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Unlocking the Nutritional Potential of Banana and Pineapple Peels as Sustainable Sources of Food Fortificants

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Abstract

Waste valorization of fruit peels presents a promising avenue for sustainable resource management and nutritional enhancement. This study was conducted from 2022 to 2024, and focused on the analysis of banana and pineapple peels, examining their proximate (Moisture content, Ash content, Crude fibre, Crude protein, Crude fat, Total carbohydrate and Energy value) biochemical (TDF, IDF, SDF, Antioxidant activity, and Total phenolic content), functional (WHC, OHC, Swelling power, Solubility and Bulk density) and antinutritional factors (Oxalate, Phytic acid and Tannic acid). The findings reveal that both peels are rich in bioactive compounds, including, total minerals (Banana peel powder (BPP)- 8.84±0.45%, Pineapple peel powder (PPP) - 4.73±0.44%) total dietary fibre (BPP-40.40±2.27 g/100g, PPP-39.90±1.94 g/100g), total phenols (BPP- 3.196±0.19 mg GAE/g, PPP-4.422±0.38 mg GAE/g), and antioxidant activity (BPP-3.14±0.33 µg/ml, PPP-12.24±0.71 µg/ml) which contribute to their potential as functional food fortificants. Notably, the antinutritional factors present in these peels were within safe limits, indicating their suitability for consumption. Specifically, the high dietary fibre and phenolic content suggest significant health benefits. Assessing these often-discarded by-products' nutritional potential, highlighted their role in food fortification. It underscores the importance of utilizing fruit peel waste to improve food quality.

***Key words*:** Banana, Fortificants, Peel powder, Pineapple, Dietary fibre, Waste valorization

As the global demand for healthier and more sustainable food options increases, there is growing interest in utilizing natural by-products as valuable sources of nutrients. Fruit and vegetable peels, which constitute 10–60% of total waste in the food industry, are often discarded, despite their rich nutritional profile. These peels contain essential compounds such as proteins, lipids, starch, micronutrients, bioactive substances, and dietary fibre, which can be extracted and repurposed into various industries to create value-added products. Their utilization can contribute to the development of functional foods, neutraceuticals, animal feeds, biofuels, bio-composites, and cosmetics, thus promoting more sustainable practices [1].

Banana peel powder (BPP) contains potassium, antioxidants like lutein, and tryptophan, which can enhance mood by increasing serotonin levels. Pineapple peel powder (PPP) is rich in vitamins, minerals, and bromelain, which aid digestion, reduce inflammation, and support immunity [2]. Banana peel powder (BPP) and pineapple peel powder (PPP) are excellent examples of value-added products derived from fruit peels, offering diverse health benefits Its high dietary fibre promotes gut health, while antioxidants protect against oxidative damage. The peel also has antimicrobial properties and benefits the skin through exfoliation and hydration. Moreover, fruit peels are packed with dietary fibre, vitamins, and minerals that offer several health benefits. Dietary fibre is considered an essential part of a healthy diet, playing a significant role in reducing the risk of numerous diseases, including diabetes and cardiovascular issues [3-4]. A higher intake of dietary fibre is linked to a decreased risk of hypertension, obesity, diabetes, coronary heart disease, stroke, and various gastrointestinal disorders. Additionally, consuming more dietary fibre has been shown to improve serum lipid levels and blood glucose control [5]. It promotes regular bowel movements, helps lower blood pressure, supports weight loss efforts, and may enhance immune function [6-7]. These fibres can also be incorporated into convenient foods like snack bars, instant soups, and instant porridge mixes for time-saving healthier diet options and promotes a circular economy in the food industry [8]. By leveraging the nutritional richness of Banana peel powder (BPP) and Pineapple peel powder (PPP), industries can develop innovative products that promote health while reducing food waste, advancing sustainability and wellness.

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The research analyzed the nutritional, antinutritional, and functional properties of banana and pineapple peel powders, an underexploited raw material as promising food fortificants. By examining these peels, the study aimed to unlock the desirable and undesirable components, ultimately highlighting their possible applications in enhancing food quality and nutrition of everyday diets.

