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Exploring the nutraceutical potential of grape (*Vitis vinifera* L.) pomace powder

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Abstract

The increasing generation of waste from grape (*Vitis vinifera* L.) processing poses environmental challenges while offering opportunities for value addition. This study aimed to valorize the paneer grape pomace by converting it into a stabilized powder and evaluating its nutritional and phytochemical properties. From 10 kg of fresh grapes, 9.8 ± 0.13 litter of juice was extracted, yielding 15 ± 0.09% fresh pomace, which was reduced to 4.73 ± 0.07% after drying. The prepared pomace powder exhibited a moisture content of 9.2 ± 0.16 g/100 g, carbohydrates of 17.0 ± 0.23 g/100 g, crude fiber of 1.2 ± 0.02 g/100 g, protein of 0.8 ± 0.00 g/100 g, fat of 0.5 ± 0.001 g/100 g and ash content of 0.4 ± 0.01 g/100 g. FTIR analysis revealed characteristic functional groups such as hydroxyl (3285 cm^{-1}), carbonyl (1741 cm^{-1}), and carbohydrate-associated C-O (1019 cm^{-1}) groups, indicating the presence of phenolics and polysaccharides. GC-MS analysis identified key bioactive compounds including dichloroacetic acid (42.30% peak area), m-cymene derivatives (6.92%) and 2,4-di-tert-butylphenol (5.68%), which are associated with antioxidant and antimicrobial activities. These results demonstrate that grape pomace powder is a stable, nutrient-rich and bioactive ingredient with potential applications in functional foods and nutraceuticals. This study provides a novel regional approach to grape waste valorization by integrating recovery efficiency with detailed spectroscopic and phytochemical characterization.

1. Introduction

Grapes (*Vitis vinifera* L.) rank among the world's most valuable fruit crops, prized for their rich nutrients and wide use from red wine to extracts blending into creams and health supplements. Cultivated for over 6,000 years, grapes originated from the Near East and are now produced globally with Italy, South Africa, France, China and the United States among the top producers (Khan *et al.,* 2020). In India, particularly in Tamil Nadu, grape cultivation has become a profitable venture since its introduction in 1832 with districts such as Theni, Dindigul and Coimbatore leading in production (Angamuthu, 2021). The crop has contributed to rural livelihoods, employment generation and agricultural diversification.

Grapes and their byproducts have recently received interest due to their biotechnological and medicinal usefulness. Grape pomace a primary by-product of wine making is rich in antibacterial, antioxidant and anti-inflammatory properties (Castro *et al*., 2023). These bioactive are increasingly being used in skincare formulations because of their ability to defend against oxidative stress and UV damage. The valorization of grape byproducts such as pomace, skins and seeds adheres to circular economy principles, converting agricultural waste into high-value nutraceutical and medicinal resources. For hundreds of years, Muscat Hamburg grapes have been farmed for fresh consumption, wine making and the production of dried fruit (Aubert *et al*., 2018), their popularity stems from their distinct flavour, dark purple black epidermis and high sugar content. These dark colours are caused by anthocyanins, which have anti-inflammatory and anticancer qualities. Another major ingredient, resveratrol, provides cardioprotective effects such as enhanced vascular function and atherosclerosis prevention. In addition to cardiovascular protection, resveratrol neuroprotective and anti-aging actions imply that this chemical could be used as a unique method in the treatment of neurodegenerative illnesses (Gal *et al*., 2023). Grapes are rich in polyphenols, which demonstrate powerful antioxidant, lipid regulating, anti-inflammatory, neuroprotective and antibacterial characteristics and have potential to cure metabolic and neurological problems (Kowalczyk *et al*., 2024; Zhao *et al*., 2020). However, their therapeutic potential has been limited by their low bioavailability owing to suboptimal absorption and rapid metabolism. To increase their efficacy, emerging technologies are being developed, such as sophisticated extraction techniques and delivery systems based on nanocarriers (Rudrapal *et al*., 2022). Because of their rich phytochemical profile, muscat hamburg grapes have a lot of potential for use in pharmaceutical, nutraceutical and functional food development (Sneha *et al*., 2025).

