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Passionfruit (*Passiflora edulis* Sims. f. *flavicarpa* O.Deg.) rind powder: Potential substrate for food and pharmaceutical applications

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Agro-waste valorisation offers a sustainable pathway for resource recovery, with numerous applications across diverse industrial sectors. This study explores the biochemical and structural characteristics of *Passiflora edulis* f. *flavicarpa* (yellow passionfruit) rind to assess its potential as a value-added substrate. The rind was subjected to comprehensive characterisation, including mineral profiling by Inductively Coupled Plasma Mass Spectrometry (ICP-MS), structural evaluation by Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and Thermogravimetric Analysis (TGA). Physicochemical, nutritional, and antinutritional analyses were also performed. The structural properties of the rind powder align with previous reports and display favourable characteristics. TGA indicates that the material maintains chemical stability up to 800°C. The rind was rich in starch, carbohydrates, and essential minerals such as potassium, while the levels of antinutritional factors were considered safe and acceptable. These findings underscore the potential of *Passiflora edulis* f. *flavicarpa* (yellow passionfruit) rind for utilisation in various industrial applications.

Keywords: Agro-waste, Characterisation, *Passiflora edulis* f. *flavicarpa*, Passionfruit, Rind, Valorisation

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Introduction

Agriculture primarily provides food and energy for humans. The energy needs of man are satiated mostly through the consumption of the edible plant parts, while the non-consumable parts are discarded as waste. Agro-waste encompasses the remnants of almost all agricultural operations, including cultivation and processing of various agricultural goods like crops, vegetables, and fruits, as well as dairy farms.

Substantial amounts of liquid and solid waste are generated during fruit and vegetable harvesting. Food-processing industries also produce significant amounts of waste. A considerable volume of this bio-waste poses threats to human health and the environment (soil and water pollution, etc.). Disposal of these waste materials is often very challenging, exacerbated by legal constraints. However, the waste contains numerous valuable and reusable substances with significant economic potential. The plant biomass constituents (cellulose, hemicellulose, and lignin) primarily offer useful resources in bulk quantities, which can be utilised judiciously[1]. Fortunately, there is growing interest in utilising agricultural residues within the farming, food, and pharmaceutical sectors. Various techniques, including physical, chemical, and biological methods, as well as environmentally friendly pretreatment approaches, are employed to extract valuable bioactive compounds. Research into developing bioactive products from agricultural waste has seen significant attention in recent years. Agro-waste materials can be treated or modified to produce specific materials with higher value (Valorisation). Value-added items, such as nutraceuticals, bioactive compounds, biopolymers, antibiotics, industrial enzymes, single-cell proteins, polysaccharides, activated carbon adsorbents, organic acids, pigments, etc., can be obtained by utilising food waste as a substrate[2].

India cultivates a diverse range of fruits and vegetables across tropical, subtropical, temperate, and arid regions. Fruit production in India has consistently risen yearly, at an estimated 81.2 million tons[3]. The food industry processes fruits, yielding considerable amounts of waste material. This waste material typically comprises peels, cores, seeds, and trimmings from overripe or defective fruits. Agro-fruit wastes

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contain substantial amounts of complex carbohydrates, proteins, fibres, polyphenolic compounds, and other bioactive components. The discarded by-products harbour a wealth of valuable compounds, serving as precious resources for the food industry's natural additive arsenal as novel, natural reservoirs for flavourings, colourants, protein, dietary fibres, antimicrobials, and antioxidants[2].

The current report is concerned with the characterisation of the fruit rind of *Passiflora edulis* Sims. f. *flavicarpa* O.Deg., a forma belonging to one of the largest genera in the family Passifloraceae. Rind, also known as skin, peel, or exocarp, is an important structural feature of fruit that is made up of specialised parenchyma cells. Fruit rind can be easily obtained from fruit processing industries as it is a non-valuable material. Among the different species of Passiflora, *Passiflora edulis* is the most important economic fruit crop, extensively seen in subtropical or tropical regions. In this genus, the most evident difference between populations is the colour of the fruit rind. In 1933, Degener named the population with yellow fruit as *Passiflora edulis* f. *flavicarpa*[4]. In India, passionfruits undergo processing into juice, beverages, squash, and syrups. The residue produced during this processing primarily comprises peel and seeds. In Kerala, with the help of Kudumbashree project (Department of Local Self Government, Government of Kerala, India), efforts to promote passionfruit cultivation are taking place across several districts, with 63.55 hectares in Malappuram, 25 in Kozhikode, 10.35 in Idukki, 10.1 in Palakkad, 5 in Thiruvananthapuram, 3.8 in Kollam, 3 in Kannur and 2 in Kottayam dedicated to this crop. This project seeks to enhance the popularity of passionfruit cultivation throughout Kerala due to its growing acceptance and potential for high returns. The most significant activity related to this crop is the production of concentrated juice, which is experiencing rapid global market growth. However, large-scale processing of passionfruit generates substantial waste, as the rind makes up over half of the fruit's mass. Thus, exploring effective ways to convert this waste into valuable products is crucial. For sustainable utilisation, the understanding of mineral, structural, thermal, and physicochemical properties of *Passiflora edulis* Sims f. *flavicarpa* fruit rind is necessary.

Therefore, the current study aimed to provide a detailed mineral, structural, thermal, physicochemical, nutritional, and antinutritional analysis of the fruit rind powder of *Passiflora edulis* Sims f. *flavicarpa*. The goal is to assess its suitability as a sustainable substrate for applications in the food industry and other industrial sectors.

Materials and Methods

Fruit collection and sample preparation

Fresh and mature fruit samples were collected from five different localities in Kerala (Kollam - KM, Thiruvananthapuram - TVM, Charummood - CMD, Chettikulangara - CKA, Pathanamthitta - PTA) during May–June 2023. The plant sample was authenticated by the Herbarium Curator of the Department of Botany, University of Kerala, and a voucher specimen was deposited in the Kerala University Botany Herbarium (KUBH). The samples were washed in running tap water and wiped clean. The fruit was cut in half, and the pulp was scraped off with a clean spatula to remove the rind and sac. The weights of the fruit pulp, sac, and rind were recorded separately using a sensitive digital balance, and the percentages were calculated. The fruit rind was cut into small pieces before being dried using a lyophiliser at -41°C. After drying, the rinds were ground into a fine powder, packed in polyethene pouches, and stored at -20°C for further analysis.

