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Comparative phytochemical profiling of passion fruit (*Passiflora edulis* Sims) rind extracts and a potential for sustainable waste valorization

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Abstract
The phytochemical profile of passion fruit (Passiflora edulis) rind remains largely unexploited, as it is primarily discarded as processing waste after juice extraction. This study aims to evaluate the physical characteristics of mature Passiflora edulis (Kaveri hybrid variety) and to investigate the qualitative phytochemical composition of its rind using three solvent extraction systems of varying polarities: distilled water, methanol, and chloroform. Physical characterization of 100 fresh fruits revealed that the rind constitutes the major portion of the biomass, representing approximately 55% of the total fruit weight (average fresh rind weight of 35 g from a 64 g fruit). Shade drying of the rind resulted in a significant mass reduction (average dry weight of 14 g), highlighting its high water-holding capacity. Qualitative phytochemical screening demonstrated a clear polarity-dependent distribution of secondary metabolites. Terpenoids, coumarins, and carotenoids were present across all three extracts. However, polar compounds such as phenols and flavonoids were selectively recovered only in the methanolic and aqueous extracts. Chloroform and distilled water extracts contained steroids and saponins, while phytosterols were uniquely found in the chloroform extract, and quinones were present exclusively in the methanol extract. These results suggest that the Kaveri hybrid passion fruit rind holds substantial promise as a sustainable, low-cost source of bioactive compounds for pharmaceutical, food, and nutraceutical applications, promoting effective waste valorization in agricultural processing industries.

Keywords: *Passiflora edulis*, passion fruit rind, phytochemical screening, solvent extraction, bioactive compounds, cold maceration, waste valorization

Introduction

Passion fruit (Passiflora edulis) is a high-value tropical climbing vine belonging to the Passifloraceae family. Originating from South America, particularly Brazil, the plant is currently cultivated extensively across tropical and subtropical regions worldwide owing to its unique sensory attributes, rich nutritional profile, and rising commercial importance (Correa *et al*. 2016) [8]. Commercially grown passion fruits mainly belong to two distinct varieties: the yellow passion fruit (Passiflora edulis f. flavicarpa) and the purple passion fruit (Passiflora edulis f. edulis) (Fonseca *et al*. 2022) [12]. While yellow passion fruit is primarily utilized for industrial juice and beverage production, the purple variety is more commonly sold in fresh fruit markets due to its sweeter pulp profile (Meletti *et al*. 2005) [24].

Beyond its direct consumption as food, P. edulis has an extensive history of use in traditional and ethnobotanical medicine. In several countries, distinct botanical parts of the vine are employed in preparations for managing conditions such as anxiety, insomnia, bronchitis, asthma, and urinary tract disorders (Otify *et al*. 2015) [28]. For instance, P. edulis leaves are utilized in Europe and the Americas as standardized herbal sedatives and anxiolytics (Fonseca *et al*. 2022) [12]. These documented therapeutic properties are fundamentally attributed to the abundance of highly active secondary metabolites synthesized throughout the plant tissues, particularly flavonoids, alkaloids, terpenoids, glycosides, and phenolic compounds (Tanmay *et al*. 2025) [40].

Among these, major flavonoids—such as quercetin, luteolin, apigenin, isovitexin, and isoorientin—represent the primary active constituents (Pinto *et al*. 2023) [30]. These molecules have been heavily studied for their diverse pharmacological profile, exhibiting anti-inflammatory, anticancer, antioxidant, neuroprotective, and antidepressant actions (Otify *et al*. 2015; Pinto *et al*. 2023) [28, 30]. Additionally, the plant tissues accumulate beta-carboline alkaloids like harmine, which demonstrate monoamine oxidase (MAO) inhibition, which may explain their sedative properties (Otify *et al*. 2015) [28].