When selecting a good dehydration technique, a variety of elements, including the beginning moisture content, temperature and the dehydration period, must be taken into account to protect the bioactive chemicals, which are often susceptible to heat and oxygen (Carmona-Jimenez *et al*., 2018). Hot air dehydration is the most widely used dehydration technology in the food industry to produce

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powdered ingredients because of its lower prices, little handling needs and complete material recovery (Panza *et al*., 2025)

Wastage of grapes occurs in three kinds. The grapes wasted in the field includes unripe and un aesthetic (improper colour development, berries too small, spots in the berries) fetch very low price for the farmers. Since they are non-remunerative and adds loss even on marketing as fresh fruits, farmers prefer not to market it. While harvesting itself, they grade it and remove the unaesthetic and unripe grapes and leave in the field to decay or collect and throw in barren lands which becomes a menace. Similarly, food processing industries use only the juice for the development of products and discard the peel and skin, which are rich source of nutraceuticals. Farmers and food processing industries are unaware of the fact. Their complex chemical composition included proteins (4 to 15%), fibers (17 to 88%), lipids (2 to 14%), carbs (12 to 40%), polyphenols (0.2 to 9%), vitamins and minerals (2 to 7%), among others (Antonic *et al*., 2020). Because of its compositional profile, the food industry may use GP as a substitute source of macro and micronutrients for the manufacture of new functional meals. This could have an effect on human nutrition and health (Pereira *et al*., 2020). The grapes represent a multidisciplinary research model integrating horticulture, biotechnology and health sciences. Their cultivation and by-product utilization exemplify sustainable agriculture and innovation, linking eco-friendly production waste reduction and human health advancement. The synergy between grape bioactive and health continues to drive advancements in both nutraceutical and cosmetic industries, reinforcing grapes role as a cornerstone of sustainable bioresource utilization. GC-MS analysis revealed the presence of bioactive compounds associated with antioxidant, antimicrobial, antitumor, antidiabetic and anti-inflammatory activities (Suwethaasri *et al.,* 2025).

This study presents a region specific approach to valorizing paneer grape pomace by converting locally discarded waste into a stable, nutraceutical rich powder. Unlike conventional studies, it integrates waste recovery efficiency, controlled drying and comprehensive characterization into a single framework. The combined use of fourier transform infrared spectroscopy and gas chromatography-mass spectrometry provides detailed insights into both functional groups and bioactive compounds. This work highlights a simple, scalable processing method that supports sustainable waste utilization and functional food development.

2. Materials and Methods

2.1 Plant material and authentication

This research was carried out at the Department of Food Science and Nutrition, Community Science Collage and Research Institute, Tamil Nadu Agricultural University (TNAU), Madurai. Grape (*Vitis vinifera* L.) used for pomace powder procured from Cumbum area of Theni District, Tamil Nadu. The Variety Certificate Number is 468 was authenticated based on its distinctive morphological characteristics such as elongated greenish yellow berries, thin skin and characteristic muscat flavor typical of paneer grapes cultivated in this region.

2.2 Grape waste collection

The paneer grape variety used in this study was procured from local vineyards in the Cumbum area of Theni District, Tamil Nadu. The variety was authenticated based on its distinctive morphological characteristics such as elongated greenish yellow berries, thin skin and characteristic muscat flavor typical of paneer grapes cultivated in this region. Freshly harvested grapes were collected during the peak season to ensure uniform quality.

2.3 Procedure for the making grape pomace powder

Collection of grape waste (Pomace)

↓

Sorting and removal of foreign materials

↓

Washing the grapes and draining

↓

Drying process (Tray dryer at 50 to 60°C for 24 to 36 h)

↓

Grinding or pulverization

↓

Sieving (60-80 mesh size and particle size 180 to 250 µm)

↓

Packaging in airtight containers and stored under 4ºC

Figure 1: Process flow chart for the preparation of grape pomace powder.

