consistent with literature data describing these fruits as low-lipid foods. Similar values have been documented for banana pulp, with contents ranging from 0.1-1.7% (Morais et al., 2017), mango pulp (0.06-0.16%) (Ubwa et al., 2014), and papaya pulp (0.14-0.53%) (Nwofia et al., 2012).

Peels showed more variability. Mango peel exhibited the highest fat content (2.466%), followed by banana (0.643%) and papaya (0.518%). Previous studies on mango peel have also reported lipid values between 2.0-2.56% (Tokas et al., 2020), which may be attributed to the presence of cuticular waxes and bioactive lipid fractions. The higher content of mango peel contributes to its increased caloric value relative to the other peels.

Carbohydrates were calculated by difference and represented the major macronutrient fraction in all pulps. Banana pulp showed the highest carbohydrate content (23.196%), significantly higher than mango (11.251%) and papaya (9.979%). This aligns with existing data indicating banana as a carbohydrate-rich fruit, particularly due to starch-to-sugar conversion during ripening.

In peels, papaya peel presented the highest carbohydrate content (16.237%), followed by mango (13.848%) and banana (8.374%). Literature reports similarly indicate that fruit peels can contain substantial amounts of structural carbohydrates, including dietary fibre and non-starch polysaccharides (Ismail et al., 2024).

The energy value reflected the macronutrient composition. Banana pulp presented the highest caloric value (101.432 kcal/100 g), approximately double that of mango (50.690 kcal/100 g) and papaya (44.318 kcal/100 g). These values are in line with commonly reported energy values for banana (approximately 89-105 kcal/100 g), mango (56-60 kcal/100 g), and papaya (40-45 kcal/100 g), according to the USDA FoodData Central database.

For peels, papaya (87.578 kcal/100 g) and mango (84.122 kcal/100 g) showed higher energy values than banana peel (43.791 kcal/100 g). The higher caloric values of mango and papaya peels are associated with their higher protein, lipid and carbohydrate contents. These findings support previous studies highlighting the nutritional potential of fruit by-products as alternative ingredients in functional foods or feed formulations (Zou et al., 2022; Tewari et al., 2025; Nitisuk et al., 2025).

In general, pulps were characterized by higher moisture and lower ash, protein and fat contents, while peels exhibited greater concentrations of minerals, proteins (notably papaya peel), and in

some cases lipids (mango peel). Banana pulp stood out for its higher carbohydrate and energy values, whereas papaya peel demonstrated superior protein and carbohydrate levels among the by-products.

These results are consistent with previously published data on banana, mango and papaya fractions, confirming that fruit processing residues, especially peels, retain considerable nutritional value. The compositional differences observed highlight the potential for valorisation of these by-products in food, nutraceutical or animal feed applications, contributing to waste reduction and sustainable agro-industrial practices.

Phytochemical properties of banana, mango and papaya pulp and peel

The phytochemical characteristics of B, M, and P (pulps and peels) are presented in Figures 1–3. Significant differences ($p < 0.05$) were observed among fruits within each anatomical fraction (pulp and peel), indicating that both species and fruit part strongly influence bioactive compound content and antioxidant capacity.

Among pulps, mango exhibited the highest TPC (1,363.091 mg GAE/100 g d.w.), followed by papaya (1,061.433 mg GAE/100 g d.w.) and banana (698.994 mg GAE/100 g d.w.). The elevated TPC of mango pulp is consistent with previous findings. Kim et al. (2010) reported TPC values for mango pulp ranging between 900 and 1,500 mg GAE/100 g d.w., depending on cultivar and ripening stage. Similarly, Maisuthisakul et al. (2007) observed that mango pulp possesses higher phenolic concentrations compared to several other tropical fruits. Banana pulp TPC values reported in the literature (Maisuthisakul et al., 2007) typically range from 500 to 900 mg GAE/100 g d.w., which aligns with those obtained in the present study.

Papaya pulp phenolic content has been reported between 800 and 1,200 mg GAE/100 g d.w. (Oloyede, 2005), which is consistent with the obtained data.

For peels, significantly higher TPC values were observed compared to pulps. Mango peel showed the highest value (2,442.065 mg GAE/100 g d.w.), followed by banana (1,605.081 mg GAE/100 g d.w.) and papaya (1,264.272 mg GAR/100 g d.w.) (Figure 1). These findings agree with Ajila et al. (2007), who reported mango peel TPC values ranging from 2,000 to 4,500 mg GAE/100 g d.w., emphasizing the richness of mango peel in phenolic acids and flavonoids. Emaga et al. (2008) also reported high phenolic levels in banana peel (approximately 1,500–2,500 mg GAE/100 g d.w.), which are similar to the current results.

