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VALORIZATION OF BANANA, POMEGRANATE AND GUAVA PEELS AS FUNCTIONAL INGREDIENTS FOR NUTRITIONAL ENHANCEMENT OF TRADITIONAL SNACK: BIOACTIVE CHARACTERIZATION, PRODUCT OPTIMIZATION AND STORAGE STABILITY

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ABSTRACT

Background: Agro-industrial fruit waste represents a major sustainability challenge, with global food waste estimated at approximately 1–3 billion tons annually, despite its richness in dietary fibre and bioactive compounds. Food waste valorization has gained increasing attention as a sustainable approach to enhance nutritional security while reducing environmental impact.

Materials and Methods: This present study investigated the potential of banana, pomegranate, and guava peel powders as functional ingredients for the nutritional enhancement of traditional South Indian snack i.e. murukku. The selected fruit peels were processed into powders, and characterized for their physicochemical, functional, proximate, phytochemical, and antioxidant properties. Peel powder was subsequently incorporated into murukku formulations, and the developed products were evaluated for proximate composition, sensory characteristics, textural quality and storage stability.

Results: Proximate analysis revealed high dietary fibre (5.63 ± 0.55 g/100 g) and protein (14.83 ± 1.76 g/100g) content in peel-incorporated samples. Sensory evaluation, employing a 9-point hedonic scale, revealed a high degree of acceptability, alongside enhancements in both texture and mouthfeel. Furthermore, shelf-life assessments indicated superior stability and no spoilage in the samples containing the incorporated ingredients after 30 days. The findings demonstrate the potential of fruit peel powders as functional ingredients for developing traditional snack foods that are both more nutritious and environmentally friendly.

Keywords: Banana, Pomegranate, Guava, Value-added, Sustainable

1 INTRODUCTION

India's rich ethnic diversity is reflected in its traditional food systems, where culinary practices are deeply rooted in regional customs, cultural identity, and social traditions. Traditional foods play a significant role in festivals and social gatherings, symbolizing the cultural identity and community bonding. These practices contribute to the preservation and continuity of indigenous food systems [1].

Traditional snacks such as murukku and thattai are integral to South Indian culinary heritage and widely consumed as everyday snacks across different socio-economic groups. Despite their widespread consumption, these products are typically low in dietary fibre and essential nutrients. This highlights the need for nutritional enhancement without compromising the traditional appeal.

In parallel, the rapid growth of horticultural production in India has contributed to nutritional diversity, food security and revenue generation for millions of farmers. Also, India is the second-largest producer of fruits and vegetables worldwide, following China [2,3].

Food waste has emerged as a critical global challenge, with an estimated 1–3 billion tons generated annually, contributing significantly to environmental pollution and resource loss. Fruit processing industries produce a significant amount of garbage, with peels accounting for about 30 – 50% of total by-products [4,5]. The effective utilization of such Agro-waste has therefore gained increasing attention as a sustainable strategy to reduce environmental burden while enhancing nutritional security [6].

Fruit peels, which are abundant and inexpensive, contain unique chemical components as well as a large potential for value development [7]. The fruit peel powders are rich sources of dietary fibre, minerals, vitamins, and phytochemicals that can be utilized in a variety of foods and food products to increase their nutraceutical potential and nutritive value [8]. They manifested protective properties, including antibacterial and antioxidant activity [9].

According to FAO (2023), India was one of the leading producers of bananas, guava and pomegranate [10]. Peels from these fruits possess considerable nutraceutical potential; however, they remain underutilized. The pomegranate peel is a rich source of tannins and flavonoids, packed with antioxidants, and known for its anti-inflammatory, anticancer, antibacterial, and antiviral properties [11]. Banana peels are known for their vital minerals and bioactive compounds, which exhibit anti-inflammatory properties [12]. Guava peels are high in bioactive compounds that have antibacterial and antioxidant properties [13,14].

Despite their nutritional potential, they are underutilized, resulting in environmental concerns and economic losses [15]. Using fruit processing waste in the preparation of food products also helps in nutrition enhancement. The focus on sustainability has led to greater interest in innovative techniques to reduce fruit peel waste and minimize environmental impacts [4].