Despite its massive commercial cultivation, the industrial processing of passion fruit for juice, pulp, and nectar generates prohibitive amounts of agricultural waste. The seeds and rinds are discarded, with the rind (peel) representing the single largest fraction of this waste, accounting for over 50% of the total fresh fruit biomass (Abdul Manap *et al*. 2020) [2]. Improper disposal of this organic waste leads to environmental challenges and high management costs for processors. However, recent waste valorization research indicates that these by-products are far

from useless. In fact, many bioactive polyphenols, fibers, and antioxidants reside in significantly higher concentrations within the discarded rind than in the consumable fruit pulp (Wang *et al*. 2024) [43].

The passion fruit rind is recognized as an abundant reservoir of pectin, crude fibers, and bioactive polysaccharides, which hold notable functional value in food formulation and clinical health (Canteri *et al*. 2020) [6]. Moreover, recent investigations have isolated powerful natural antioxidants, including anthocyanins, flavonoids, and coumarins, which play a direct role in mitigating oxidative stress and inhibiting microbial proliferation (Rojas-Garbanzo 2025) [32]. Exploiting these natural compounds not only yields high-value bioactive raw materials for the functional food and pharmaceutical sectors but also represents a highly sustainable, circular-economy-aligned strategy for agricultural waste management (Correa *et al*. 2016) [8].

To maximize the recovery of these targeted compounds, optimization of the extraction phase is of paramount importance. The yield and composition of isolated phytochemicals are heavily dictated by the extraction solvent's chemical properties, especially polarity (Azmir *et al*. 2013) [4]. Because phytochemical classes possess highly diverse chemical structures, their solubility varies from highly hydrophilic (polar) to highly lipophilic (non-polar) (Pinto *et al*. 2023) [30]. While some non-polar solvents are effective for extracting lipophilic phytosterols, highly polar solvents are required to recover free polyphenols and glycosides (Wang *et al*. 2024) [43]. Consequently, comparing extraction efficiencies across solvents of differing polarities is crucial to map the complete phytochemical profile of passion fruit rind.

Although previous research has touched upon specific compounds in passion fruit rinds, comparative profiles assessing extraction efficiencies using water, alcohol, and organic systems remain scarce in the literature (Correa *et al*. 2016) [8]. This study addresses this gap by investigating the physical characteristics and conducting a comparative qualitative phytochemical screening of the rind of P. edulis (Kaveri hybrid variety) using three distinct extraction solvents: distilled water (highly polar), methanol (moderately polar), and chloroform (non-polar). The findings aim to facilitate the selection of appropriate extraction strategies for downstream functional food and drug development, shifting agricultural by-products into high-value biological resources.

Materials and Methods

1. Raw Material Acquisition and Botanical Authentication

Fresh, healthy, and mature passion fruits (Passiflora edulis) were harvested during the monsoon season of 2023–2024[26, 33] from an experimental kitchen garden situated in Nargund Taluk, Gadag District, and Karnataka, India. The cultivation was initiated using high-quality hybrid Kaveri seeds supplied directly by the Indian Institute of Horticultural Research (ICAR-IIHR), Bangalore, and Karnataka, India. Botanical identification and formal authentication of the plant specimens were conducted by the Botanical Survey of India (BSI), Coimbatore, Tamil Nadu, India, and an authenticating certificate was officially issued to the research scholar.

