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EXPLORING THE PHYSICAL, CHEMICAL AND FUNCTIONAL CHARACTERISTICS OF PINEAPPLE PEEL AND CROWN

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Abstract– This study systematically evaluated the physical, chemical, mineral, functional, and colour characteristics of powders derived from pineapple (*Ananas comosus*) peel and crown. During pineapple processing, approximately 26-32% of the fruit mass is discarded as peel and crown, which is typically disposed of in the open environment, thereby contributing to pollution and greenhouse gas emissions. Comprehensive analyses revealed that both pineapple peel and crown powders are rich sources of dietary fiber and minerals, with potential for value addition. Specifically, dietary fiber content was determined to be 42.23±0.15% in pineapple peel powder and 66.89±0.47% in crown powder. The crown powder exhibited higher concentrations of essential minerals, including calcium, magnesium, zinc, nitrogen, phosphorus, and potassium, compared to the peel powder. Colour analysis indicated favorable consumer acceptance, with L*, a*, and b* values for pineapple peel powder recorded at 66.01±0.57, 7.34±0.01, and 24.90±0.01, respectively, and for crown powder at 62.23±0.03, 2.60±0.02, and 24.21±0.02, respectively. The findings suggest that pineapple peel and crown powders represent valuable raw materials for the development of sustainable packaging, plant nutrient enhancers, biofertilizers, and fortification agents in cattle feed, thereby promoting waste valorization and environmental sustainability.

INTRODUCTION

India is the second largest producer of fruits in the world and accounts for about 12% of the total world fruit production. The Food and Agriculture Organization (FAO) estimates that food wastage occurs at various stages such as harvesting, preliminary operations, processing, handling and transportation (Nirmal *et al.*, 2023). Fruit processing waste presents a significant challenge on a global scale, particularly in India, where the agricultural sector generates substantial volumes of waste. In 2022 worldwide, around 1.05 billion tonnes of waste were generated. With global fruit production exceeding one billion tons annually, it is estimated that approximately 45% of fruits produced worldwide are wasted each year. In India, the scenario is particularly alarming. The country produces around 150 million tons of fruits, resulting in nearly 50 million tons of waste from processing activities alone (Lucarini *et al.*, 2021).

The environmental impacts of fruit processing waste are profound and multifaceted. Decomposing organic waste contributes significantly to methane emissions, exacerbating climate change. Additionally, improper disposal methods lead to soil and water contamination, further threatening ecosystems and public health (Bancal and Ray, 2022). This staggering figure contributes to around 11.8% of all global greenhouse gas emissions, highlighting the need for effective waste management strategies. The failure to utilize valuable by-products results in lost opportunities for recovering nutrients and bioactive compounds that could benefit both the economy and the environment. The processing of major fruits such as mango, pineapple, watermelon, banana, and citrus generates significant amounts of waste, presenting both challenges and opportunities for sustainable management. 20-40% of waste is generated during fruit processing during the preparation of fruit juices, pulp, jam, jelly; fruit preserve etc. is in the form of peel, leaves, stalks, seeds and pomace (Sha *et al.,* 2023). Generated waste is a good source of bioactive components, antioxidants, dietary fibres, vitamins, minerals and enzymes (Nirmal *et al.,* 2023). Overall, the substantial waste generated from fruit processing not only poses environmental challenges but also offers significant opportunities for innovation by converting bioactive components into valuable resources, thereby promoting a circular economy and reducing food waste.

Pineapple (*Ananas comosus*) processing generates significant waste, primarily in the form of peels, crowns, and cores, with estimates indicating that about 45-55% of the fruit's total weight is discarded during processing (Fouda-Mbanga and Tywabi-Ngeva, 2022). This waste presents a substantial environmental challenge, with approximately 22.5 million tons of pineapple waste produced globally (Kengkhetkit and Amornsakchai, 2014**)**. The chemical composition of pineapple peels and crowns is rich in bioactive compounds, including dietary fibre, pectin, phenolic compounds, and bromelain, a proteolytic enzyme. These components make pineapple waste suitable for developing sustainable packaging materials and value added processed products (Meena *et al.,* 2022). For instance, the high fibre content in pineapple peel and crown can be utilized to create biodegradable materials that decompose naturally. By transforming pineapple waste into valuable materials for packaging, industries can contribute to waste reduction while promoting sustainability in food systems.