Reagents

All chemicals and reagents used for the study were of analytical grade.

Total waste generated from passionfruit

The fruits from each locality were grouped into samples of 10 each. The weight of the whole fruit, pulp, sac, and rind was recorded separately for each fruit. The percentage of inedible waste generated from the fruits was calculated using the following formula[5].

$$\text{Agro} - \text{waste generated } (\%) = \frac{Weight\ of\ the\ rind\ (g) + Weight\ of\ the\ sac\ (g)}{Weight\ of\ the\ whole\ fruit\ (g)} \times 100$$

Characterisation of rind powder

Organoleptic evaluation

Sensory evaluation of the rind powder was conducted through a survey amongst panellists (ten randomly selected members aged 20-30) using a structured questionnaire specifically developed for dry powder assessment. Sensory evaluation was conducted using a 9-point hedonic scale, with ratings ranging from 1 (lowest) to 9 (highest). Panellists rated attributes using the Hedonic scale. The attributes evaluated were: i) colour, ii) aroma, iii) texture, iv) taste, and v) overall acceptability. The judges average response was calculated for each attribute[6].

Fluorescence analysis

About 0.5 g of rind powder was taken into clean and dry test tubes. About 5 mL of ten different organic solvents was added to each tube. Subsequently, all the tubes were shaken and allowed to stand for about 20-25 minutes to develop characteristic colour reactions. The solution mixtures were observed under visible light and UV light, and the colours were recorded and compared with a standard colour chart[7].

Inductively Coupled Plasma Mass Spectrometric Analysis (ICPMS)

The rind powder was used to determine the mineral profile by Inductively Coupled Plasma Mass Spectrometry (Thermo Scientific iCAP Qc ICP-MS). For elemental determination, 0.9 mg of dried rind powder was digested with 10 mL of 69% Nitric acid in a closed-vessel microwave digestion system. Consequently, the digested plant samples were diluted to 100 mL with distilled water and stored at 4°C until further analysis[8].

Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectrum of rind powder was scanned in the 500- 4000 cm^{-1} range (Thermoscientific Nicolet iS50).

Scanning Electron Microscopy (SEM) studies

The microstructure of the powdered sample was observed under a scanning electron microscope (Carl Zeiss EVO 18 Research) at different magnifications.

Thermogravimetric analysis

Thermal stability studies of the rind powder were carried out by thermogravimetric analysis in a Simultaneous Thermal Analyser (PerkinElmer STA 8000). Ten milligrams of the samples were used for analysis. The samples were heated from 30 to 800°C at a constant temperature rate of 10°C/min under a nitrogen atmosphere[9].

Physicochemical analysis

About 9 physicochemical parameters (LOD at 150°C, Total ash, Acid-soluble ash, water-soluble ash, alcohol-soluble extractives, pH of water extract, swelling index, foaming index, and volatile oil) were analysed according to the official methods and guidelines on quality control for medicinal plant materials described by WHO[10].

Nutritional and antinutritional analysis

Determination of the nutritional and antinutritional factors was done using standard methods for Estimation of Starch[11], Estimation of Carbohydrates[12], Estimation of crude fibre content[13], Estimation of Vitamin C[14], Estimation of Protein[15], Estimation of Amino acid[16], Oxalate Estimation[17], Estimation of Phytic acid[18], Estimation of Saponin[19], Estimation of Tannin[20].

Statistical analysis

All experiments were carried out in triplicate, and the results are presented as the mean ± standard deviation. Descriptive statistics (Excel, Microsoft 2016) were used to summarise and assess the central tendency and dispersion of each variable in the physicochemical, nutritional, and antinutritional analyses.

Results and Discussion

Characterisation of rind powder

Percentage of agro-wastes produced from the fruit of Passiflora edulis f. flavicarpa

Observations of the current study showed that the fruit of *Passiflora edulis* f. *flavicarpa* (yellow passionfruit) is globose in shape with a weight that varies from 55 g to 113 g (Fig. 1). The fruit rind has an intense yellow colour at ripening. Processing this fruit results in an enormous amount of rind as agrowaste, consisting of the white mesocarp and yellow epicarp (Fig. 2). Fig. 3 compares the percentages of edible and agrowaste across the five locations. The visual comparison shows that KLM, TVM, and CKA have a higher percentage of agrowaste than the edible part. In contrast, CMD and PTA have a higher percentage of the edible part than agrowaste. Earlier reports indicated that variations are likely among plants growing in different microenvironments. For example, a study reported that above-optimum Potassium (K) levels in plants will result in large individual fruits with coarse, thick rinds and a higher number of fruits at harvest, whereas low K levels will produce small fruits with thin rinds[21]. The current study revealed that approximately 46.08-56.65% of the fruit weight was discarded as agro-waste, indicating that nearly half of the fruit went unused. Similar findings were reported

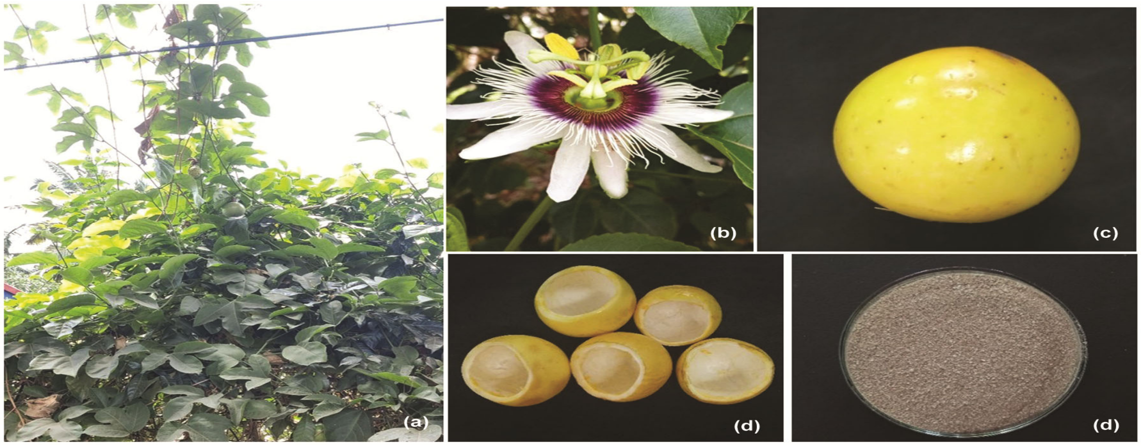

Fig. 1 — Photographs of *P. edulis* f. *flavicarpa:* (a) Habit, (b) Flower, (c) Whole fruit, (d) Rind, and (e) Rind powder.