The higher phenolic concentration in peels compared to pulps reflects the protective function of phenolic compounds in fruit outer tissues, where they act as defence molecules against environmental stress.

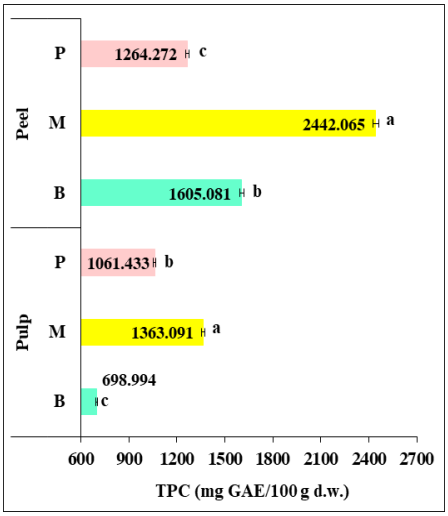

Figure 1. Total phenolic content (TPC) in the investigated fruit samples (pulp and peel). B: banana; M: mango; P: papaya. Data are expressed as mean ± standard deviation of three independent analyses (n = 3). Different letters above the columns indicate significant differences within the same group (pulp or peel) according to one-way ANOVA ($p < 0.05$)

A similar trend was observed for TFC. Mango pulp presented the highest value (631.767 mg QE/100 g d.w.), followed by papaya (497.471 mg QE/100 g d.w.) and banana (321.226 mg QE/100 g d.w.). These results are consistent with reports by Maisuthisakul et al. (2007), who found mango pulp flavonoid content significantly higher than banana and papaya.

In peel samples, mango peel again exhibited the highest TFC (1,058.748 mg QE/100 g d.w.), followed by banana (762.231 mg QE/100 g d.w.) and papaya (669.251 mg QE/100 g d.w.) (Figure 2). Ajila et al. (2007) and Larrauri et al.

(1996) also reported elevated flavonoid concentrations in mango peel due to the presence of quercetin, kaempferol and catechin derivates.
The consistently higher TFC values in peels reinforce their potential as sources of natural antioxidants for functional food formulations.

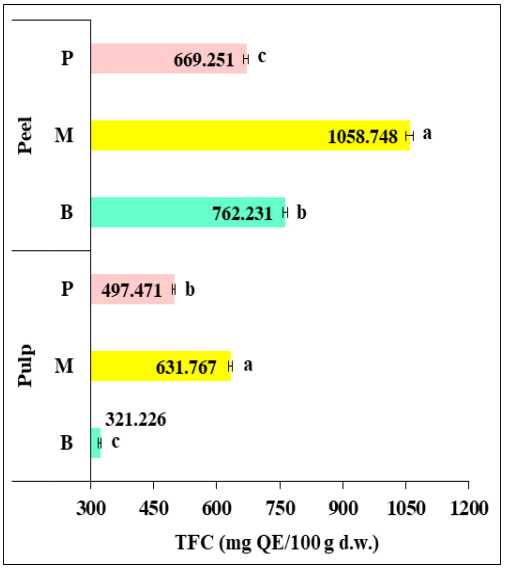

Figure 2. Total flavonoid content (TFC) in the investigated fruit samples (pulp and peel). B: banana; M: mango; P: papaya. Data are presented as mean ± standard deviation of three independent analyses (n = 3). Different letters above the columns indicate significant differences within each group (pulp or peel) according to one-way ANOVA ($p < 0.05$)

The antioxidant capacity measured by FRAP followed the same general pattern as TPC and TFC. Mango pulp showed the highest FRAP value (95.882 µM Fe^{2+}/g d.w.), followed by banana (59.574 µM Fe^{2+}/g d.w.) and papaya (41.635 µM Fe^{2+}/g d.w.). These results are comparable with those reported by Thaipong et al. (2006), who observed FRAP values in mango pulp between 50 and 120 µM Fe^{2+}/g d.w., depending on cultivar.
For peels, mango (166.894 µM Fe^{2+}/g d.w.) and banana (150.569 µM Fe^{2+}/g d.w.) exhibited significantly higher antioxidant capacity than papaya peel (48.788 µM Fe^{2+}/g d.w.). Similar trends were reported by Emaga et al. (2008) and Ajila et al. (2007), who demonstrated strong antioxidant activity in mango and banana peels due to their elevated phenolic and flavonoid concentrations (Figure 3).