Figure 1 indicates the procedure followed for the preparation of grape pomace powder. Grape waste was collected from a local juice processing unit immediately after juice extraction. The collected grape pomace (Figure 2), consisting mainly of skins, seeds and residual pulp was manually sorted to remove stems and foreign materials. It was then washed thoroughly with potable water to eliminate surface impurities, followed by draining and blot drying to remove excess moisture. The cleaned pomace was dried in a tray dryer at a controlled temperature 50 to 60°C for 24 to 36 h until constant weight was achieved. The drying process was monitored at regular intervals to ensure uniform moisture removal. The endpoint of drying was confirmed when no significant change in weight was observed between successive measurements. This drying temperature was selected to minimize thermal degradation of heat sensitive bioactive compounds such as phenolics. To ensure uniform particle size, the dried material was crushed with a mechanical grinder and sieved through a 60 to 80 mesh sieve (particle size 180 to 250 µm). Finally, the grape pomace powder was placed in airtight containers and kept at 4°C or room temperature until further investigation.

Figure 2: Grape pomace and grape pomace powder.

2.4 Grape pomace powder storage

The prepared grape pomace powder was packed in airtight, moisture proof polyethylene containers and stored under ambient storage 25 ± 2°C. Samples were protected from light and humidity to prevent oxidation and degradation of bioactive compounds. All analyses were performed within a specified storage period of 30 days to ensure sample stability.

2.5 Proximate analysis of grape pomace powder

The proximate composition of the produced grape pomace powder was analyzed using standard analytical techniques. Moisture content was evaluated using the hot air oven drying method in accordance with AOAC (1995) recommendations. The crude protein content was determined using the Kjeldahl technique (AOAC, 2005). Crude fat was determined using the Soxhlet extraction method in accordance with AOAC standards. The ash content was determined by incineration in a muffle furnace at 550°C until a consistent weight was achieved. Crude fiber was evaluated using Sadasivam and Manickam (1996) method and carbohydrate content was estimated by difference. The overall energy value was calculated with Atwater coefficients based on protein, fat and carbohydrate composition. After wet digestion with a tri-acid mixture, the samples mineral content, which included calcium, iron, zinc, magnesium, potassium and sodium was determined by Atomic Absorption Spectrop-hotometry (AAS). All analyses were performed in triplicate and results were expressed as mean ± standard deviation on a dry weight basis.

2.6 Statistical analysis

All experiments were carried out in triplicate (n=3) and results were expressed as mean ± standard deviation. Statistical analysis was performed using one-way analysis of variance (ANOVA) and differences between means were considered statistically significant at $p<0.05$. Statistical analyses were performed using AGRES software.

3. Results

3.1 Waste recovery of the grape pomace making process

Grape waste was collected from the farm and the discarded grapes were processed to produce grape pomace powder from which the yield was calculated. According to the Table 1, 9.8 ± 0.13 litter of juice was effectively extracted from 10 ± 0.18 kg of grape sample, indicating a high juice recovery efficiency with little variation between trials. A substantial amount of the fruit remains as solid residue following juice extraction, as seen by the fresh pomace 15 ± 0.09% of the total grape weight. The pomace yield decreased to 4.73 ± 0.07% after drying, indicating significant moisture loss and verifying successful dehydration. Good experimental consistency and repeatability are shown by the low standard deviation values for all parameters. All things considered, the findings Statistical analysis showed that the reduction in pomace weight before and after drying was statistically significant ($p<0.05$), confirming effective dehydration. The low standard deviation values indicate good repeatability and consistency of the experimental process.

Table 1: Waste recovery of grape pomace powder

Grape sample (kg)	Juice (lt)	Fresh pomace (%)	Dried pomace (%)
10 ± 0.18	9.8 ± 0.13	15 ± 0.09	4.73 ± 0.07

3.2 Proximate composition of grape pomace powder

According to Table 2, the sample exhibited a moisture content of 9.2 g/100 g, indicating relatively low water activity, which may enhance storage stability. The ash content (0.4 g/100 g) reflects the presence of total mineral constituents. The protein and fat contents were comparatively low, at 0.8 g/100 g and 0.5 g/100 g, respectively. Total carbohydrates accounted for 17 g/100 g, suggesting that carbohydrates constitute the major macronutrient fraction of the sample. Additionally, the crude fiber content was 1.2 g/100 g, indicating a moderate contribution to dietary fiber. Statistical analysis revealed that carbohydrates were significantly higher ($p<0.05$) compared to protein and fat content. The variation among proximate components was found to be statistically significant ($p<0.05$), indicating a distinct compositional profile.