MATERIALS AND METHODS

Place of experiment

The study was conducted at the Department of Postharvest Management, College of Agriculture, Vellanikkara, Thrissur, Kerala

Collection of raw materials

Ripe peels of the Mauritius variety of pineapple and Nendran variety of banana were collected from the various processing units and farmers of Thrissur district of Kerala.

Preparation of peel/rind powder

The fresh peels of banana and pineapple were processed into a powder following the technique proposed by [9]. The rinds and peels were cut into pieces measuring 5-10 mm. They were soaked in freshly prepared 0.5% citric acid solution for 30 minutes to reduce enzymatic browning. After draining the solution, the pieces were dried in a cabinet drier (RRLT- NC DRIER) at 60°C for 12 hours until it attained a constant weight. Once dried, they were ground to a mesh size 40 and stored in a laminated aluminum pouch at room temperature.

Proximate analyses

Proximate analyses were carried out by determining parameters such as moisture content, ash content, crude fat, crude protein, crude fibre, total carbohydrate and energy value.

Moisture content

Five grams of powdered sample was placed in a pre-weighed dish and kept in a hot air oven at 85°C. The weight of the dish with the sample was measured every two hours until a constant weight was achieved. The moisture content was expressed in percentage and calculated using the formula given below:

$$\text{Moisture (\%)} = \frac{W1 - W2}{W1 - W3} \times 100$$

W_1: Weight of sample with dish
W_2: Weight of empty dish
W_3: Weight of dried sample with dish

Ash content

A five-gram powdered sample was placed in a pre-weighed silica crucible and ignited at 650°C for 6 hours using a Bunsen burner. The ash content was expressed in percentage and calculated using the following equation:

$$\text{Ash content (\%)} = \frac{W1 - W2}{W} \times 100$$

W_1: Weight of crucible after ashing
W_2: Weight of empty crucible
W: Weight of the sample taken

Crude fat

The fat content was determined using the A.O.A.C. (2012) method using a Soxhlet apparatus with petroleum ether as the solvent. The fat content was expressed as a percentage and calculated using the following formula:

$$\text{Fat (\%)} = \frac{W2 - W1}{W} \times 100$$

W_1: Initial weight of the beaker
W_2: Final weight of the beaker
W: Weight of the sample taken

Crude protein

The absorbance readings were taken at 660 nm. The protein content of the sample was calculated from the standard graph and expressed as g/100g.

Crude fibre

The crude fibre was calculated using the formula provided.

$$\text{\% Crude fibre} = \frac{(W2 - W1) - (W3 - W1)}{W} \times 100$$

W_1: Empty weight of ashing dish
W_2: Weight of ashing dish with dried sample
W_3: Weight of ashing dish with ignited sample
W: Weight of the sample taken

Total carbohydrate

The total carbohydrate content was determined using anthrone reagent. Absorbance was measured at 630 nm. A standard graph was plotted using different concentrations of glucose and expressed in g/100g.

Energy value

The energy value can be calculated by summing the known energy contributions from the crude protein, crude fat, and carbohydrate fractions of the sample using Atwater's conversion factors. It was expressed in kilocalories (Kcal) and calculated from the following equation:

$$\text{Energy (Kcal)} = (\text{Carbohydrate} \times 4) + (\text{Protein} \times 4) + (\text{Fat} \times 9)$$

Biochemical parameters

Biochemical parameters such as total dietary fibre (TDF), soluble dietary fibre (SDF), insoluble dietary fibre (IDF), antioxidant activity and total phenolic content were analyzed.

Total dietary fibre (TDF)

Total dietary fibre content was estimated by the A.O.A.C. (985.29) method employing the enzymatic gravimetric method using TDF 100A-1KT. It was expressed in g/100g and calculated using the formula:

$$\text{\% TDF} = \frac{\text{Corrected sample residue}}{\text{Sample weight (g)}} \times 100$$

Insoluble dietary fibre (IDF)

Insoluble dietary fibre content was estimated by the A.O.A.C. (991.42) method. It was expressed in g/100g and calculated using the formula:

$$\text{\% IDF} = \frac{\text{Corrected sample residue}}{\text{Sample weight (g)}} \times 100$$

Soluble dietary fibre (SDF)