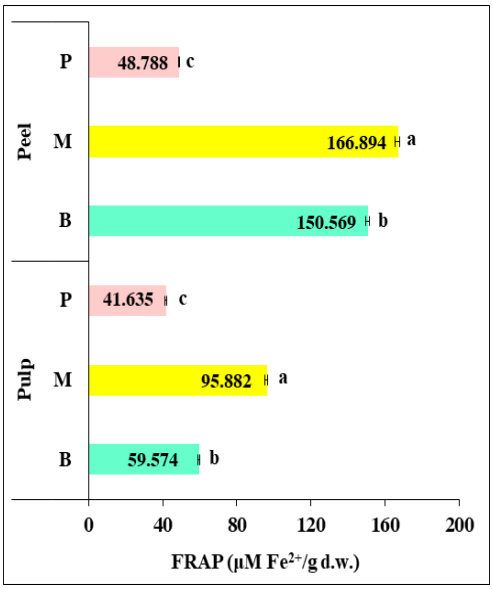

Figure 3. Antioxidant activity (FRAP assay) in the investigated fruit samples (pulp and peel). B: banana; M: mango; P: papaya. Data are presented as mean ± standard deviation (n = 3). Different letters above the columns indicate significant differences within each group (pulp or peel) according to one-way ANOVA ($p < 0.05$)

The similar trends observed between TPC and FRAP, as well as between TFC and FRAP, indicate that both total phenolics and flavonoids may contribute to antioxidant capacity, as previously reported in other plant-origin matrices (Metzner Ungureanu et al., 2020). The increased TPC and TFC contents in the fruit fractions are closely associated with their improved FRAP antioxidant capacity. This pattern further supports the role of phenolic compounds as major contributors to the overall reducing power of plant materials, in agreement with the findings of Poiana et al. (2023), who also reported a strong relationship between total phenolic content and antioxidant activity.
In all investigated fruits, peel samples exhibited significantly higher TPC, TFC, and FRAP values compared to pulp samples ($p < 0.05$). Mango peel was identified as the richest source of bioactive compounds, followed by banana peel and papaya peel. Among pulps, mango pulp exhibited superior phytochemical and antioxidant properties.
These findings are in agreement with previous literature demonstrating that fruit processing by-products, particularly peels, contain higher

concentrations of phenolic compounds than edible pulp fractions (Islam et al., 2021; Rodrigues-Rodrigues et al., 2026; Ismail et al., 2024). The results highlight the potential of banana, mango and papaya peels as low-cost sources of natural antioxidants for nutraceutical, pharmaceutical and food industry applications.
The valorisation of these by-products may contribute to waste reduction and to the development of functional ingredients with enhanced health-promoting properties.

Potential applications of banana, mango and papaya pulp and peel

The compositional and phytochemical profiles obtained in this study highlight the significant potential of both pulp and peel fractions for various industrial and nutritional applications. The observed differences between fruit parts suggest that each fraction may be better suited for specific valorization pathway.
The high carbohydrate content and energy value of banana pulp indicate its suitability as an energy-rich ingredient in food formulations such as purees, beverages, and bakery products. In contrast, mango and papaya pulps, characterized by higher moisture and lower caloric content, may be more appropriate for low-energy or refreshing food products, including juices and functional beverages.
Fruit peels, often considered agro-industrial waste, demonstrated higher concentrations of ash, protein (particular in papaya peel), and bioactive compounds (phenolics and flavonoids), as well as stronger antioxidant activity. These characteristics make them promising candidates for incorporation into functional foods as natural sources of dietary fiber and antioxidants. For instance, mango peel, which exhibited the highest total phenolic and flavonoid contents, could be used as a natural antioxidant extract to enhance the shelf life and nutritional quality of food products.
Also, banana peel, with its appreciable fiber and phenolic content, may be utilized in the development of fiber-enriched flours or as an ingredient in bakery products. Previous studies (Ahmed et al., 2021; Ismail et al., 2024; Weshah, 2026) have demonstrated successful incorporation of banana peel flour into bread and biscuits, improving both nutritional value and capacity.
Papaya peel, characterized by its relatively high protein and carbohydrate content, also presents potential for use in animal feed formulations, contributing to both energy and nutrient supply. In addition, its bioactive profile suggests possible applications in nutraceutical formulations.
The high antioxidant activity observed in peel fractions, particularly mango and banana, supports their use as natural alternatives to synthetic antioxidants in food preservation systems. This is increasingly important given consumer demand for clean-label products.
The results emphasize that fruit peels should not be regarded as waste but rather as valuable raw materials for the development of functional ingredients, nutraceuticals, and sustainable food products. These potential applications place our analytical findings into a broader applied context and highlights the relevance of fruit by-products in sustainable food systems and waste valorization strategies. The valorization of these by-products aligns with current trends in circular economy and sustainable agro-industrial practices, contributing to waste reduction and added economic value.