In view of this fact the present study was carried out to find out the suitability of pineapple peel and crown for sustainable packaging development and value addition based on its physical, chemical, colour and functional characteristics.

MATERIALS AND METHODS

Preparation of pineapple peels and crown powder

Pineapple peel and crown as waste generated during processing was collected from juice centre, Parbhani, Maharashtra, India. Collected pineapple peels and crown cleaned by washing with water to remove dirt, foreign material and waxy layer. Water is drained off, peels and crown were cut into small pieces. Prepared pieces of peels and corwn dried in cabinet tray drier at 60 °C for 5hrs. Dried pineapple peel and crown converted into powder form with the help of grinder. Prepared powder packed in PET jar and used for further characterization. The chemicals and reagents used for analysis were of analytical grade.

Physical properties

Bulk density, tapped density and true density of prepared powder were determined as per the procedure given by Gani *et al*. (2015). Porosity (%) was calculated from true and bulk density as per the formula given by Vanrnamkhasti *et al.* (2008). Compressibility index (%) of the powdered peel and crown was calculated by using the tapped density and bulk density (Singh *et al*., 2010). Angle of repose was calculated by the formula and method given by Singh *et al*. (2010).

Chemical composition

Percent moisture and ash content of pineapple peel and crown powder was determined as per the standard method given by (AOAC, 2000). Dietary fibre content of raw material was measured by enzymatic-gravimetric analysis as per the AOAC official methos (AOAC, 2005).

Cellulose, hemicellulose and lignin content of the pineapple peel and crown powder was calculated by the procedure given by (Ning *et al*., 2022). Pectin content from raw material was calculated by the formula given by Ranganna (1986).

Mineral composition

Mineral composition of raw material including calcium, magnesium, zinc, nitrogen, phosphorus and potassium was estimated by method given by Ranganna (1986).

Functional properties

Functional properties including water absorption capacity, solubility, wettability, rehydration ratio and swelling index of powdered material were determined the methodology given by (Kumar *et al*., 2017 and Kaur *et al.*, 2006).

Colour characteristics

Colour characteristics of pineapple peel and crown powder were determined by using Colour Flex EZ (Model Lab 15Scan-XE, Hunter Associates

Laboratory Inc. USA). L*, a*, b* values were recorded. The system determines the L*, a*, b* values, where L* represents lightness or darkness; a* represents the opposition between green and red colour ranging from positive (red) to negative (green) values; and b* represents yellow/blue.

Statistical analysis

Obtained results were represented as mean and standard deviation using Microsoft excel.

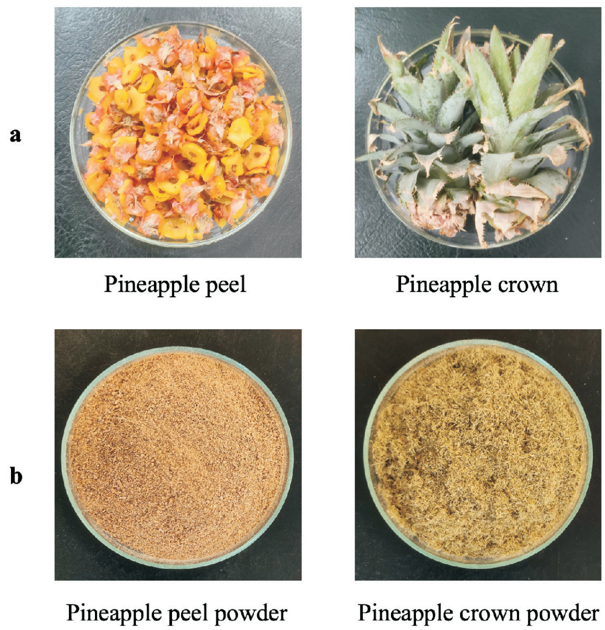

Fig. 1. a) Pineapple peel and crown b) Pineapple peel and crown powder

RESULTS AND DISCUSSION

Physical properties

Different physical properties such as bulk density, tapped density, true density, porosity, compressibility index and angle of repose for the pineapple peel and crown powder were evaluated and the obtained data of results are summarised in Table 1.