Table 2: Proximate composition of grape pomace powder

Parameter	Value (g/100 g)
Moisture	9.2 ± 0.16
Ash	0.4 ± 0.01
Protein	0.8 ± 0.01
Fat	0.5 ± 0.01
Carbohydrates	17 ± 0.23
Crude fiber	1.2 ± 0.02

3.3 Mineral composition of grape pomace powder

The mineral composition of grape pomace powder shown in Table 3, determined using atomic absorption spectrophotometry, indicates the presence of essential macro and micro minerals. Potassium was the most abundant (800 ± 50 mg/100 g), followed by calcium (150 ± 10 mg/100 g) and magnesium (100 ± 8 mg/100 g), while sodium was comparatively low (20 ± 2 mg/100 g). Trace minerals such as iron (5 ± 0.5 mg/100 g) and zinc (1 ± 0.1 mg/100 g) were also present, contributing to nutritional value. The variation among mineral contents was statistically significant ($p<0.05$), confirming a distinct mineral profile (AOAC, 2016).

Table 3: Mineral composition of grape pomace powder

Mineral	Value (mg/100 g)
Calcium (Ca)	150 ± 10
Potassium (K)	800 ± 50
Magnesium (Mg)	100 ± 8
Sodium (Na)	20 ± 2
Iron (Fe)	5 ± 0.5
Zinc (Zn)	1 ± 0.1

3.4 Fourier transform infrared spectroscopy (FTIR) screening of grape pomace powder

FTIR analysis (AOAC, 2016) was performed to identify the functional groups present in grape pomace powder using an FTIR spectrophotometer. The sample was prepared by mixing dried powder with potassium bromide (KBr) in a 1:100 ratio and compressing it into a pellet. Spectra were recorded in the range of 400 to 4000 cm^{-1} at a resolution of 4 cm^{-1} with 32 scans.

The FTIR spectrum showed characteristic absorption bands of plant bioactive compounds. A broad peak at 3200 to 3400 cm^{-1} indicates O-H stretching of phenolics and carbohydrates. Peaks at 2920 to 2850 cm^{-1} correspond to C-H stretching of aliphatic compounds. The band near 1740 cm^{-1} represents C=O stretching of esters and fatty acids, while the peak around 1630 cm^{-1} suggests C=C stretching of polyphenols. Bands between 1450 to 1370 cm^{-1} are due to CH bending and strong peaks at 1200 to 1000 cm^{-1} indicate C-O stretching of carbohydrates. Minor peaks below 900 cm^{-1} are associated with aromatic structures. Overall, the results confirm the presence of phenolics, carbohydrates and other bioactive compounds, supporting the functional potential of grape pomace powder.