CONCLUSIONS

The results of the present study demonstrate that both pulp and peel fraction of banana, mango and papaya possess distinct and valuable nutritional and phytochemical characteristics. Significant differences ($p < 0.05$) were observed among fruit species and anatomical fractions, confirming that both botanical origin and fruit part strongly influence proximate composition and antioxidant potential. The findings confirm that fruit processing by-products, particularly peels, retain considerable nutritional and functional value. Their elevated mineral, protein (notably in papaya peel), lipid (in mango peel), and phenolic contents highlight their potential for valorization as functional food ingredients, natural antioxidants, nutraceutical raw materials, or components in animal feed formulations. In this context, the present research addresses the broader challenge of managing fruit processing residues, emphasizing their potential integration into sustainable production systems. The recovery and utilization of banana, mango and papaya peels represent a sustainable strategy for waste reduction and the develop-

ment of value-added products, supporting resource efficiency and the advancement of circular economy principles within the agro-industrial sector.

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REFERENCES

Ahmed, Z., El-Sharnouby, G. A., & El-Waseif, M. A. (2021). Use of banana peel as a by-product to increase the nutritive value of the cake. *Journal of Food and Dairy Sciences*, *12*(4), 87–97.

Ajila, C. M., Naidu, K. A., Bhat, S. G., & Rao, U. P. (2007). Bioactive compounds and antioxidant potential of mango peel extract. *Food chemistry, 105*(3), 982–988.

Ajila, C. M., Aalami, M., Leelavathi, K., & Rao, U. P. (2010). Mango peel powder: A potential source of antioxidant and dietary fiber in macaroni preparations. *Innovative Food Science & Emerging Technologies, 11*(1), 219–224.

Akintunde, A. O., Kolu, P., Akintunde, I. A., Adewole, S. A., Akinboye, O. E., Afodu, O. J., & Shobo, B. A. (2022). Evaluation of the nutritive values of Carica papaya fruit peels as a potential ingredient in livestock nutrition. *Animal Production, 24*(2), 104–113.

Anyasi, T. A., Jideani, A. I., & Mchau, G. R. (2013). Functional properties and postharvest utilization of commercial and noncommercial banana cultivars. *Comprehensive Reviews in Food Science and Food Safety, 12*(5), 509–522.

AOAC (2000). Official Methods of Analysis, Association of Official Analytical Chemist. EUA.

Aravind, G., Bhowmik, D., Duraivel, S., & Harish, G. (2013). Traditional and medicinal uses of Carica papaya. *Journal of Medicinal Plants Studies, 1*(1), 7–15.

Ayala-Zavala, J. F. N., Vega-Vega, V., Rosas-Domínguez, C., Palafox-Carlos, H., Villa-Rodriguez, J. A., Siddiqui, M. W., & González-Aguilar, G. A. (2011). Agro-industrial potential of exotic fruit byproducts as a source of food additives. *Food Research International, 44*(7), 1866–1874.

Berardini, N., Knödler, M., Schieber, A., & Carle, R. (2005). Utilization of mango peels as a source of pectin and polyphenolics. *Innovative Food Science & Emerging Technologies, 6*(4), 442–452.

Calvache, J. N., Cueto, M., Farroni, A., de Escalada Pla, M., & Gerschenson, L. N. (2016). Antioxidant characterization of new dietary fiber concentrates from papaya pulp and peel (*Carica papaya* L.). *Journal of Functional Foods, 27*, 319–328.

Das, P. C., Khan, M. J., Rahman, M. S., Majumder, S., & Islam, M. N. (2019). Comparison of the physico-chemical and functional properties of mango kernel flour with wheat flour and development of mango kernel flour based composite cakes. *NFS Journal, 17*, 1–7.