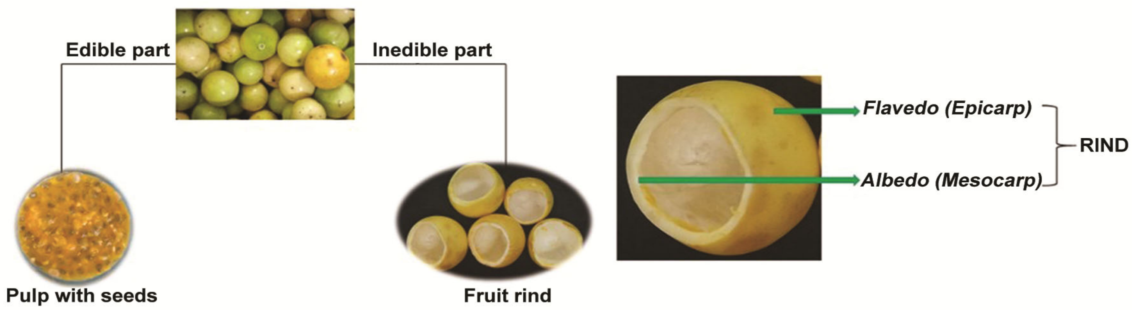

Fig. 2 — Edible and inedible parts of *P. edulis* f. *flavicarpa* and structure of fruit rind of *P. edulis* f. *flavicarpa*.

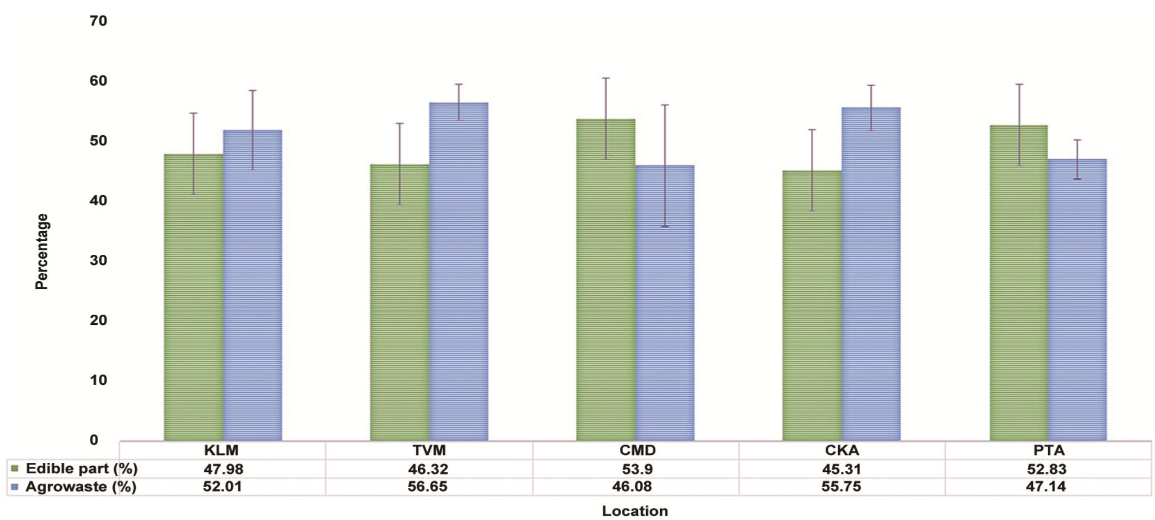

Fig. 3 — Agrowaste (%) generated from passionfruit across samples from different localities (n=10, Error bars represent SD).

by previous studies[22] as well. The literature indicates that the fruit rind has potential as a functional food. From the available literature[22] and data from the current study, it appears that processing passionfruit as fruit preserves in fruit processing industries is likely to generate large amounts of rind, which is of great economic, scientific, and technological interest.

Characterisation studies of rind powder

Organoleptic analysis

Accurate identification of the study material is crucial for evaluating and standardising it, guaranteeing consistent quality and significantly enhancing the safety and effectiveness of the value-added product. Sensory evaluation of the organoleptic characteristics of the rind powder revealed that its colour was consistent (mean score: 8.7±0.48). The aroma (mean score: 8.6±0.51), texture (mean score: 8.8±0.42), and taste (mean score: 8.9±0.31) were also found to be nearly uniform and consistent. Based on the above parameters, the overall acceptability values were also high (8.7±0.48).

Fluorescence analysis

Fluorescence analysis is a key parameter in phyto-pharmacognostic studies that characterise plant powders. Fluorescence analysis is used to identify and standardise drugs and distinguish them from adulterants using various chemical reagents that elicit distinct colours in different plant samples (Table 1). The characteristic colours are representative of the *P. edulis* f. *flavicarpa* fruit rind powder and could be used to earmark unknown samples.

Mineral analysis

Among the macro elements tested, Potassium (K) was found at the highest level (284.59 mg/kg). Among microelements tested, Selenium (Se) and Sodium (Na) were found in higher amounts. The results (Fig. 4) of this study also show that the rind was free of contamination by Cobalt (Co), Cadmium (Cd), and Lead (Pb). Compared with the existing literature, a study by Gondim *et al*.[23] reported higher Ca, Na, and Mg content in the rind of yellow passionfruit than the current study. However, the K content was higher in the current report. A study by Dos *et al.*[24] also reported a higher amount of P, K, Ca, and other microelements in the fresh yellow passionfruit rind. Even though there is fluctuation in mineral element content, it appears that the rind sample is a good source of essential mineral components.