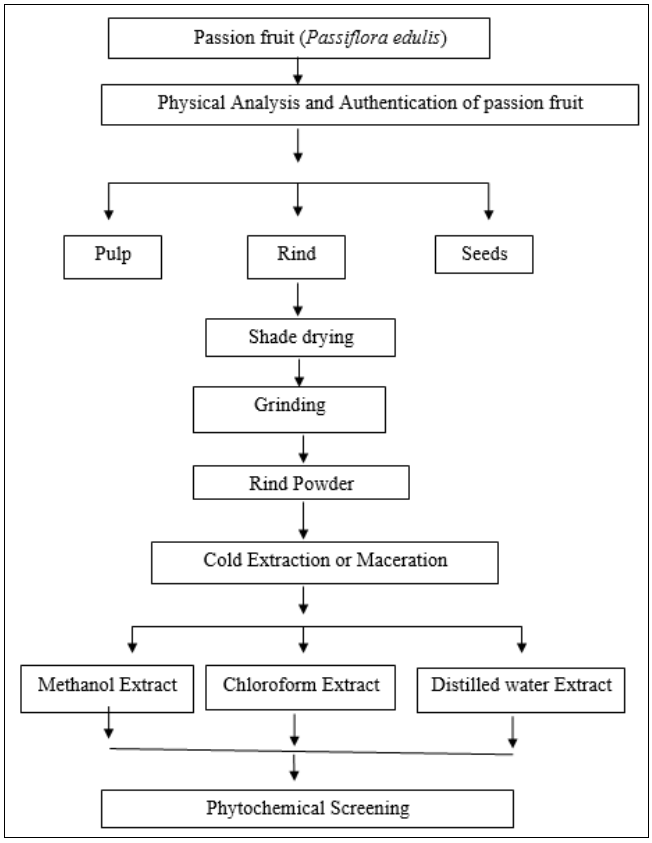

Fig 1: Represents the method used in the preparation and qualitative phytochemical screening of *Passiflora edulis* rind.

2. Morphological and Physical Characterization

A representative cohort of 100 fresh, undamaged passion fruits was randomly selected, cleaned, and analyzed to characterize physical attributes. The whole fruits were weighed individually, and their physical dimensions (length and equatorial diameter) were measured using digital vernier calipers. Subsequently, each fruit was cut open manually using a clean stainless-steel scalpel, and the inner components—namely the seed-bearing pulp and the surrounding rind (peel)—were carefully separated. The separate weights of the pulp, seeds, and fresh rind were recorded. The average values were computed using the standard formula:

$$Average\ Weight = \frac{Total\ Weight}{Total\ Number\ of\ Fruits} \quad (N = 100)$$

3. Preparation and Drying of Passion Fruit Rind

Following separation, the fresh passion fruit rinds were thoroughly rinsed in deionized water to remove any remaining pulp debris. Excess surface moisture was blotted dry using sterile paper towels. To stabilize the raw material and prevent the degradation of heat-sensitive phytochemicals, the rinds were placed in a thin layer on clean drying trays and subjected to shade drying under a continuous-circulation air system (ambient temperature) until their mass stabilized (approximately 5 days) (Wasagu *et al*. 2016) [44]. Once dried, the rinds were re-weighed to assess moisture loss and water-holding capacity. Finally, the dried rinds were pulverized into a uniform fine powder using a laboratory mortar and pestle and passed through a 60-mesh sieve. The powder was stored in hermetically sealed, light-resistant containers at room temperature until further analysis.

Fig 2: Rind of passion fruits is harvested, dried and pulverized into fine powder form for the extraction process.

4. Solvent Extraction via Cold Maceration

Extraction was executed via cold maceration to protect thermolabile compounds from thermal degradation (Handa *et al*. 2008) [15]. Three extraction solvents of contrasting polarities were utilized: distilled water (polar, dielectric constant ε = 80.1), methanol (moderately polar, ε = 32.7), and chloroform (non-polar, ε = 4.8) (Azmir *et al*. 2013) [4]. For each solvent, a 25.0 g portion of the dry rind powder was macerated in 250 mL of the solvent, maintaining a strict 1:10 (w/v) solid-to-solvent ratio (Handa *et al*. 2008) [15]. The mixture was kept in dark glass Erlenmeyer flasks at room temperature (25 ± 2 °C) overnight. To ensure thorough solvent-matrix contact and maximize mass transfer, the flasks were shaken periodically at regular intervals. After 24 hours, the mixtures were filtered through double-layered Whatman No. 1 filter paper. The resulting clear liquid filtrates (aqueous, methanolic, and chloroform extracts) were collected, volume-standardized to 200 mL, and stored in tightly sealed amber vials in the dark at 4 °C to prevent photo-oxidation.

5. Qualitative Phytochemical Screening Protocols

The three crude solvent extracts were subjected to qualitative phytochemical screening to identify key groups of secondary metabolites. The screenings were conducted using established standard biochemical protocols as detailed in Table 1.