The bulk density, tapped density and true density of pineapple peel powder were 363.73±0.005, 447.44±0.007 and 1031.3±0.020 kg/m^3 respectively. However bulk density, tapped density and true density of pineapple crown powder were 167.7±0.004, 251.05±0.005 and 1699±0.040 kg/m^3 respectively. A higher bulk density indicates superior packing ability, as seen in the pineapple peel powder. Conversely, the lower bulk density of pineapple crown powder suggests a more compact and fibrous structure (Ding *et al*., 2020). Materials with higher bulk density are generally easier to handle. The lower tapped density of pineapple crown powder can be attributed to its irregular particle size and increased void spaces. In contrast, higher tapped density is associated with better compatibility of the final product (Ramm *et al*., 2022). The true density was highest in pineapple crown powder, likely due to greater fibre compaction.

Porosity, which reflects the proportion of void spaces within the bulk material, was found to be 64.72/±/0.508% for pineapple peel powder and 90.12/±/0.250% for crown powder. The higher porosity of the crown powder is a result of its loose structure and lower bulk density. Increased porosity in raw materials is advantageous for producing lightweight packaging, though it also leads to higher water absorption (Ganasen *et al*., 2025). The compressibility index, an indicator of flow properties, was 18.70/±/0.876% for pineapple peel powder and 33.17/±/0.142% for crown powder. The higher compressibility index of the crown powder is due to its fibrous nature and reduced free-flowing ability. The angle of repose, another measure of flowability, was 37.92/±/0.365° for peel powder and 38.55/±/0.706° for crown powder. The lower angle of repose for the peel powder indicates superior flow characteristics compared to the crown powder.

Table 1. Physical properties of of pineapple peel and crown powder

Parameter	Pineapple peel powder	Pineapple crown powder
Bulk density (kg/m^3)	363.73±0.005	167.7±0.004
Tapped density (kg/m^3)	447.44±0.007	251.05±0.005
True density (kg/m^3)	1031.3±0.020	1699±0.040
Porosity (%)	64.72±0.508	90.12±0.250
Compressibility index (%)	18.70±0.876	33.17±0.142
Angle of repose (°)	37.92±0.365	38.55±0.706

Each observation is an average of three determinations (mean±SD)

Chemical composition

Chemical composition of pineapple peel powder and crown powder were analysed for the parameters such as percent moisture, ash, dietary fibre, cellulose, hemicellulose, lignin and pectin content and the obtained results are expressed in percentages and depicted in Table 2.

Table 2. Chemical composition of pineapple peels and crown powder

Parameters (%)	Pineapple peel powder	Pineapple crown powder
Moisture	7.03±0.08	5.14±0.02
Ash	4.67±0.06	4.77±0.03
Dietary fibre	42.23±0.15	66.89±0.47
Cellulose	29.92±0.18	40.58±0.37
Hemicellulose	22.36±0.28	20.34±0.20
Lignin	18.32±0.20	12.28±0.36
Pectin	9.32±0.15	3.33±0.18

Each observation is an average of three determinations (mean±SD)