Fourier transform infrared spectroscopy

FTIR analysis was used to determine the functional groups of the rind powder of *P. edulis* f. *flavicarpa.* In the FTIR spectra (Fig. 5), most wave numbers were found between 1740 and 1000 cm^{-1} bands. Approximately similar FTIR peak regions were reported earlier[25]. In FTIR spectroscopy, the mid-IR

Table 1 — Fluorescence analysis of *Passiflora edulis* f *flavicarpa* fruit rind under visible light and UV fluorescence

S. No	Reagent	Visible light	UV Fluorescence	
			254 nm	365 nm
1	Rind powder + NaOH	Reddish brown	Light blue	Dark blue
2	Rind powder+ HCl	Light brown	Blue	Blue
3	Rind powder + Hexane	Transparent	Light yellow	Transparent
4	Rind powder + Ethyl acetate	Pale Yellow	Light blue	Light blue
5	Rind powder + Methanol	Pale Orange	Light blue	Blue
6	Rind powder + Ethanol	Pale yellow	Greenish yellow	Transparent
7	Rind powder + Toluene	Transparent	Transparent	Transparent
8	Rind powder + Acetone	Transparent	Transparent	Transparent
9	Rind powder + Distilled water	Light brown	Blue	Blue
10	Rind powder + Chloroform	Transparent	Transparent	Transparent

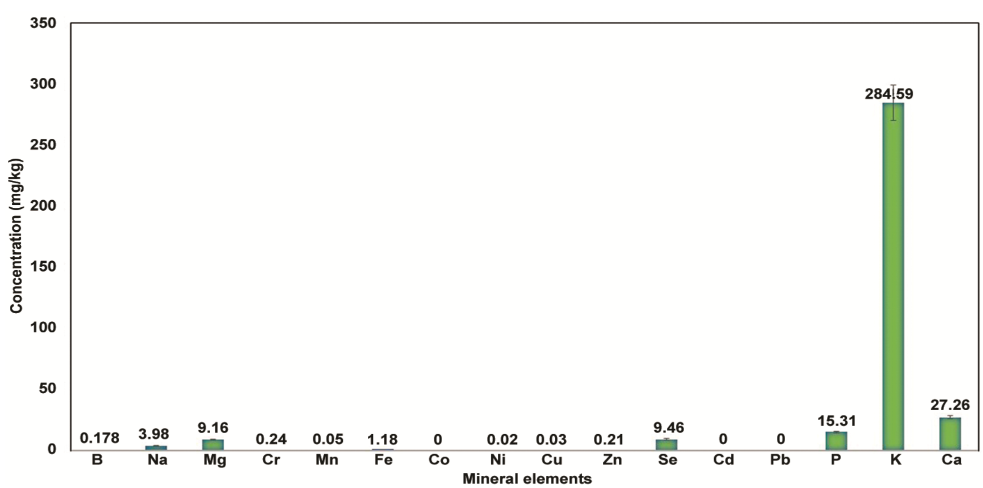

Fig. 4 — Mineral composition of fruit rind of *P. edulis* f. *flavicarpa* (n=3, Error bars represent SD).

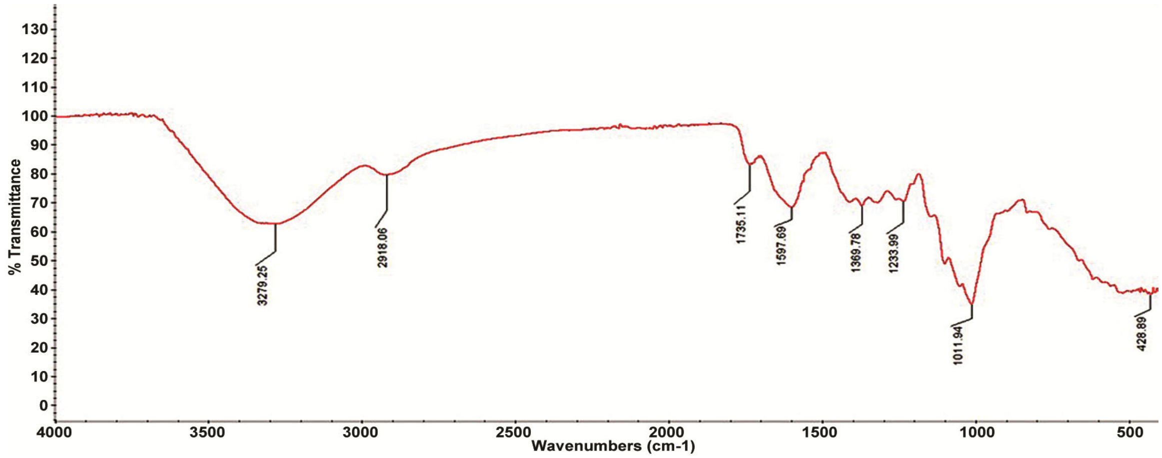

Fig. 5 — FTIR spectra of rind powder of *P. edulis* f. *flavicarpa*.

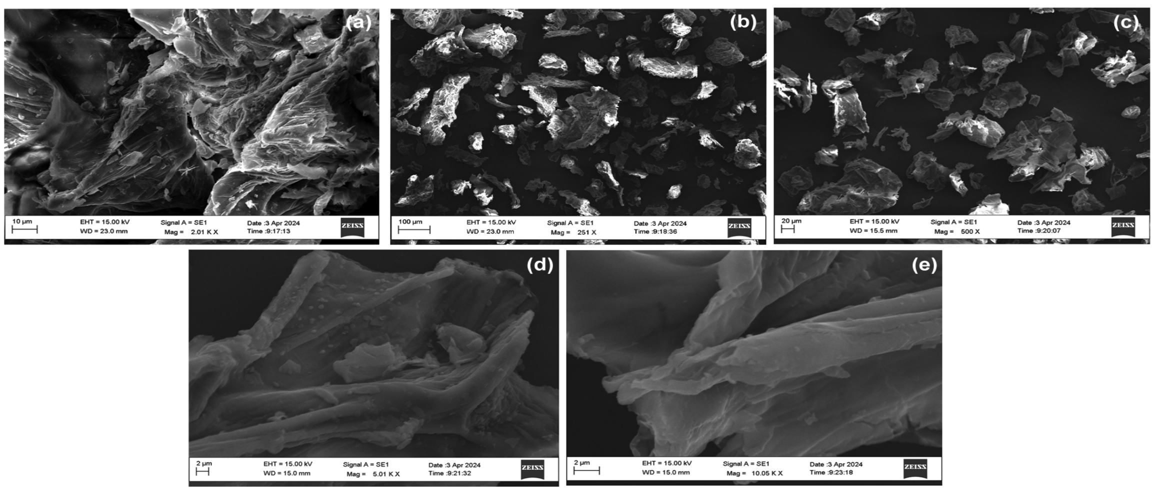

Fig. 6 — Micrograph of (SEM images) rind powder of *P. edulis* f. *flavicarpa*.