Soluble dietary fibre content was estimated by the A.O.A.C. (993.19) method. It was expressed in g/100g and calculated using the formula:

$$\% \text{ SDF } = \frac{\text{Corrected sample residue}}{\text{Sample weight (g)}} \times 100$$

Antioxidant activity

Antioxidant activity was evaluated using the method with the DPPH reagent (1,1-diphenyl-1-picryl hydrazine). Absorbance readings were recorded at 517 nm. The percentage inhibition or DPPH scavenging effect was calculated using the following formula:

$$\text{Scavenging activity (\%)} = \frac{A_0 - A_S}{A_0} \times 100$$

A_0: Absorbance of control
A_S: Absorbance of sample

Total phenolic content (TPC)

Total phenolic content was estimated using Folin-Ciocalteau reagent. The intensity of the blue colour represents the concentration of phenol in the sample. The absorbance was measured at 650 nm. A standard curve was prepared using various concentrations of catechol. The concentration of phenol in the sample was found using standard curve and expressed in mg /g.

Functional parameters

Functional parameters such as swelling power (SP) (w/w) and solubility (%), oil holding capacity (OHC) and water holding capacity (WHC) and bulk density were determined using the standardized procedures.

Antinutritional factors

Antinutritional factors such as oxalates, phytic acids and tannins were determined in the study according to the standardized procedures. Oxalate ions were estimated volumetrically by titrating the dilution with standard $KMnO_4$ solution, whereas phtytic acids was estimated using the Wade reagent. The tannin content in the samples was analyzed according to the standardized procedure. The results were expressed in mg/g.

RESULTS AND DISCUSSION

Proximate analysis is a fundamental technique in the food industry for assessing moisture, ash, protein, fibre, fat, and carbohydrates in products. It ensures accurate nutritional labeling, regulatory compliance, and food quality, fostering consumer trust and supporting informed dietary choices. This analysis also aids in developing innovative, health-oriented foods. The results from the proximate analysis are summarized in (Table 1). The moisture content of BPP and PPP was determined to be 7.11% and 4.89% respectively. The moisture content found in BPP was consistent with the findings (6.39%) of Eshak [10], who reported that banana peel powder could be utilized as a functional ingredient to enhance the nutritional profile of flatbread. The findings (6.8%) of Akram *et al*. [11] were also in line with the moisture content of BPP. In this study, a significantly low moisture content of 4.89% was found for PPP, which was comparable to the results (5.1%) reported by Owoeye *et al*. [12], who investigated the proximate analysis and phytochemical constituents of dried pineapple peels. In general, low moisture levels improved stability and shelf life of powders, minimizing the risk of microbial growth and spoilage, which is essential for ensuring food safety. Additionally, it helps retain the nutritional quality of the powder, facilitating its integration into various food products.

The Ash content observed in the BPP was 8.84%, which was similar to the findings (8.8%) of Pyar and Peh [13], who studied the chemical composition of banana peel using proximate analysis. The observed ash value indicated that BPP powder is rich in essential minerals (calcium, magnesium, potassium, and phosphorous). The percentage of ash in PPP was determined to be 4.73%, which was in line with the result of Sah *et al.* [14], who reported that oven-dried pineapple peel powder yielded about 4.56% of total ash content. Fortified food with mineral-rich peel powder can improve micronutrient intake, addressing the problem of mineral deficiencies in populations. Additionally, it offers a cost-effective, natural alternative to synthetic supplements.

The results showed that crude fat content was fairly low for BPP and PPP. Through proximate analysis crude fat extracted from BPP was 6.16%, which was lower than the findings (10.22%) of Segura-Badilla *et al*. [15],. According to Akram *et al.* [11], variation in crude fat could be attributed to differences in geographical regions or banana varieties. The crude fat content recorded for PPP was 2.13%, which was closer to the finding of [16]. Low crude fat content indicates a healthier nutritional profile, it also enhances shelf life, as lower fat content reduces the risk of oxidation and rancidity, improving product stability. The proximate analysis revealed that the crude protein content of BPP was 5.27%, which was comparable to the findings by El-Kholie *et al*. [17], in which they explored the potential of mango and banana peels for cake production. In addition, the crude protein percentage of PPP was recorded to be 5.90%, which aligns with the findings of [16]. In another study by Owoeye *et al*. [12] on proximate composition and phytochemical constituents of dry pineapple peels, they reported that the crude protein content was 5.78%, which was also in line with the current study. In a study by Segura-Badilla *et al*. [15], the crude fibre content was 14.38 %, which aligned with the crude fibre value of 13.2% recorded for BPP.