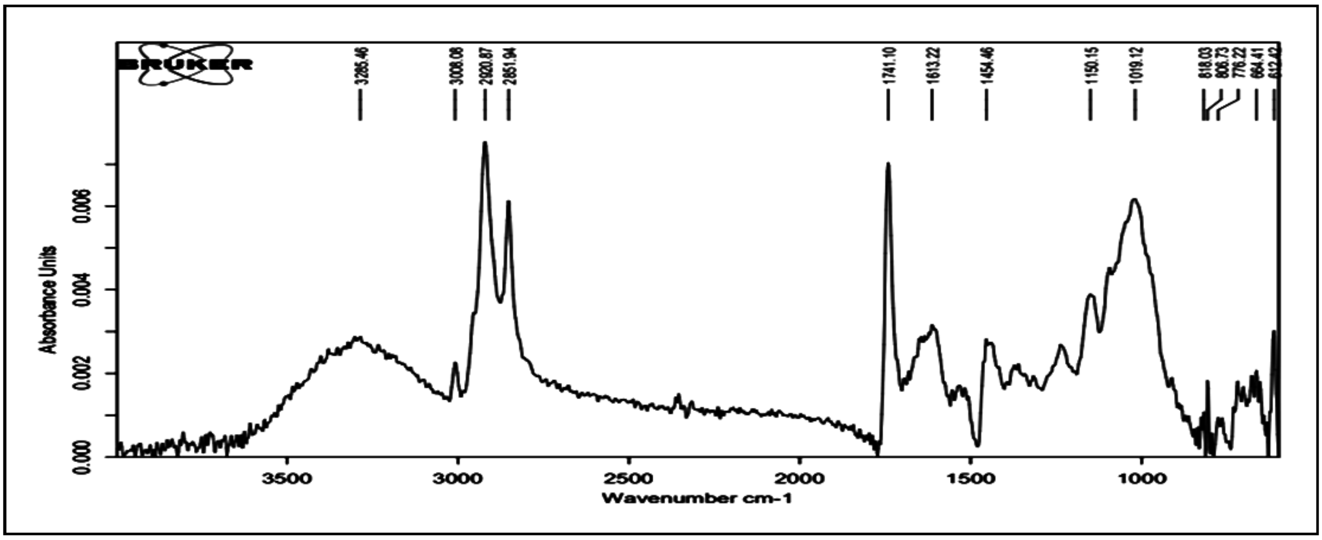

Figure 3: Fourier transform infrared spectroscopy (FTIR) screening of grape pomace powder.

Table 4: Identification of functional groups in grape derived powder by FTIR spectroscopy

S.No.	Wave number (cm^{-1})	Relative intensity	Functional group	Assignment	References
1	3285	114.73	O-H stretch	Alcohols/phenols	Tsapou *et al.,* 2024
2	3028	36.93	=C-H stretch	Aromatic compounds	Schorn-Garcia *et al.,* 2023
3	2928	14.63	C-H stretch	Alkanes (lipids)	Junges *et al.,* 2022
4	1741	24.90	C=O stretch	Esters/carboxylic acids	Menozzi *et al.,* 2024
5	1634	50.42	C=C/Amide I	Alkenes/proteins	Binati *et al.,* 2024
6	1510	33.30	N-H bending	Proteins (Amide II)	Binati *et al.,* 2024
7	1019	165.65	C-O stretch	Carbohydrates	Schorn-Garcia *et al.,* 2023
8	818	15.89	C-H bending	Aromatic compounds	Punetha and Vuppu, 2023
9	786	6.21	C-H bending	Aromatic compounds	Punetha and Vuppu, 2023
10	664	83.13	C-Cl stretch	Halogen compounds	Punetha and Vuppu, 2023
11	612	11.89	C-Br stretch	Halogen compounds	Punetha and Vuppu, 2023

3.5 Gas chromatography-mass spectrometry (GC-MS) screening of grape pomace powder

GC-MS analysis was performed to identify the volatile and semi volatile bioactive compounds present in grape pomace powder. The analysis was carried out using a GC-MS system (*e.g.,* Agilent 7890 GC coupled with a 5975 MS detector). Separation was achieved using a capillary column (*e.g.,* HP-5MS, 30 m × 0.25 mm × 0.25 µm film thickness). Helium (99.999% purity) was used as the carrier gas at a flow rate of 1 ml per min. The injection volume was 1 µl and samples were introduced in split mode with a split ratio of 10:1. The oven temperature was initially set at 50°C (held for 2 min), then increased to 150°C at a rate of 10°C/min, followed by a further increase to 280°C at 5°C/min and held for 10 min. Mass spectrometry was performed under electron ionization (EI) mode at 70 eV with a scan range of m/z 50-600 and an ion source temperature of 230°C. The identification of compounds was carried out by comparing the obtained mass spectra with standard libraries such as the NIST (National Institute of Standards and Technology) database.