Table 1: Qualitative screening tests and references used for phytochemical profiling.

Phytochemical Group	Common Screening Method	Standard Literary References
Alkaloids	Dragendorff's bismuth potassium iodide test	Trease and Evans (2009); Harborne (1998) [16, 41]
Phenols	Ferric chloride complexation test	Harborne (1998); Sofowora (1993) [16, 36]
Flavonoids	Shinoda reduction test (Mg + HCl)	Trease and Evans (2009); Kokate (2008) [22, 41]
Terpenoids	Salkowski chloroform-acid ring test	Harborne (1998); Ayoola *et al*. (2008) [3, 16]
Steroids	Liebermann–Burchard acetic anhydride test	Trease and Evans (2009) [41]
Saponins	Frothing index test (aqueous agitation)	Harborne (1998); Kokate (2008) [16, 22]
Tannins	Gelatin precipitation test	Trease and Evans (2009); Sofowora (1993) [36, 41]
Glycosides	Keller–Kiliani glacial acetic acid test	Trease and Evans (2009) [41]
Phytosterols	Liebermann–Burchard modification test	Kokate (2008) [22]
Lignins	Phloroglucinol–HCl stain test	Johansen (1940); Trease and Evans (2009) [19, 41]
Quinones	Bornträger's alkaline extraction test	Harborne (1998) [16]; Evans (2002)
Anthocyanins	NaOH / HCl color shift test	Harborne (1998) [16]
Coumarins	NaOH alkali-UV fluorescence test	Trease and Evans (2009) [41]
Carotenoids	Concentrated sulfuric acid dehydration test	Harborne (1998) [16]

Results

1. Morphological and Physical Characteristics of the Fresh Fruit

The physical profile of 100 mature fresh passion fruits of the Kaveri hybrid variety was analyzed. The fruit shape was predominantly oval-to-round, characterized by an intense colored exocarp (purple/yellow) and a distinct white fibrous endocarp. The sweet-sour orange-colored pulp encapsulated numerous small, mature black seeds. The average values recorded for fruit mass, physical dimensions, and component weights are summarized in Table 2.

Table 2: Mean physical metrics and component weight distribution of fresh P. edulis (n = 100).

Physical Parameter / Component	Mean Measured Value (± SD / Weight %)
Total weight of fresh fruit	64.0 g
Length of fresh fruit	10.0 cm
Equatorial diameter of fresh fruit	9.5 cm
Consumable pulp and seed weight	29.0 g (45.3%)
Pulp weight (isolated)	17.0 g (26.6%)
Seed weight (isolated)	12.0 g (18.7%)
Rind weight (fresh status)	35.0 g (54.7%)
Rind weight (shade-dried status)	14.0 g (21.9% of fresh fruit weight)

A critical analysis of the mass distribution data reveals that the rind constitutes the largest single component of the passion fruit, comprising approximately 55% of the total fresh fruit weight. The isolated pulp and seeds accounted for 26.6% and 18.7% respectively. Upon drying, a drastic mass reduction was observed in the rind: its average weight dropped from 35.0 g to 14.0 g. This equates to a 60% mass loss, primarily due to the evaporation of free moisture, which reflects the high initial water-holding capacity and moisture content of the fresh outer pericarp tissues.

2. Comparative Phytochemical Screening of Rind Extracts

The cold maceration process yielded exactly 200 mL of concentrated extract for each of the three solvent systems (aqueous, methanol, and chloroform) from the initial 25 g of dried rind powder.