region is most widely used for sample analysis. The mid-spectrum is divided into four regions: the single bond region (2500-4000 cm^{-1}), the triple bond region (2000-2500 cm^{-1}), the double bond region (1500-2000 cm$^{-1)}$, and the fingerprint region (600-1500 cm^{-1})[26]. The FTIR spectra of the rind powder in the current study showed eight absorption bands, suggesting that the molecule is complex. In the single-bond region, a broad absorption band was observed at 3279.25, indicating the presence of a hydrogen bond, likely a hydroxyl group. A narrow band at 2918.06 indicates the existence of aliphatic compounds; most probably, it may represent a long-chain linear aliphatic compound. No triple bond region was detected, indicating no $C \equiv C$ in the material. In the double bond region, there are two absorption bands. The absorption band at 1735.11 cm^{-1} represents carbonyl compounds. Another band at 1597.69 cm^{-1} stands for an aromatic ring. The fingerprint region (600-1500 cm^{-1}) is typically specific and unique for each biological sample. Here, there are three absorption bands, with a peak at 1369.78, which is a CH_3 bending, probably due to the presence of sugars, organic acids, or phenolics. Peak at 1233.99, indicating the stretching of the lignin C-O bond, and the peak at 1011.94 is C-O/C-O-C stretching due to the presence of carbohydrates or glycosides[27]. Slight variations in the spectra of the current study with those in the existing literature may be due to the material processing methods, as mentioned previously[25].

Scanning electron microscopy

The surface morphology of biomass can undergo significant changes depending on the drying and grinding pattern during sample preparation. Fig. 6 shows the micrograph of the passionfruit rind powder under different magnifications. The SEM images of the rind powder showed a rough, slightly wrinkled surface. A study by Rosell *et al.*[28] reported similar microstructural images of some vegetal samples with high fibre content. This roughness and wrinkled nature may also be due to the breakdown of thermosensitive compounds within the rind, as suggested by Kazemi *et al.*[29]. Oliviera *et al.*[30] and Macedo *et al.*[25] reported similar results when the drying condition was increased to 60°C. The irregular surface pattern of the powder increases surface contact, facilitating easier product dispersion in solutions and enhancing the powder's water retention[31].

Thermogravimetric analysis (TGA)

Details of intermolecular structural variation induced by temperature changes are prerequisites for determining the thermal tolerance of a biological material. Thermogravimetric analysis plays a crucial role in understanding the thermal properties, thermal degradation, and weight loss of materials with variation in temperature[9]. Understanding the basic thermal properties of a material is crucial for further applications such as material design and analysis. Key tools for investigating these properties include thermogravimetric analysis (TGA). TGA monitors changes in a material's weight as it is heated or cooled. By using this technique, we can assess various properties such as heat capacity and thermal stability of the material. Here, Fig. 7 shows the TGA thermogram curves of the rind powder. The weight loss of rind powder may be divided into three regions[32]. It appears that in the first region (up to 200°C), mostly water and other volatile compounds were removed from the rind. In the second region (200-400°C), decomposition of organic compounds occurred in the rind. In the third region (300-800°C), secondary decarboxylation of the acid side groups and decomposition of carbon occurred in the ring molecules. When the temperature reached 800°C, at least 20% biomass of the rind powder was left, which indicates the good thermal tolerance capacity of the powder. The thermal tolerance of the passionfruit peel/rind powder suggests its potential use as a flour in baked goods, especially breads and cookies.

Physicochemical analysis

Physicochemical assessment of plant material is essential for identifying adulteration or mishandling of plant powders[33]. Several factors, including soil composition, fertiliser application, weather conditions, irrigation, and plant genetic traits, can influence the material's physicochemical properties and lead to variations. Results for physicochemical, nutritional, and antinutritional components in the rind powder were analysed descriptively and are listed in Table 2. In the analysis, the coefficient of variation (CV%) is useful for comparing variability across

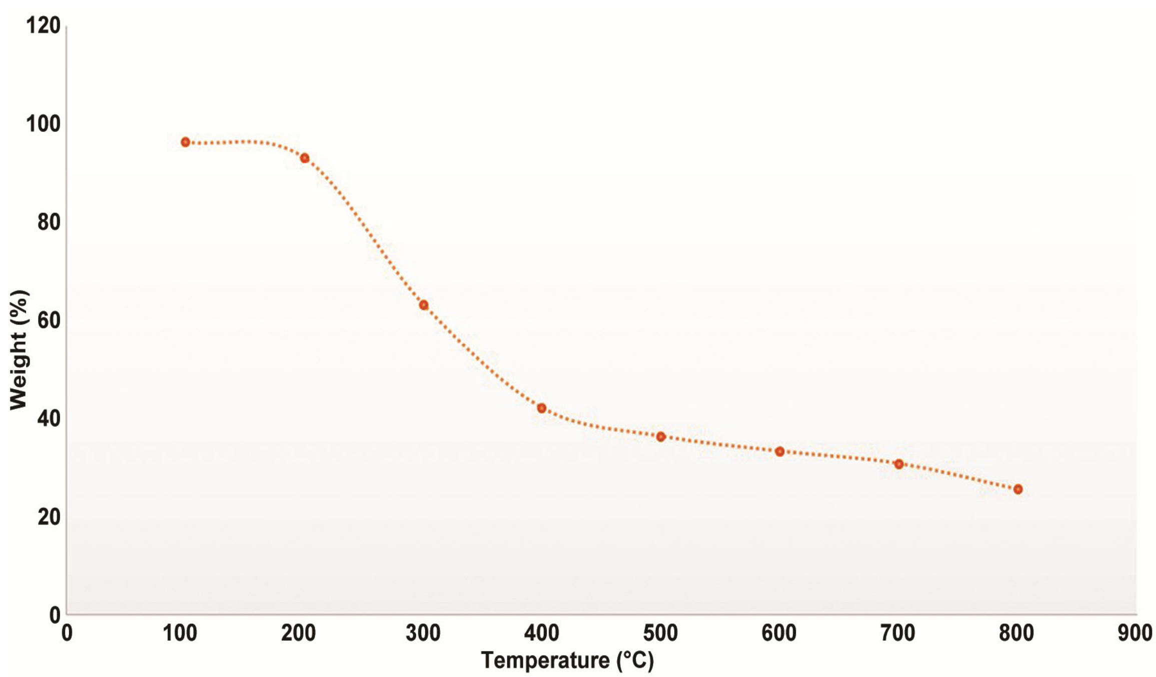

Fig. 7 — Thermogram of rind powder of *P. edulis f. flavicarpa*.