Whereas, the crude fibre value recorded for PPP was 11.76%, which was close enough to the findings of [16]. The results revealed that BPP and PPP had a significant amount of crude fibre, which could impart various health benefits and overall well-being. Carbohydrates are the primary energy source for the body, fueling essential functions and daily activities. Evaluation of the proximate composition of BPP indicated that it contained a significant amount of carbohydrates. The carbohydrate content recorded for BPP was 46.71g/100g, the value was close enough to the findings (46.93%) of Eshak [10], who has done nutritional and sensory evaluation of bread enriched with banana peels. Additionally, the value of carbohydrate content was similar to the findings of Ahmed *et al*. [18], who attempted to enhance the nutritional value of cake by incorporating banana peel. Proximate determination highlighted that there was a considerable amount of carbohydrates in PPP. The value recorded was 67.7g/100g, which was comparable to the findings of [16].

Energy content refers to the total calories obtained from food through oxidation. It is influenced by the composition of protein, carbohydrates, and fats present in the food [19]. The energy value of Banana peel powder (BPP) calculated from the proximate determination was 263.36 Kcal, this was lower than the findings of [17]. The lower energy value might be attributed to lower carbohydrate content than the above study. From the aligned proximate determination of pineapple peel powder (PPP) the energy value was calculated to be 315.37 Kcal, which with the value recorded by [12].

Table 1 The proximate composition of peel powders

S. No.	Parameters	Banana peel powder (BPP)	Pineapple peel powder (PPP)
1	Moisture content (%)	7.11±0.07	4.89±0.36
2	Ash content (%)	8.84±0.45	4.73±0.44
3	Crude fat (%)	6.16±0.67	2.13±0.45
4	Crude protein (%)	5.27±0.78	5.90±0.79
5	Crude fibre (%)	13.2±1.73	11.76±0.66
6	Total carbohydrate (g/100g)	46.71±8.65	67.7±8.49
7	Energy value (Kcal)	263.36±36.88	315.37±39.37