However, limited studies have explored the incorporation of fruit peel by-products into traditional snacks with a combined assessment of nutritional, functional, and storage stability aspects. The present study addresses this gap by developing fibre-enriched traditional snacks using fruit peel powders and evaluating their performance through a multi-dimensional framework.

This approach not only enhances the nutritional profile of widely consumed foods but also contributes to sustainable food processing through improved resource utilization and waste reduction. Therefore, the objective of this study is to develop and evaluate fruit peel-incorporated traditional snacks in terms of nutritional composition, functional properties, sensory acceptability, and storage stability.

2 MATERIALS

The selected fruits (Banana, Pomegranate & Guava) were procured from local farmers in Natham. Other ingredients, including rice flour, urad dal flour, asafetida powder, salt and oil, were purchased from a local retail market in Natham, Dindigul (Dt), Tamil Nadu.

2.1 Preparation of Fruit Peel Powder

The fruits were sorted and thoroughly washed. Banana peels were manually separated, while pomegranate and guava peels were removed using stainless steel knives. The peels were weighed initially and subjected to drying in a cabinet dryer at 80° C. Guava peels were dried for 3 hours, while banana and pomegranate peels were dried for 8 hours to

achieve a uniform texture. The dried peels were ground into fine powder using a mechanical grinder, sieved for uniform particle size and stored in an airtight container at ambient conditions for further analysis.

2.2 Evaluation of Functional characteristics of the fruit peel powder

The selected fruit peels were analyzed for their functional properties, including physicochemical properties, proximate composition, phytochemical analysis and Antioxidant activity.

The physicochemical properties, such as water absorption capacity, oil absorption capacity, and solubility, were determined using standard methods [16]. Proximate composition was analyzed for Ash [17], Moisture, Carbohydrate content by Phenol-sulfuric acid method [18], Protein content using Lowry method [19], Fat [17], and Crude fibre [17]. The qualitative phytochemical analysis was carried out in aqueous extracts. Antioxidant activity of the aqueous extracts was determined using DPPH (2,2 – diphenyl –1- picrylhydrazyl) [20].

2.3 Development and Evaluation of Fruit Peel-Incorporated Food Snacks

Traditional snack (murukku) samples were prepared by incorporating fruit peel powders at selected levels into the standard formulation. The developed products were evaluated for nutritional composition, sensory attributes and textural changes.

The nutritional composition includes moisture (using KINGLAB Moisture Analyzer), Ash, Energy, Carbohydrates, Protein, Fat and Crude fibre. The sensory evaluation was conducted using a point hedonic scale with a panel of 20 semi-trained members, assessing aroma, taste, texture, mouthfeel, appearance and overall acceptability.

2.4 Statistical Analysis

All experiments were conducted in triplicate, and the results were expressed as mean $\pm$ SD. Statistical analysis was performed in SPSS version 27.0, using One-way ANOVA followed by Tukey's post hoc test to determine the significant differences among the samples. A p-value < 0.05 was considered statistically significant.

3 RESULTS AND DISCUSSION

3.1 Functional Characteristics of Fruit Peel Powder

3.1.1 Proximate Analysis

The results were consistent with the previous findings reported by [22,23]. One-way ANOVA indicated that peel type had a statistically significant effect on moisture, ash, carbohydrate, protein and fat content ($p < 0.001$), while no significant difference was observed in Crude fibre ($p > 0.05$). Tukey's post hoc test indicated significant differences among banana, guava and pomegranate peels ($p < 0.05$), with banana peel exhibiting the highest mean values, followed by guava and pomegranate peels. The findings indicated that peel type significantly influences most proximate composition parameters, highlighting their nutritional profile as functional ingredients. The results were presented in Table 1 and Figure 1.