Emaga, T. H., Robert, C., Ronkart, S. N., Wathelet, B., & Paquot, M. (2008). Dietary fibre components and pectin chemical features of peels during ripening in banana and plantain varieties. *Bioresource Technology, 99*(10), 4346–4354.

Emaga, T. H., Bindelle, J., Agneesens, R., Buldgen, A., Wathelet, B., & Paquot, M. (2011). Ripening influences banana and plantain peels composition and energy content. *Tropical animal health and production, 43*(1), 171–177.

FAO. (2022). FAOSTAT statistical database. Food and Agriculture Organization of the United Nations.

FDA. (2019). FoodData Central. United States Department of Agriculture, Agricultural Research Service.

Forster, M., Rodríguez Rodríguez, E., Darias Martín, J., & Díaz Romero, C. (2003). Distribution of nutrients in edible banana pulp. *Food Technology and Biotechnology, 41*(2), 167–171.

Instituto Brasileiro de Geografia e Estatística (IBGE). (2011). *Tabela brasileira de composição de alimentos* (TACO), 4ª ed. NEPA–UNICAMP.

Islam, M. R., Haque, A. R., Kabir, M. R., Hasan, M. M., Khushe, K. J., & Hasan, S. K. (2021). Fruit by-products: the potential natural sources of antioxidants and α-glucosidase inhibitors. *Journal of food science and technology*, *58*(5), 1715–1726.

Ismail, S., Dubey, P. K., Mishra, A. A., & Ashka, F. (2024). Valorisation of banana peel and mango peel as functional ingredients in baked products: A review. *International Journal of Food Science and Technology, 59*(9), 5938–5950.

Kader, A. A. (2008). Flavor quality of fruits and vegetables. *Journal of the Science of Food and Agriculture, 88*(11), 1863–1868.

Kim, H., Moon, J. Y., Kim, H., Lee, D. S., Cho, M., Choi, H. K., & Cho, S. K. (2010). Antioxidant and antiproliferative activities of mango (*Mangifera indica* L.) flesh and peel. *Food chemistry, 121*(2), 429–436.

Larrauri, J. A., Rupérez, P., Borroto, B., & Saura-Calixto, F. (1996). Mango peels as a new tropical fibre: preparation and characterization. *LWT-Food Science and Technology, 29*(8), 729–733.

Liu, R. H. (2013). Health-promoting components of fruits and vegetables in the diet. *Advances in nutrition, 4*(3), 384S–392S.

Macedo, A., Gomes, T., Ribeiro, C., Moldão-Martins, M., Duarte, E., & Alves, V. D. (2022). Membrane technology for valorization of mango peel extracts. *Foods, 11*(17), 2581.

Maisarah, A. M., Asmah, R., & Fauziah, O. (2014). Proximate analysis, antioxidant and anti proliferative activities of different parts of *Carica papaya*. *Journal of tissue science & engineering, 5*(1), 1.

Maisuthisakul, P., Suttajit, M., & Pongsawatmanit, R. (2007). Assessment of phenolic content and free

radical-scavenging capacity of some Thai indigenous plants. *Food chemistry, 100*(4), 1409–1418.

Masibo, M., & He, Q. (2009). Mango bioactive compounds and related nutraceutical properties—a review. *Food Reviews International, 25*(4), 346–370.

Metzner Ungureanu, C. R., Lupitu, A. I., Moisa, C., Rivis, A., Copolovici, L. O., & Poiana, M. A. (2020). Investigation on high-value bioactive compounds and antioxidant properties of blackberries and their fractions obtained by home-scale juice processing. *Sustainability*, *12*(14), 5681.

Morais, D. R., Rotta, E. M., Sargi, S. C., Bonafe, E. G., Suzuki, R. M., Souza, N. E., & Visentainer, J. V. (2017). Proximate composition, mineral contents and fatty acid composition of the different parts and dried peels of tropical fruits cultivated in Brazil. *Journal of the Brazilian Chemical Society, 28*(2), 308–318.

Mukta, M. M., Hossain, M. F., Arefin, P., & Ahmed, S. (2025). Exploring nutritional composition and antioxidant potential of papaya peels in Bangladesh. *Journal of Applied Horticulture, 27*(2), 318–322.

Nadeeshani, H., Samarasinghe, G., Silva, R., Hunter, D., & Madhujith, T. (2021). Proximate composition, fatty acid profile, vitamin and mineral content of selected banana varieties grown in Sri Lanka. *Journal of Food Composition and Analysis, 100*, 103887.