Table 2 — Descriptive statistical analysis table for physicochemical, nutritional and antinutritional analysis of fruit rind of *Passiflora edulis* f. *flavicarpa* (Current study and comparison with previous reports about orange peel)

	Current study			Previous studies (Orange Peel)[41-44]
Component	Mean±SD	CV%	Cl (95%)	Mean±SD
LOD (%)	8.02 ±0.00	0.07	0.01	9.2±0.01
Total ash (%)	7.02 ±0.00	0.08	0.01	78± 001
Acid-insoluble ash	0		0	-
Water-soluble ash (%)	5.65±001	017	0.02	-
Alcohol-soluble extractives (%)	12.38±001	0.13	0.04	-
pH of water extract	4.5±0	0	0	-
Swelling index (mL)	14±0 mL	0	0	8.08%
Foaming index	>100	-	-	-
Volatile oil	ND*	-	0	2.4-3.6%
Starch (g/100g)	66.35±000	0	0.01	-
Carbohydrate(g/100g)	44.88±0.01	0.02	0.02	52.43± 0.42 (%)
Crude fibre (%)	19.83±0.05	0.29	0.14	12.47± 0.05(%)
Vitamin C (mg/100 g)	12.04±0	0.04	0.01	6.6±0.01(mg/100 g)
Protein (g/100g)	0.05±0	10.82	0.01	3.94± 0.25 (%)
Amino acid (mg/g)	7.04±0	0.08	0.01	-
Oxalate (mg/g)	2.43±005	2.37	0.14	0.11±000 (%)
Phytic acid(mg/g)	4.74±001	0.32	0.03	0.09±003(%)
Saponin (mg/g)	2.26±005	2.54	0.14	0.03±005(%)
Tannin	ND*	-	0	1.04± 04(%)

*ND: Not detected

components, while the confidence interval (CI) provides insight into the precision of the average value. A low CV and CI in the observations indicate that the measurements are relatively consistent across replicates, suggesting high reliability and stability in the data.

The moisture content of the rind powder was 8.03%. A moisture content of less than 15% is generally preferred for plant powders, as it can help prevent bacterial and fungal proliferation[34]. Thus, it is evident that the rind powder is suitable for long-term storage. Ash values represent the quality and purity of plant powder. The total ash and water-soluble ash in the rind powder were 7.03 and 5.57%, respectively. The total ash value from the current study is closely related to the findings of Macedo *et al.*[25] [7.28±0.11]. The water-soluble ash value indicates the total amount of inorganic compounds in the powder. The result of acid-insoluble ash confirmed that the rind powder was free from earthy material contamination. Extractive values indicate the amount of active constituents released from plant powder into specific solvents. It also provides an indication of whether the plant powder is adulterated[35]. Alcohol-soluble extractives were found to be 12.39% in fruit rind powder. Compared with earlier findings[36], ash values and the percentage of alcohol-soluble extractives are within acceptable levels, suggesting that the rind powder is not adulterated.

The pH of the aqueous extract of rind powder was 4.5, indicating a slightly acidic nature. A neutral or alkaline pH is known to stimulate high microbial contamination levels in herbal preparations[37], and therefore, it may be said that the rind powder has greater stability.

The swelling and forming indices of the rind powder were 14 mL and >100 units, respectively. The swelling index is a measure of the gelling nature of the sample and refers to the millilitre volume to which 1 g of herbal material swells under specific conditions[38]. The foaming index gauges the foam production ability of a liquid extract from plant materials, indicating the presence of active surface agents like saponins. The lower swelling and foaming indices of the rind powder show a low level of gel-forming capacity and saponin (antinutritional factor) content. Although the fruit had a characteristic smell, volatile oil was not detected in the rind powder sample.

Nutritional and antinutritional analysis

Nutrients, including carbohydrates, vitamins, minerals, and fats, are essential in our food. These components are crucial for the survival of all living organisms. While plants can produce these nutrients, we rely on plants and other animals, directly or indirectly, to meet our nutritional needs. The results of the nutritional analysis of the rind powder showed higher levels of Starch (66.35 g/100 g) and carbohydrates (44.87 g/100 g). Previous studies also reported that these nutritional factors are present in greater amounts in the rind powder of *P. edulis* f. *flavicarpa*[24,25]. Compared with the existing literature[24], the current study reported a notably higher amount of starch content than previous studies. Plants with higher starch content can be used for many purposes, including the production of industrially important solvents such as ethanol, bioethanol, and lactic acid, as well as animal feed and food[39]. The results of the current study also suggest that the biomass could be utilised for different applications, such as food and biofuel.

The crude fibre content of rind powder was detected to be low (19.80%). Earlier, a total fibre content of 61.16% from this fruit rind was reported[24]. Oliveira *et al.*[30] reported that total dietary fibre ranged from 63.98 to 72.62%, with significant pectin content. Only a trace amount of Vitamin C (12.04 mg/100 g) and protein (0.05 g /100 g) were found in rind powder. The amino acid content in the fruit rind was 7.05 mg/g in the current study. Amino acids like lysine, threonine, leucine, and valine were previously isolated from purple passionfruit[40].

The results for the antinutritional content of the rind are also presented. The only antinutritional factor that appeared to be high was phytic acid (4.76 mg/100 g). Phytic acid is a traditional anti-nutrient that binds to minerals such as iron, zinc, calcium, and magnesium, preventing their absorption. It appears that phytate should be removed before use. However, the oxalate and saponin levels in the sample are below the permissible limits, and tannin was absent, ensuring they do not present any health risks.

The findings regarding the physicochemical and nutritional composition from this study were compared to the existing literature on orange peels[41-44], which are commercially used as a potential source of beneficial compounds and valuable materials[45]. The comparison revealed that certain factors in passionfruit rind powder were very similar to those of orange peels, specifically, moisture content and ash values. Additionally, the nutrient composition showed similarities in the carbohydrate and crude fibre content. However, passionfruit rind powder exhibited a higher vitamin C content, aligning with the findings of Chuku *et al.*[46]. These results indicate that passionfruit rind can substitute for orange peels and serve in similar applications.