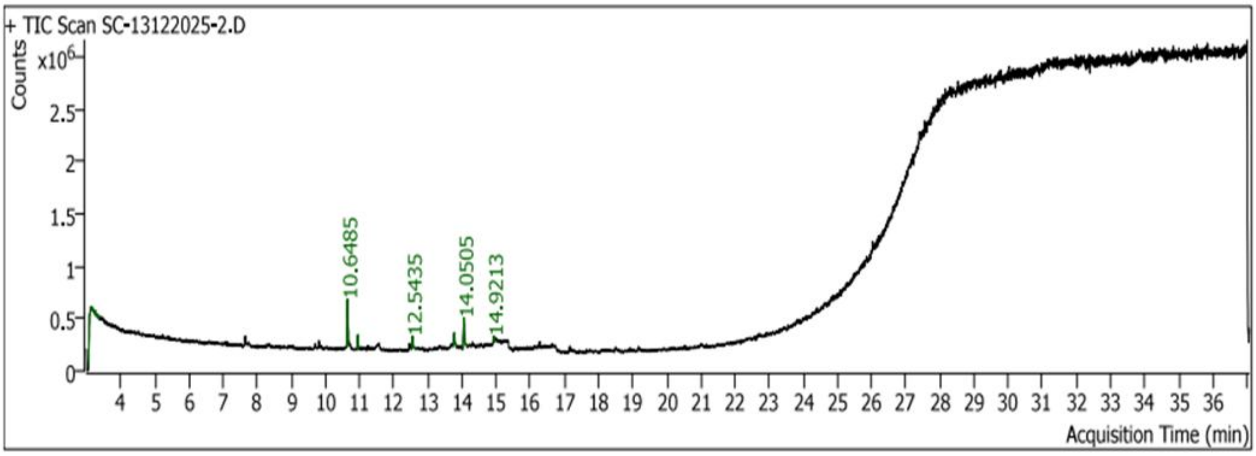

Figure 4: Gas chromatography-mass spectrometry (GC-MS) screening of grape pomace powder.

Figure 4 shows that the GC-MS chromatogram of grape pomace powder exhibited several distinct peaks indicating the presence of a wide range of volatile and semi volatile bioactive compounds. Major peaks were observed at retention times of approximately 10.65, 12.54, 14.50 and 14.92 min, suggesting the presence of phenolic derivatives, fatty acids, esters and other phytoconstituents. Early eluting compounds (retention time <15 min) are typically low molecular weight volatile compounds such as alcohols, aldehydes and esters. The variation in peak areas of the identified compounds was found to be statistically significant ($p<0.05$), indicating differences in the relative abundance of bioactive constituents. Compounds with higher peak area percentages contribute more significantly to the overall biological activity of the sample. The GC-MS analysis confirms that grape pomace powder contains a diverse range of bioactive compounds, supporting its potential application in functional foods, nutraceuticals and other value added products.

Table 5: Identification of bioactive compounds with biological activity of grape pomace powder

RT (min)	Compound name	Area (%)	Molecular formula	Mol. weight (g/mol)	Biological activity	References
3.14	Dichloroacetic acid	42.309	$C_2H_2Cl_2O_2$	128.94	Antimicrobial, metabolic modulator	Stacpoole *et al*., 1998
10.64	m-Cymene, 5-tert-butyl-	6.927	$C_{14}H_{22}$	190.33	Antioxidant, antimicrobial	Burt, 2004
14.05	2,4-Di-tert-butylphenol	5.680	$C_{14}H_{22}O$	206.32	Strong antioxidant, anti-microbial, antifungal	Kumar *et al*., 2014; Nandhini *et al*., 2015
13.77	Octadecane, 1,1'-[1,3 -propanediylbis (oxy)] bis-	3.026	$C_{39}H_{80}O_2$	580.07	Antimicrobial activity	Pavithra *et al*., 2015
12.54	Tetra tetracontane	2.327	$C_{44}H_{90}$	619.19	Antioxidant activity	Hema *et al*., 2011
10.94	Tetra tetracontane	1.756	$C_{44}H_{90}$	619.19	Antioxidant, protective hydrocarbon	Hema *et al*., 2011
14.92	5H-Cyclopropa [3,4] Benz[1,2-e] azulen-5-one derivative	1.670	$C_{28}H_{36}O_{11}$	548	Anti-inflammatory, antimicrobial (Terpenoid derivative)	Singh *et al*., 2019