Nitisuk, P., Wanyo, P., Chamsai, T., & Charoenjit, K. (2025). Sustainable valorization of tropical fruit peels for sustainable production of natural antioxidants and functional food ingredients. *Sustainable Food Technology, 3*(4), 1189–1202.

Nwofia, G. E., Ojimelukwe, P., & Eji, C. (2012). Chemical composition of leaves, fruit pulp and seeds in some *Carica papaya* (L) morphotypes. *Int.J.Med. Arom. Plants, 2*(1), 200–206.

Oloyede, O. I. (2005). Chemical profile of unripe pulp of *Carica papaya*. *Pakistan Journal of Nutrition, 4*(6), 379–381.

Pereira, A., & Maraschin, M. (2015). Banana (*Musa* spp) from peel to pulp: ethnopharmacology, source of bioactive compounds and its relevance for human health. *Journal of Ethnopharmacology, 160*, 149–163.

Poiana, M. A., Alexa, E., Radulov, I., Raba, D. N., Cocan, I., Negrea, M., Misca, C. D., Dragomir, C., Dossa, C., & Suster, G. (2023). Strategies to formulate value-added pastry products from composite flours based on spelt flour and grape pomace powder. *Foods*, *12*(17), 3239.

Rivera-Pastrana, D. M., Yahia, E. M., & González-Aguilar, G. A. (2010). Phenolic and carotenoid profiles of papaya fruit (Carica papaya L.) and their contents under low temperature storage. *Journal of the Science of Food and Agriculture, 90*(14), 2358–2365.

Rodríguez-Rodríguez, E., Ojeda, G. A., Sgroppo, S. C., Olmedilla-Alonso, B., Sánchez-Moreno, C., Sánchez-Prieto, M., & De Ancos, B. (2026). Green extraction of phenolic compounds and carotenoids from the pulp and peel of mango criollo by sustainable emerging technologies. *Sustainable Food Technology*, *4*(1), 470–481.

Shahidi, F., & Ambigaipalan, P. (2015). Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects – A review. *Journal of Functional Foods, 18*, 820–897.

Slavin, J. L., & Lloyd, B. (2012). Health benefits of fruits and vegetables. Advances in nutrition, 3(4), 506-516.

Tewari, S., Govindrao, S. S., Raut, K. R., Majumdar, A., & Parida, S. (2025). Formulation and Nutritional Evaluation of Fruit-Waste–Based Fish Feeds for Sustainable Aquaculture. *Uttar Pradesh Journal of Zoology, 46*(22), 223–229.

Thaipong, K., Boonprakob, U., Crosby, K., Cisneros-Zevallos, L., & Byrne, D. H. (2006). Comparison of ABTS, DPPH, FRAP, and ORAC assays for estimating antioxidant activity from guava fruit extracts. *Journal of Food Composition and Analysis, 19*(6-7), 669–675.

Tokas, J., Punia, H., Baloda, S., & Sheokand, R. N. (2020). Mango peel: a potential source of bioactive compounds and phytochemicals. *Austin Food Sci, 5*(1), 1–7.

Ubwa, S. T., Ishu, M. O., Offem, J. O., Tyohemba, R. L., & Igbum, G. O. (2014). Proximate composition and some physical attributes of three mango (*Mangifera indica* L.) fruit varieties. *International Journal of Agronomy and Agricultural Research, 4*(2), 21–29.

USDA Food Composition Databases (USDA National Nutrient Database).

Vu, H. T., Scarlett, C. J., & Vuong, Q. V. (2018). Phenolic compounds within banana peel and their potential uses: A review. *Journal of Functional Foods, 40*, 238–248.

Wall, M. M. (2006). Ascorbic acid, vitamin A, and mineral composition of banana (*Musa* sp.) and papaya (*Carica papaya*) cultivars grown in Hawaii. *Journal of Food Composition and Analysis, 19*(5), 434–445.

Weshah, S. F. (2026). Innovative methods: Banana peel powder to enhance nutritional, microbial, and sensory quality of bakery products. *Revista Facultad Nacional de Agronomía Medellín*, *79*, e121832.

Zou, F., Tan, C., Zhang, B., Wu, W., & Shang, N. (2022). The valorization of banana by-products: nutritional composition, bioactivities, applications, and future development. *Foods, 11*(20), 3170.