Overall, the nutritional analysis indicates a high content of starch and total carbohydrates. Also, the antinutritional contents were below the acceptable level. Hence, it is evident that the fruit rind powder can be consumed without fear of toxicity. Since the rind has a high carbohydrate content, it may be processed into flours for various food applications. Additionally, the thermogravimetric properties of the rind would facilitate processing, as most food applications require transformation through heat processing before use.

Conclusion

The study revealed that nearly half of the *Passiflora edulis* f. *flavicarpa* fruit (51%) is discarded as agro-waste at least in the sites included in the present study. However, it appears that the agrowaste biomass from the fruit rind of *P. edulis* f. *flavicarpa* could be a cost-effective resource for other food industries. The findings of this study could reveal the importance of the rind powder. Sensory evaluation of the rind powder revealed that colour, aroma, texture and taste were consistent and rated as highly acceptable. The structural properties (FTIR and SEM) of the rind powder displayed favourable characteristics. The thermogravimetric analysis showed that the rind powder exhibits better thermal tolerance (up to 800°C), suggesting its potential for use as a feed in the food industry. The comprehensive physicochemical, nutritional [starch (66.35±0 g/100 g), carbohydrates (44.88±0.01 g/100 g)] and antinutritional analyses, and mineral profiling (Potassium-284.58 mg) indicate that the rind powder could be used judiciously. Thus, the agrowaste from *Passiflora edulis* f. *flavicarpa* in food preserve processing industries could serve as a base flour for various foods and for the value addition of other food products.

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Conflict of interest

The authors of the present work declare that there is no conflict of interest associated with this manuscript.

References

1 Rekha V, Bhanu C, Prakash and Gowri K, Synthesis and characterization of superabsorbent natural polymers from agro-waste fibres, *Indian J Fibre Text Res*, 2022, 47(4), 395-402, doi: 10.56042/ijftr.v47i4.54789.

2 Xiong X, Yu I K M, Tsang D C, Bolan N S, Ok Y S, *et al.*, Value-added chemicals from food supply chain wastes: State-of-the-art review and future prospects, *Chem Eng J*, 2019, 375(1), 121983, doi: 10. 1016 /j. cej. 2019 .121983.

3 Mitra S, Tropical and subtropical fruits in India, *J Trop Crop Sci*, 2014, **1**(1), 1–2, doi: 1029244/jtcs111-2.

4 Bernacci L C, Soares-Scott M D, Junqueira N T V, Passos I R D S and Meletti, *Passiflora edulis* Sims: the correct taxonomic way to cite the yellow passion fruit (and of others colors), *Rev Bras Frutic*, 2008, 30(1), 566-576.

5 Madalageri D M, Bharati P and Kage U, Physicochemical properties, nutritional and antinutritional composition of pulp and peel of three mango varieties, *Int J Educ Sci Res*, 2017, **7**(1), 81-94.

6 Nii K K, George T O, Mary O, Papa T A, Wiafe-Kwagyan M, *et al.*, Sensory evaluation, descriptive textural analysis, and consumer acceptance profile of steamed gamma-irradiated Pleurotus ostreatus (Ex. Fr.) Kummer kept in two different storage packs, *Sci Afr*, 2020, 8(1), e00328, doi: 10.1016/j.sciaf.2020.e00328.

7 Nanna R S, Banala M, Pamulaparthi A, Kurra A and Kagithoju S, Evaluation of phytochemicals and fluorescent analysis of seed and leaf extracts of *Cajanus cajan* L, *Int J Pharm Sci Rev Res*, 2013, 22(1), 11-18.

8 Olawuwo O S, Abdalla M A, Mühling K H and McGaw L J, Proximate analysis of nutrients and *in vitro* radical scavenging efficacy in selected medicinal plant powders with potential for use as poultry feed additives, *S Afr J Bot*, 2022, 146(1), 103-110, doi: 101016/ jsajb 2021 09038.

9 Shivangi S, Dorairaj D, Negi P S and Shetty N P, Development and characterisation of a pectin-based edible film that contains mulberry leaf extract and its bio-active components, *Food Hydrocoll*, 2021, 121(1), 107046, doi: 101016/jfoodhyd2021107046.

10 World Health Organization, *Quality control methods for medicinal plant materials*, World Health Organization, 1998.

11 Hansen J and Møller I B, Percolation of starch and soluble carbohydrates from plant tissue for quantitative determination with anthrone, *Anal Biochem*, 1975, 68(1), 87-94, doi: 101016/0003-26977590682-X.

12 Hedge J E and Hofreiter B T, *Carbohydrate chemistry*, Whistler R L and Be Miller J N, Eds, (Academic Press, New York), 17, 1962.

13 Rahul C, Lincy J, Methew G and Pankaj P, Pharmacognostic standardization and phytochemical screening of *Albizzia lebbeck*, *J Chem Pharm Res*, 2010, 21(1), 432-443.

14 Rao B and Deshpande V, *Experimental Biochemistry*, (Tunbridge Wells, Kent: Anshan), 2006.

15 Bradford M M, Rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding, *Anal Biochem*, 1976, 72(1), 248–254, doi: 101006/abio19769999.

16 Moore S and Stein W H, Photometric ninhydrin method for use in the chromatography of amino acids, *J Biol Chem*, 1948, 176(1), 367–388, doi: 101016/S0021-92581851034-6.

17 Ohlweiler A O M and Schneider M H, Standardization of potassium permanganate by titration of sodium oxalate in presence of perchloric acid and manganeseII sulfate, *Anal Chim Acta*, 1972, 58(1), 477–480, doi: 101016/S0003-26707280031-X.

18 Latta M and Eskin M, A simple and rapid colorimetric method for phytate determination, *J Agric Food Chem*, 1980, 28(1), 1313–1315.

19 Chen Y F, Yang C H, Chang M S, Ciou Y P and Huang Y C, Foam properties and detergent abilities of the saponins from *Camellia oleifera*, *Int J Mol Sci*, 2010, **11**(11), 4417-4425, doi: 103390/ijms11114417.

20 Schanderi S H, *Methods in food analysis*, (Academic Press, New York), 1970.

21 Reese R L and Koo R C J, N and K fertilization effects on leaf analysis, tree size, and yield of three major Florida orange cultivars, *J Am Soc Hortc Sci*, 1975, 100(1), 195-198.

22 Kulkarni S G and Vijayanand P, Effect of extraction conditions on the quality characteristics of pectin from passion fruit peel *Passiflora edulis* f *flavicarpa*, *LWT-Food Sci Technol*, 2010, 43(1), 1026–1031, doi: 101016/jlwt200911006.