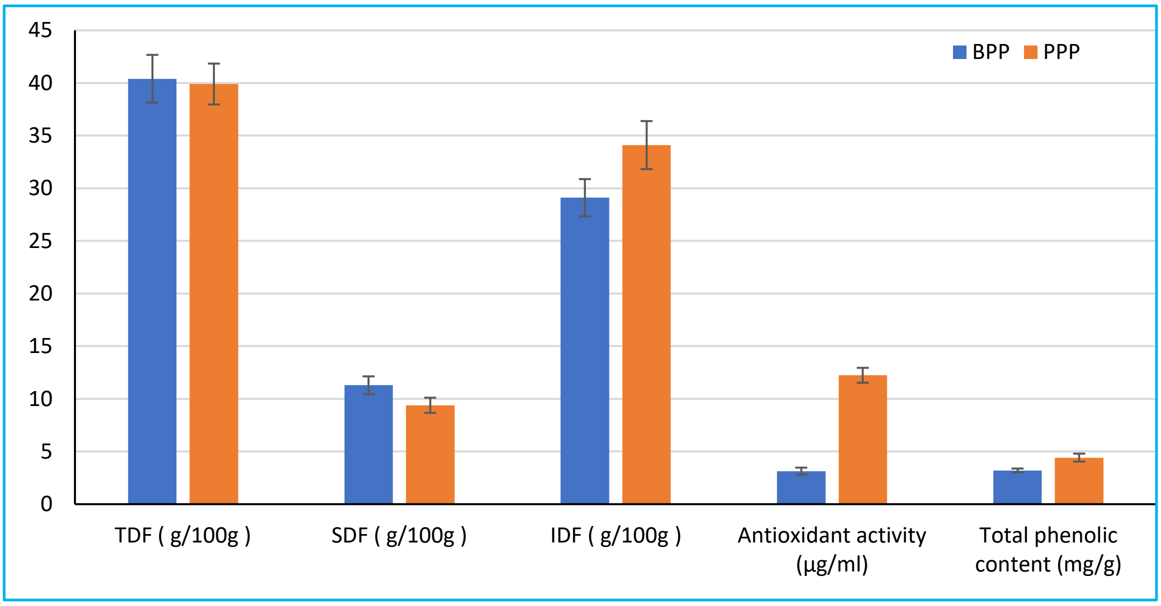

Fig 1 Biochemical composition of peel powders

Biochemical composition of peel powders

Dietary fibre refers to carbohydrate polymers with ten or more monomer units, which are resistant to digestion by enzymes in the human digestive system. It is classified into soluble and insoluble forms. Soluble fibre expands significantly, reducing food bulk density, while insoluble fiber absorbs water, increasing bowel movements and aiding in waste removal. Consequently, a fibre-rich diet promotes digestion and prevents constipation. Fruit and vegetable byproducts are rich in dietary fibre, particularly soluble fibre, and have the potential for developing innovative formulated food products. The content of TDF, SDF and IDF of BPP was recorded as 40.40 g/100g, 11.30 g/100g and 29.10 g/100g respectively, which was in concordance with the findings (TDF- 43.2%, SDF- 7.0%, IDF-27.3%) of a study by Emaga *et al*. [20], who examined the chemical composition of the peels from six different varieties of banana and plantain. In PPP 39.90 g/100g of TDF content was recorded, which was close enough to the results of [21]. Whereas the SDF and IDF content of PPP was determined to be 9.39 g/100g and 34.10 g/100g respectively, the values were consistent with the results of [22].

Antioxidants are phytochemicals found in small amounts that can slow down, inhibit, or delay the oxidation of a substrate, resulting in the formation of stable free radicals. The extract of banana peel powder (BPP) has demonstrated antioxidant effectiveness. According to the results from the antioxidant ability test, the inhibitory concentration at 50% (IC_{50}) for the DPPH scavenging activity of BPP extract was noted to be 3.196 µg/ml, which aligns closely with the result of [18]. According to Mrvcic *et al*. [23], the potent antioxidant properties of banana extracts could be attributed to the various antioxidant components.

DPPH assay of PPP recorded an IC_{50} value of 12.24 µg/ml, which was almost in line with the findings of Samarakoon and Rajapakse [24], where Butylated Hydroxy Toluene extract yielded an IC50 value of 8.60 µg/ml. A slight variation in IC50 value could be attributed to the difference in the solvent used for extraction, which is evident from the study of [24].

Total phenolic compounds (TPC) are the range of phenolic substances in a plant or food sample, including phenolic acids, flavonoids, tannins, and other polyphenols. These naturally occurring chemicals have hydroxyl groups attached to aromatic rings. Phenolic compounds, such as flavonoids, play a key role in the antioxidant activity of natural products [24]. The Folin–Ciocalteu method revealed that the TPC content in BPP was 3.196 mg GAE/g. According to the findings of Hernández-Carranza *et al*. (2016) [25], the TPC content of banana peel was found to be 4.95 mg GAE/g, which was comparable with the result of the present study. The TPC content of the ethanolic extract of pineapple peel was determined to be 4.422 mg GAE/g, which varied slightly from the results of Li *et al*. [26], who reported the TPC content of pineapple peel as 7.98 mg GAE/g, in addition, they concluded that different solvents recorded different yields of polyphenols (Fig 1).

Functional parameters of peel powders

Evaluating functional properties is crucial as it reveals how ingredients perform during preparation and cooking, as well as their impact on the appearance, taste, and texture of the final food product. Additionally, it holds significance from physicochemical and technological perspectives [27]. Assessment of functional properties of BPP recorded values of water holding capacity (WHC), oil holding capacity (OHC) and swelling power as 5.89 ml/g, 0.73 ml/g, and 4.99 respectively. The WHC and OHC values were consistent with the findings of Alam *et al*. [27], while the recorded swelling power was lower than this work due to factors like variety, particle size, and processing methods.