3.1.2 Physicochemical Properties

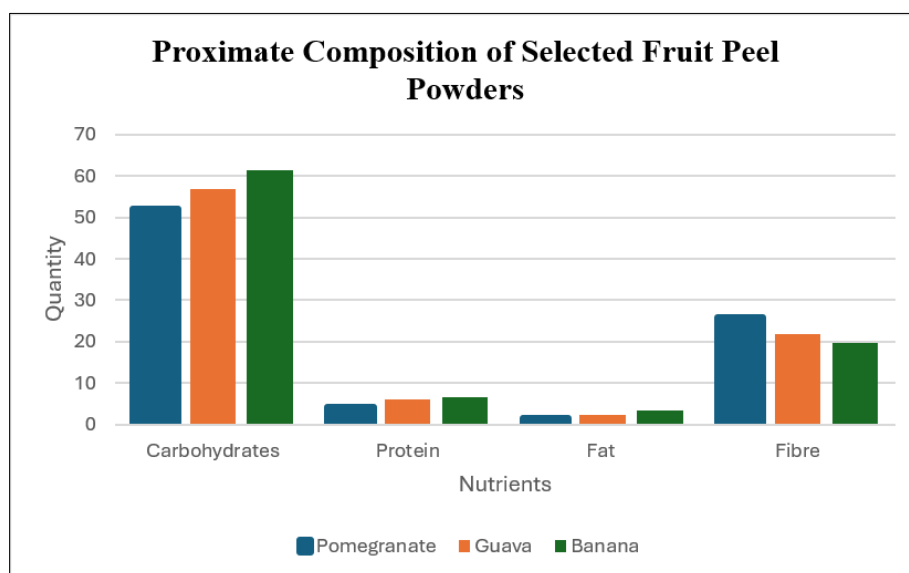
The functional properties of fruit peel powders, including Water absorption capacity (WAC), Oil absorption capacity (OAC) and solubility, showed notable differences among the samples. Banana peel exhibited the highest WAC (3.93 ± 0.51), although the difference was not statistically significant. This suggests its potential to improve moisture retention and texture in food formulations. OAC values differed significantly ($p < 0.05$), with banana peel showing the highest OAC.

Solubility is an important functional property for assessing their characteristic in aqueous solution. Solubility showed a significant decreasing trend from pomegranate to banana peel. The higher solubility in pomegranate peel could be attributed to the presence of soluble phenolic compounds and lower structural rigidity. The results were tabulated in Table 1.

Table 1: Physicochemical and Proximate Analysis of the fruit peel powder

Parameter	Pomegranate peel	Guava peel	Banana peel	F value	p-value
WAC	3.23 ± 0.55 ^b	3.17 ± 0.35 ^c	3.93 ± 0.51 ^a	2.353	0.176
OAC	1.80 ± 0.30 ^c	2.00 ± 0.20 ^b	2.50 ± 0.30 ^a	0.532	0.047
Solubility	16.80 ± 1.25 ^a	10.13 ± 0.95 ^b	6.40 ± 0.79 ^c	80.498	< 0.001
Moisture (%)	8.80 ± 0.26 ^c	9.30 ± 0.26 ^b	17.37 ± 0.32 ^a	855.055	< 0.001
Ash (%)	6.90 ± 0.10 ^b	5.40 ± 0.26 ^c	9.27 ± 0.25 ^a	238.628	< 0.001
Carbohydrate (g/100 g)	51.97 ± 0.45 ^c	56.90 ± 0.20 ^b	61.30 ± 0.93 ^a	77.298	< 0.001
Protein (g/100 g)	4.20 ± 0.21 ^c	5.93 ± 0.25 ^b	6.60 ± 0.17 ^a	104.12	< 0.001
Fat (%)	1.63 ± 0.15 ^c	2.20 ± 0.18 ^b	3.37 ± 0.15 ^a	89.063	< 0.001
Crude fibre (g/100 g)	25.86 ± 0.56 ^a	21.80 ± 0.21 ^b	19.57 ± 0.40 ^c	2.343	0.177

Note: Values are mean ± SD. Different superscripts within a row indicate significant difference ($p < 0.05$). WAC – Water absorption capacity; OAC – oil absorption capacity