23 Gondim J A M, Moura M F V, Dantas A S, Medeiros R L S and Santos K M, Composicao centesimal e de mineraisemcascas de frutas, *Food Sci Technol*, 2005, 254(1), 825–827.

24 Dos Reis L C R, Facco E M P, Salvador M, Flôres S H and de Oliveira Rios A, Antioxidant potential and physicochemical characterization of yellow, purple and orange passion fruit, *J Food Sci Technol*, 2018, 55(1), 2679-2691, doi: 101007/s13197-018-3190-2.

25 Macedo M C C, Correia V T D V, Silva V D M, Pereira D T V, Augusti R, *et al.*, Development and characterization of yellow passion fruit peel flour *Passiflora edulis* f *flavicarpa*, *Metabolites*, 2023, 136(1), 684, doi: 103390/metabo13060684.

26 Nandiyanto A B D, Oktiani R and Ragadhita R, How to read and interpret FTIR spectroscope of organic material, *Indones J Sci Technol*, 2019, 41(1), 97-118, doi: 1017509/ijostv4i115806.

27 Alaa El-Din G, Amer A A, Malsh G and Hussein M, Study on the use of banana peels for oil spill removal, *Alex Eng J*, 2018, 57(1), 2061–2068, doi: 101016/jaej201705020.

28 Rosell C M, Santos E and Collar C, Physico-chemical properties of commercial fibres from different sources: A comparative approach, *Food Res Int*, 2009, 42(1), 176–184.

29 Kazemi M, Khodaiyan F, Labbafi M, Saeid Hosseini S and Hojjati M, Pistachio green hull pectin: Optimization of microwave-assisted extraction and evaluation of its physicochemical, structural and functional properties, *Food Chem*, 2019, 271(1), 663–672.

30 Oliveira C F, Gurak, P D, Cladera-Olivera F and Marczak L D F, Evaluation of physicochemical, technological and morphological characteristics of powdered yellow passion fruit peel, *Int Food Res J*, 2016, 234(1), 1653-1662.

31 da Silva Alves P L, Berrios Jose J D J, Pan J and Ramirez Ascheri J L, Passion fruit shell flour and rice blends processed into fiber-rich expanded extrudates, *CYTA-J Food*, 2018, 16(1), 901–908.

32 Garcia M V, Milani M S and Ries E F, Production optimization of passion fruit peel flour and its incorporation into dietary food, *Food Sci Technol Int*, 2020, 262(1), 132-139, doi: 101177/1082013219870011.

33 Sumitra C, Dishant D and Disha M, Pharmacognostic, phytochemical, physicochemical and fluorescence analysis of *Terminalia bellerica* leaf and stem, *World J Pharm Sci*, 2014, 24(1), 390-396.

34 Singh H, Mishra A and Mishra A K, Pharmacognostical and physicochemical analysis of *Cleome viscosa* L seeds, *Pharmacogn J*, 2017, 93(1), 372-377, doi: 105530/pj2017363.

35 Tatiya A, Surana S, Bhavsar S, Patil D and Patil Y, Pharmacognostic and preliminary phytochemical investigation of *Eulophiaherbacea* Lindl. Tubers Orchidaceae, *Asian Pac J Trop Dis*, 2012, 21(1), 50-55, doi: 101016/S2222-18081260123-6.

36 Gempo N, Yeshi K, Jamtsho T, Jamtsho L and Wangchuk P, Development of quality control parameters for two Bhutanese medicinal plants *Aster flaccidus* Bunge and *Aster diplostephioides* DC Benth ex CB Clarke using traditional and modern pharmacognostical platforms, *Heliyon*, 2024, 10(3), e24969, doi: 101016/jheliyon2024e24969.

37 Aziz N, Wal A, Wal P and Pal R S, Preparation and evaluation of the polyherbal powder: the nature's pharmacy for the treatment of diabetes mellitus and its complications, *Pharmacophore*, 2019, 10(2019), 60-70.

38 Gaila N M, Buba M and Ahmed A, Evaluation of the swelling ability and water binding capacity of some local plant consumed in adamawa state, *J Chem Soc Niger*, 2020, 45(5), doi: 1046602/jcsnv45i5530.

39 Teles G H, dos Santos E C, da Silva G B, Da Silva M G L, da Silva J M, *et al.*, Full utilization of the yellow passion fruit peel: Chemical characterization and valorization to reduce biomass waste, *Ind Crop Prod*, 2023, 206(1), 117593, doi: 101016/jindcrop2023117593.

40 He X, Luan F, Yang Y, Wang Z, Zhao Z, *et al.*, *Passiflora edulis*: an insight into current researches on phytochemistry and pharmacology, *Frontpharmacol*, 2020, **11**(1), 617, doi: 103389/fphar202000617.

41 Gotmare S and Gade J, Orange peel: A potential source of phytochemical compounds, *Int J Chem Tech Res*, 2018, 11(1), 240-243.

42 Mishra S and Singh S, Organoleptic and morphological analysis of citrus peel powder, *Asian Food Sci J*, 2022, 21(11), 1-11, doi: 109734/afsj/2022/v21i11591.

43 Anwar T, Qureshi H, Fatima A, Sattar K, Albasher G, *et al.*, *Citrus sinensis* peel oil extraction and evaluation as an antibacterial and antifungal agent, *Microorganisms*, 2023, 117(1), 1662, doi: 103390/microorganisms11071662.

44 Akinlabu K D, Owoeye T F, Emetere M E, Jonathan H O, Owoeye D I, *et al.*, Investigation of proximate analysis and phytochemical screening of dry orange waste *Citrus sinensis* extract: From Agrowaste to sustainable development, In *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2024, 1342(1), 012016, doi: 101088/1755 1315/1342/1/012016.

45 Jena S R, Das S, Pradhan A, Samal A, Sahoo S, *et al.*, Orange peel pectin-functionalized schiff base hydrogel ameliorates wound healing via regulating M2 macrophage-polarization: Insights from *In vitro* and zebrafish model studies, *ACS Appl Bio Mater*, 2026, 9(3), 1606-1621, doi: 10.1021/acsabm.5c02 130.

46 Chuku E C, Agbagwa S S, Wekhe O E and Chuku O S, Evaluation of nutrient, anti-nutrient and acids compositions of citrus peels, *J Agric Environ Res Manag*, 2020, 52(1), 530-540.