The chemical composition analysis of pineapple peel and crown powders revealed notable differences and similarities that highlight their potential uses and nutritional value. Pineapple crown powder had a lower moisture content (5.14±0.02%) than peel powder (7.03±0.08%), which enhances its shelf stability and reduces microbial risk. Both pineapple peel and crown powders had similar ash content of (4.67±0.06 and 4.77±0.03%), indicating comparable mineral levels. However, crown powder stands out with a much higher dietary fibre (66.89±0.47%) and cellulose content (40.58±0.37%) compared to the peel (42.23±0.15% and 29.92±0.18%, respectively), making the crown a superior source of insoluble fibre, which is beneficial for digestive health and can aid in satiety and bowel regularity. This difference can be attributed to the structural role of cellulose in the tougher crown tissues. In contrast, the peel contains more hemicellulose (22.36±0.28% vs. 20.34±0.20%) and significantly more lignin (18.32±0.20% vs. 12.28±0.36%), both of which contribute to the rigidity and protective function of the fruit's outer layer (Liu *et al*., 2020). Notably, the peel was also much richer in pectin (9.32±0.15% vs. 3.33±0.18%), a soluble fibre with gelling properties, making it valuable for use in food processing industries, particularly in the production of jams, jellies, and as a natural thickening or stabilizing agent in various food products (Mellinas *et al*., 2020).

Mineral composition

Mineral composition of pineapple peel and crown powder focuses on determination of key minerals such as calcium (Ca), magnesium (Mg), zinc (Zn), nitrogen (N), phosphorus (P), and potassium (K), expressed as mg/100g. The obtained results for the mineral composition are presented in Table 3.

Table 3. Mineral composition of pineapple peels and crown powder

Parameters (mg/100g)	Pineapple peel powder	Pineapple crown powder
Calcium	231.10±18.46	728±17.43
Magnesium	73.60±2.40	164.89±3.28
Zinc	1.64±0.07	3.66±0.15
Nitrogen	442.90±5.19	845.97±20.35
Phosphorus	136.30±3.69	144.46±3.58
Potassium	1130.02±14.88	1340.45±18.77

Each observation is an average of three determinations (mean ± SD)

The mineral composition analysis revealed that pineapple crown powder contains significantly higher levels of essential minerals compared to pineapple peel powder. Specifically, crown powder had 728±17.43 mg/100 g calcium, 164.89±3.28 mg/100 g magnesium, 3.66±0.15 mg/100 g zinc, 845.97±20.35 mg/100 g nitrogen, 144.46±3.58 mg/100 g phosphorus, and 1340.45±18.77 mg/100 g potassium, whereas peel powder contains 231.10±18.46 mg/100 g calcium, 73.60±2.40 mg/100 g magnesium, 1.64±0.07 mg/100 g zinc, 442.90±5.19 mg/100 g nitrogen, 136.30±3.69 mg/100g phosphorus, and 1130.02±14.88 mg/100 g potassium. The higher mineral content in the crown is likely due to its physiological role in supporting plant structure and growth, which requires greater accumulation of minerals for metabolic and structural functions. These findings suggest that pineapple peel and crown powder, often considered a waste by-product, could serve as a superior source of essential minerals for food fortification or nutritional applications. Pineapple peel and crown powder could be used in a cattle feed and bio fertilizers as a nutritional supplement (Tian *et al*., 2021).

Functional properties

Functional properties of pineapple peel and crown powder were analysed for the parameters water absorption capacity (WAC), solubility, wettability, rehydration ratio and swelling index. Obtained results for the functional properties presented in Table 4.