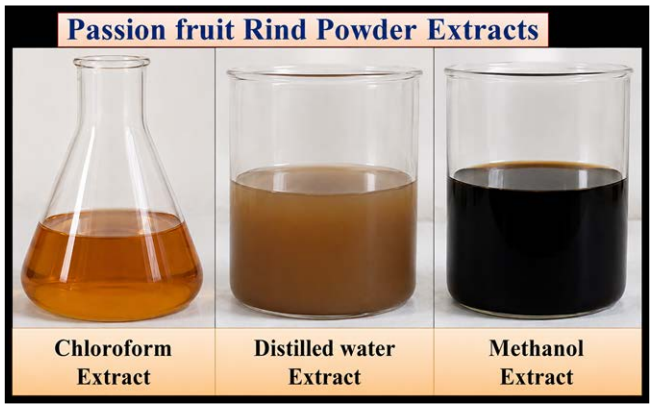

Fig 4: Solvent extracts prepared from dried yellow passion fruit rind powder using chloroform, methanol and distilled water.

Qualitative phytochemical profiling of these extracts revealed an active presence of several valuable classes of secondary metabolites, with their distribution strongly correlated to solvent polarity. The consolidated screening results are presented in Table 3.

Table 3: Qualitative phytochemical screening of P. edulis rind in different solvents.

Phytochemical Group	Chloroform (Non-Polar)	Methanol (Mod. Polar)	Distilled Water (Polar)
Alkaloids	−	−	−
Phenols	−	+	−
Flavonoids	−	+	+
Terpenoids	+	+	+
Steroids	+	−	−
Saponins	+	−	+
Tannins	−	−	+
Glycosides	−	−	+
Phlobatannins	−	−	−
Phytosterols	+	−	−
Lignins	−	−	−
Quinones	−	+	−
Anthocyanins	−	−	−
Coumarins	+	+	+
Carotenoids	+	+	+

A clear partition of phytochemicals based on solvent polarity was observed. Terpenoids, coumarins, and carotenoids were identified in all three extracts, showing their high extraction versatility across both polar and lipophilic environments. In contrast, highly polar phenolic compounds and flavonoids were restricted to polar matrices. Phenols were detected solely in the methanol extract, while flavonoids were positive in both methanol and distilled water extracts. Non-polar lipophilic phytosterols and steroids were successfully recovered only in the chloroform extract. Saponins were found in both the distilled water and chloroform extracts, but were absent in the methanolic extract. Additionally, quinones were uniquely isolated within the methanolic system. Certain classes of compounds—specifically alkaloids, tannins, glycosides, phlobatannins, lignins, and anthocyanins—were not detected in any of the extracts under the current qualitative screening conditions.

Discussion

1. Physical Traits and Bio-Resource Feasibility

The physical analysis confirmed that the rind constitutes approximately 55% of the total fresh passion fruit mass (Table 2), highlighting its major volume in industrial fruit-processing by-products. These morphological values align closely with previous phenotypic reports for Passiflora species, which establish that the thick peel typically makes up the bulk of the fruit (Meletti *et al*. 2005) [24]. The massive drop in rind weight during shade drying (from 35 g to 14 g) points to a high water-holding capacity. This physical property is linked to the high concentrations of pectins, structural dietary fibers, and complex cell-wall polysaccharides present in the passion fruit pericarp (Canteri *et al*. 2020) [6]. For processing industries, this high moisture level represents a critical hazard. Dehydration is essential prior to long-term storage, as high water activity promotes rapid microbial degradation and enzymatic hydrolysis of active principles. Therefore, air-controlled shade drying represents a simple, low-cost stabilization method that halts microbial growth and preserves the chemical integrity of the rind powder (Wasagu *et al*. 2016) [44].

2. Influence of Solvent Polarity on Extraction Selectivity

The qualitative profile (Table 3) clearly indicates that solvent polarity plays a key role in dictating the extraction pattern of secondary metabolites. This selectivity is governed by the 'like dissolves like' principle, where compounds dissolve in solvents of similar dielectric constants (Azmir *et al*. 2013) [4]. Polar phenolic and flavonoid molecules showed strong solubility in methanol and water. Phenols and flavonoids are renowned for their structural hydroxyl groups, which readily form hydrogen bonds with polar oxygen atoms in water and methanol (Wang *et al*. 2024) [43]. Interestingly, phenols were positive only in the methanolic system, indicating that water maceration might not be sufficient to break certain cell-wall matrices or that some phenolics are less soluble in purely aqueous environments without an organic co-solvent (Selvi *et al*. 2024) [33].