**Figure 1: Proximate Composition**

3.1.3 Phytochemical Analysis

The qualitative phytochemical screening was conducted in the aqueous extract (Cold & Hot) of the selected fruit peel powder. Nearly 13 phytonutrients were screened in the selected peels. From the results, flavonoids, tannins, saponins, phenols and glycosides were present in all the extracts. Alkaloids, steroids and terpenoids varied among samples. Anthraquinones and Phlorotannins were absent in all the samples. The enhanced extraction efficiency in hot extracts may be due to increased solubility and diffusion of phytochemicals at elevated temperatures. The presence of phenolic compounds and flavonoids suggests that these peels may play a role in enhancing oxidative stability and extending the shelf life of food products. The results were similar to the findings reported by [21]. The results were represented in Table 2.

Table 2: Qualitative Phytonutrient analysis of the fruit peel powder

Phytonutrient	ACE			AHE		
	Pomegranate peel	Guava peel	Banana peel	Pomegranate peel	Guava peel	Banana peel
Flavonoids	+	+	+	+	+	+
Alkaloids	-	+	-	+	+	-
Steroids	+	+	-	+	+	+
Saponin	+	+	+	+	+	+
Anthraquinone	-	-	-	-	-	-
Tannins	+	+	+	+	+	+
Terpenoids	+	+	-	+	+	+
Glycosides	+	+	+	+	+	+
Cardiac glycosides	-	-	-	-	+	-
Quinones	+	+	-	+	+	+
Phlorotannin	-	-	-	-	-	-
Coumarins	+	+	-	+	+	-
Phenols	+	+	+	+	+	+

Note: ACE: Aqueous Cold extract; AHE: Aqueous Hot extract; (+) Presence, (-) Negative;

3.1.4 *In vitro* Antioxidant activity of Fruit peel powder

The antioxidant activity of the fruit peel powders was assessed using the DPPH assay, which showed a concentration-dependent increase in radical-scavenging activity. Among the samples, Pomegranate peel exhibited the highest antioxidant activity, achieving $96.30 \pm 0.05\%$ inhibition at a 2.0% concentration in the hot extract. Guava peel showed moderate antioxidant activity, while banana peel exhibited comparatively lower values. In all cases, hot water extracts demonstrated significantly higher antioxidant activity than cold extracts. The results were presented in Table 3.

Table 3: *In vitro* Antioxidant activity of fruit peel powders

Fruit peel	Concentration (%)	DPPH % inhibition	
		Cold extract	Hot extract
Pomegranate peel	1.0	68.42 ± 0.15	82.14 ± 0.22
	1.5	79.18 ± 0.32	88.45 ± 0.14
	2.0	91.55 ± 0.08	96.30 ± 0.05
Guava peel	1.0	42.15 ± 0.24	58.70 ± 0.31
	1.5	56.30 ± 0.19	69.22 ± 0.25
	2.0	70.84 ± 0.41	81.50 ± 0.18
Banana peel	1.0	24.60 ± 0.12	36.48 ± 0.20
	1.5	38.92 ± 0.35	51.30 ± 0.42
	2.0	52.17 ± 0.28	64.85 ± 0.33

Note: Values are mean $\pm$ SD.

3.2 Evaluation of Fruit Peel Powder- Incorporated Food Snacks

The food sample was tested for chemical analysis, and the results were presented in the following sections.

3.2.1 Moisture and Ash content

The moisture and ash content of the food sample was assessed. The incorporation significantly influenced the moisture and ash content of the developed snack. The peel-incorporated sample exhibited higher moisture content ($5.83 \pm 0.25\%$) compared to the control ($2.83 \pm 0.32\%$). Similarly, the ash content increased from $1.20 \pm 0.20\%$ in the control sample to $3.20 \pm 0.26\%$ in the incorporated food snack, indicating enhanced mineral content. These findings suggest that peel incorporation contributes to the improved nutritional quality of the product. The results were tabulated in Table 4.