According to Alam *et al*. [27], swelling power can vary depending bulk density range of 0.39 g/cm³ to 0.54 g/cm³. This aligns with the bulk density value obtained in the present study, which was 0.57 g/cm³. The study determined the water holding capacity (WHC), oil holding capacity (OHC), swelling power, and bulk density values of PPP to be 4.22 ml/g, 0.89 ml/g, 5.65, and 0.53 g/cm³, respectively.

The WHC and bulk density values were comparable with the findings of Mala *et al*. [16], whereas the OHC and swelling power values differed slightly from their findings. These variations could be attributed to differences in variety or the drying processes used. The percent solubility of BPP and PPP were found to be 15.40% and 12.99% respectively. Higher solubility facilitates better incorporation into formulations, improving nutritional profiles and functional properties of the final products (Fig 2).

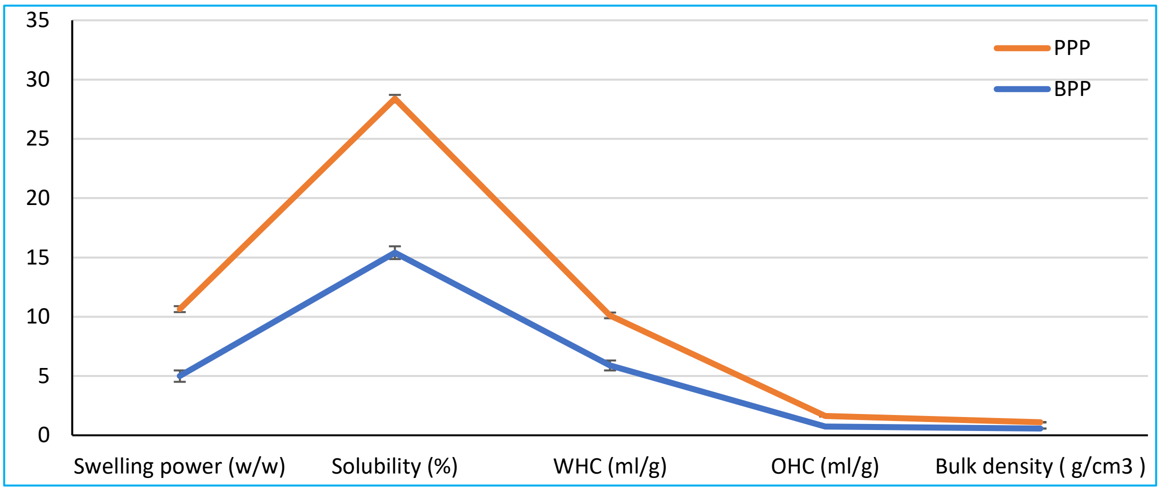

Fig 2 Functional parameters of peel powder

Table 2 Antinutritional factors of peel powder

S. No.	Antinutritional factors	BPP	PPP
1	Oxalate (mg/g)	8.40	22.6
2	Phytic acid (mg/g)	1.65	1.63
3	Tannic acid (mg/g)	3.14	8.23

Antinutritional factors of peel powder

The data depicted in (Table 2) presented the levels of antinutritional components found in those samples. Oxalate, phytic acid and tannic acid present in BPP were 8.4mg/g, 1.648 mg/g and 3.14 mg/g, whereas PPP contains 22.3mg/g, 1.625 mg/g and 8.23 mg/g of respective antinutritional factors. The presence of antinutritional factors in human diets can hinder the digestion and absorption of nutrients. They diminish the bioavailability of minerals and the absorption of proteins from food, contributing to micronutrient malnutrition and mineral deficiencies. The antinutritional factors present in the samples of the present study were within the safe limit. Proper pretreatment of the raw material, such as heat processing, soaking, or fermentation, should be conducted to effectively lower the levels of these antinutritional factors.

CONCLUSION

The findings presented in this study indicate that both BPP and PPP possessed significant nutritional and functional benefits while maintaining antinutrient levels below acceptable safety limits. The analysis of their nutritional profiles reveals that these agricultural by-products are valuable raw materials with a promising potential for use in the food industry. The study suggested that banana and pineapple peels could be effective food fortificants. The choice of BPP and PPP could be made based on the food product and the sensory perception of the products prepared using these raw materials. This approach not only boosts the nutritional value of food products but also creates potential for developing commercially viable and sustainable options in the food industry.

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