In contrast, the non-polar organic solvent chloroform was highly effective in extracting lipophilic phytosterols and steroids, which were completely absent in the methanolic phase. Interestingly, saponins were positive in both the aqueous and chloroform extracts. Saponins are amphiphilic glycosides composed of a lipophilic aglycone (sapogenin) and a polar sugar chain (Trease and Evans 2009) [41]. This structural duality explains their solubility across contrasting polarities, as they partition into water via their sugar moieties and into chloroform via their triterpenoid/steroid core (Kokate 2008) [22]. The unique presence of quinones in the methanolic extract suggests their moderate polarity and selective affinity for alcohols. Meanwhile, the wide distribution of terpenoids, coumarins, and carotenoids in all three solvents reflects their structural diversity, representing families of molecules that range from highly polar oxygenated derivatives to completely non-polar hydrocarbons (Harborne 1998; Chen *et al*. 2023) [7, 16].

3. Gaps, Limitations, and Technical Variables

In this study, alkaloids, tannins, glycosides, phlobatannins, lignins, and anthocyanins were not detected. This absence should be interpreted with caution. Qualitative screening tests rely on visible colorimetric shifts and precipitation, which have inherent detection limits and can be subject to steric or chemical interferences from other abundant compounds in crude extracts (Harborne 1998) [16]. Thus, these compounds might still be present in the rind below the sensory threshold of qualitative reagents (Rojas-Garbanzo 2025) [32]. Furthermore, phytochemical accumulation is highly dynamic, heavily influenced by genotype (e.g., hybrid Kaveri vs. pure parental lines), localized cultivation conditions (Nargund Taluk soil, monsoon climate), seasonal harvest timings, and developmental maturity stages (Correa *et al*. 2016) [8].

4. Industrial Valorization and Sustainable Circular Economy

The presence of highly active phenols, flavonoids, and coumarins in the Kaveri passion fruit rind highlights its substantial nutraceutical and pharmaceutical value. These compounds are widely recognized as powerful natural antioxidants capable of scavenging free radicals, chelating metal ions, and inhibiting lipid peroxidation (Rojas-Garbanzo 2025) [32]. Utilizing this rind waste as an industrial source of high-purity antioxidants and functional fibers aligns with green chemistry principles and sustainable circular economy objectives (Correa *et al*. 2016) [8]. Rather than being discarded as a processing by-product, the rind can be upcycled into functional food ingredients, natural preservatives, and bioactive supplements, offering a highly profitable avenue for the agricultural sector.

Conclusion

This study successfully evaluated the physical profile and solvent extraction characteristics of Passiflora edulis (Kaveri hybrid variety) rind. The rind represents a dominant fraction (55%) of the total fruit mass and holds significant potential as a sustainable bio-resource. Qualitative analysis confirmed that solvent polarity is a critical parameter for recovering bioactive compounds, with polar solvents (water and methanol) being ideal for phenolics and flavonoids, and non-polar chloroform being effective for lipophilic phytosterols and steroids. The extensive presence of terpenoids, coumarins, and carotenoids across all systems underscores the chemical versatility of this material. These results provide a robust foundation for future research. It is recommended that subsequent studies employ advanced quantitative chromatography (such as HPLC-MS) and *in vitro* biological assays to precisely measure antioxidant, anti-inflammatory, and antimicrobial potencies, driving the practical development of rind-derived functional products.

Declarations

Funding: The authors declare that no external funding was received for this research.

Conflict of Interest: The authors declare that they have no conflicts of interest.

Ethics Approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Data Availability: The raw experimental datasets generated during the current study are available from the corresponding author on reasonable request.

Authors' Contributions: SK, PSJ, and SVJ conceptualized and designed the study. SK, SVJ, and KHS conducted the field collections, plant preparation, and laboratory experiments. SGJ and SVJ performed the qualitative screening assays and data tabulation. PSJ supervised the overall progress and draft reviews. All authors read, contributed to, and approved the final manuscript.

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