Table 4: Moisture and Ash content in Food sample

Sample	Moisture (%)	Ash (%)
Food peel incorporated sample	5.83 ± 0.25^a	3.20 ± 0.26^b
Control sample	2.83 ± 0.32^a	1.20 ± 0.20^b

Note: Values are mean $\pm$ SD. Superscripts indicate statistical comparison within column.

3.2.2 Nutritional Composition

The nutritional composition of the incorporated snack was compared with that of the control group. The incorporated sample showed a substantial reduction in energy, carbohydrate, and fat content ($p < 0.001$). In contrast, protein and crude fibre contents were significantly higher in the incorporated snack ($p < 0.05$). The peel incorporation enhanced the snack's nutritional quality by improving its functional and health-promoting attributes. The results were presented in Table 5.

Table 5: Nutritional composition

Analysis	Value per 100g (in the incorporated food sample)	Value per 100g (in control food sample)	Level of significance
Energy (kcal)	245.00 ± 0.90^b	487.00 ± 0.88^a	< 0.001
Carbohydrates (g)	22.00 ± 3.00^b	48.00 ± 2.65^a	< 0.001
Protein (g)	14.83 ± 1.76^a	6.93 ± 0.31^b	0.002
Fat (g)	18.50 ± 1.83^b	36.67 ± 1.53^a	< 0.001
Crude fibre (g)	5.63 ± 0.55^a	1.73 ± 0.47^b	< 0.001

Note: Values are mean $\pm$ SD. Significant at $p < 0.05$

3.2.3 Texture changes

The textural stability of the samples was monitored over a storage period of 30 days. Both samples exhibited changes in texture during storage. The control sample exhibited a gradual decline in quality, with noticeable spoilage by the 30th day. In contrast, the peel-incorporated snack maintained acceptable crispness and showed no signs of spoilage throughout the storage period. This improved stability may be attributed to the presence of bioactive compounds, which may reduce moisture migration and inhibit microbial growth. These findings revealed that fruit peel incorporation not only enhances nutritional quality but also improves the shelf life of traditional snack products. The textural changes were presented in Table 6.

Table 6: Textural changes

Storage period	Control snack	Peel-incorporated snack
0 day	Excellent acceptability	Excellent acceptability
15 th day	Slight loss of crispness	Acceptable crispness
30 th day	Noticeable quality loss, spoilage occurs	Acceptable with no spoilage

3.2.4 Sensory Evaluation

Sensory evaluation indicated high acceptability for both control and peel-incorporated snack, with scores above 8.0 on a 9-point hedonic scale. Although the incorporated sample showed slightly higher mean scores for aroma, taste, and overall acceptability, the differences were not statistically significant ($p > 0.05$). This indicates that incorporation did not adversely affect sensory attributes, and the developed product was well accepted by the panelists. The ability to enhance nutritional value without compromising sensory quality is a key factor in the successful development of functional traditional foods. The sensory evaluation results were presented in Table 7.

Table 7: Sensory evaluation

Characteristics	Incorporated snack	Control snack	Level of significance
Appearance	8.67 $\pm$ 0.58	8.33 $\pm$ 0.58	0.519
Aroma	8.33 $\pm$ 0.58	7.33 $\pm$ 0.58	0.101
Taste	9.00 $\pm$ 0.00	8.67 $\pm$ 0.58	0.374
Texture	8.67 $\pm$ 0.58	8.67 $\pm$ 0.58	1.000
Mouthfeel	9.00 $\pm$ 0.00	8.67 $\pm$ 0.58	0.374
Overall Acceptability	9.00 $\pm$ 0.00	8.67 $\pm$ 0.58	0.374

Note: Values are mean $\pm$ SD. No significant difference observed ($p > 0.05$).

4 CONCLUSION

The results demonstrate that fruit peel powders can serve as effective functional ingredients in traditional snack formulations, offering a dual advantage of nutritional enhancement and improved shelf stability. The study highlights the potential of utilizing agro-waste as a sustainable solution for developing value-added food products with enhanced health benefits. This approach not only enhances nutritional quality but also contributes to improved resource utilization and food security.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declares no conflict of interest

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