The functional properties of pineapple peel and crown powder revealed distinct differences that can be attributed to their compositional and structural characteristics. Pineapple crown powder exhibits a significantly higher water absorption capacity (WAC) of 581.42±3.23% compared to 400.23±1.57% for peel powder, indicating a greater ability to bind water, which may be due to a higher content of hydrophilic components such as fibers in the crown (Elleuch *et al.*, 2011). However, peel powder demonstrates higher solubility (46.86±0.28%) than crown powder (39.36±0.76%), suggesting that the peel contains more water-soluble constituents, possibly due to a higher proportion of simple sugars or soluble fibers (Navasingh *et al.*, 2023). The wettability, which reflects how quickly the powder can be wetted by water, was much lower (faster) for crown powder (1.54±0.015 min) than for peel powder (12.39±0.20 min), indicating that crown powder disperses more readily in aqueous systems, likely due to its finer particle size or surface properties. The rehydration ratio was also higher for crown powder (3.56±0.090) compared to peel powder (2.82±0.056), implying that crown powder can absorb and retain more water upon rehydration, which is advantageous for applications requiring rapid and efficient water uptake. Conversely, the swelling index was markedly higher in peel powder (3.116±0.07 ml/g) than in crown powder (1.133±0.045 ml/g), suggesting that the peel contains more insoluble fibers capable of swelling upon hydration. These results collectively indicate that while pineapple crown powder excels in water absorption and rehydration properties, making it suitable for use in products where rapid hydration is needed, pineapple peel powder's higher solubility and swelling index make it more suitable for applications requiring bulk and water-holding capacity, such as fiber-enriched products. The observed differences are likely due to variations in fiber composition, particle size, and the presence of soluble versus insoluble components between the peel and crown fractions (Norhayati *et al.*, 2021).

Table 4. Functional properties of pineapple peel and crown powder

Parameters	Pineapple peel powder	Pineapple crown powder
WAC (%)	400.23±1.57	581.42±3.23
Solubility (%)	46.86±0.28	39.36±0.76
Wettability (min)	12.39±0.20	1.54±0.015
Rehydration ratio	2.82±0.056	3.56±0.090
Swelling index (ml/g)	3.116±0.07	1.133±0.045

Each observation is an average of three determinations (mean±SD)

Colour characteristics

Table 5 presents the colour properties of pineapple peel and crown powder as measured by a Hunter colour lab which will be finally reflected in the appearance for consumer acceptability. The parameters include L* (lightness), a* (redness/greenness) and b* (yellowness/blueness).

The colour characteristics of pineapple peel and crown powders revealed notable differences that can be attributed to their compositional and structural properties. The L* value, which represents lightness, was higher in pineapple peel powder (66.00±0.57) compared to crown powder (62.23±0.03), indicating that the peel powder is lighter in colour. This higher lightness could be due to the presence of more surface waxes, lighter-coloured fibres and less dense pigmentation in the peel compared to the crown.

The a* value, which measures the red-green axis, was substantially higher in peel powder (7.34±0.01) than in crown powder (2.60±0.02), suggesting that the peel powder has a more pronounced red hue. This difference could be attributed to the presence of carotenoids or other red pigments in the peel, which are less abundant in the crown. The crown powder's lower a* value indicates a greener appearance, likely reflecting the higher chlorophyll content typically found in vegetative tissues like the crown. The b* value, which represents the yellow-blue axis, was similar for both powders (24.90±0.01 for peel and 24.21±0.02 for crown), indicating that both powders have a comparable yellow coloration. This similarity suggests that yellow pigments, possibly flavonoids or certain carotenoids, are present in both the peel

Table 5. Colour characteristics of pineapple peel and crown powder

Raw material	L*	a*	b*
Pineapple peel powder	66.006±0.57	7.34±0.01	24.90±0.01
Pineapple crown powder	62.23±0.03	2.60±0.02	24.21±0.02

Each observation is an average of three determinations (mean±SD) and crown, although their relative abundance and interaction with other pigments may differ (Baini and Langrish, 2009).

CONCLUSION

The findings of this study demonstrate that both pineapple peel and crown powders exhibit favorable storage stability and flow properties. Chemical analyses confirmed that both powders are substantial sources of dietary fiber, while mineral profiling indicated a robust essential mineral content. The color characteristics further support their suitability for consumer acceptance and potential value-added applications. Collectively, these results suggest that, based on their physical, chemical, mineral, functional, and color attributes, pineapple peel and crown powders possess significant potential for utilization in sustainable packaging, nutrient supplementation, pectin and pigment extraction, fortification of cattle feed, and as biofertilizers and nutrient enhancers for plants. These applications underscore the value of pineapple processing waste as sustainable resources for diverse industrial and agricultural uses.

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