4. Discussion

The findings of this study clearly demonstrate that grape processing waste, often considered a low-value by-product, possesses considerable nutritional and functional potential when effectively utilized. From the initial 10 kg of grapes used for juice extraction, 1.5 kg of fresh pomace was obtained (15%), indicating that a substantial portion of the fruit remains unutilized after processing. Similar recovery levels have been reported in previous studies, where grape pomace yield ranged between 12 to 20% depending on the variety and processing conditions (Schieber *et al*., 2001; Rockenbach *et al.,* 2011). This consistency suggests that grape pomace generation is significant across different processing systems and highlights its potential for valorization. Upon drying, 0.473 kg of pomace powder was obtained, corresponding to a drying yield of 31.53% from fresh pomace and 4.73% from the total grape sample. This reduction is primarily due to the high moisture content of fresh pomace, which has also been observed in earlier studies (Llobera and Canellas, 2007). The final moisture content of 9.2% in the present study falls within the recommended safe storage range (<10%), which aligns with findings reported by Deng *et al.* (2011), confirming improved shelf stability and reduced microbial susceptibility.

The proximate composition analysis revealed that grape pomace powder is predominantly composed of carbohydrates (17%) and dietary fiber (1.2%) with relatively low protein (0.8%) and fat (0.5%) content. Comparable compositional profiles have been documented in other studies, although slightly higher fiber contents (ranging from 20 to 60%) have been reported depending on grape variety and processing methods (Tseng and Zhao, 2013; Mirabella *et al.,* 2014). The relatively lower fiber content observed in this study may be attributed to differences in raw material composition or drying conditions. Nevertheless, the presence of dietary fiber supports its role in improving digestive health and functional food applications.

The mineral content, though represented by a low ash value (0.4%), included essential elements such as calcium, iron, magnesium, potassium and zinc. Similar mineral profiles have been reported in grape by-products (Goula *et al.,* 2016), emphasizing their contribution to physiological functions such as bone health, oxygen transport and electrolyte balance. One of the most significant outcomes of this study is the retention of phenolic compounds in grape pomace powder. Since phenolics are mainly concentrated in grape skins and seeds, their abundance in pomace is well supported by literature. Previous studies have reported high total phenolic content and strong antioxidant activity in grape pomace extracts (Rockenbach *et al.,* 2011; Maier *et al.,* 2009). The observed DPPH radical scavenging activity in this study is consistent with these findings, confirming the ability of grape pomace to act as a natural antioxidant source. This suggests its potential application as a natural preservative, replacing synthetic antioxidants in food systems.

The FTIR analysis further supported these findings by identifying functional groups associated with phenolic compounds, carbohydrates and lipids. The presence of broad O-H stretching bands and characteristic aromatic peaks is consistent with earlier FTIR studies on grape pomace, which also confirmed the dominance of polyphenolic structures (Basalekou *et al.,* 2020). These similarities validate the chemical composition observed in the present study.

In addition, GC-MS analysis revealed a diverse range of volatile and semi volatile compounds, including phenolic derivatives, terpenoids and long chain hydrocarbons. Compounds such as 2,4-di-tert-butylphenol and m-cymene derivatives identified in this study have also been reported in other plant based by-products with known antioxidant and antimicrobial activities (Kumar *et al.,* 2014). The presence of these bioactive compounds reinforces the functional potential of grape pomace powder. From an environmental and economic standpoint, the conversion of grape waste into pomace powder offers a sustainable waste management strategy. Similar approaches have been emphasized in recent studies focusing on agro industrial waste valorization, where grape pomace has been successfully incorporated into bakery products, functional beverages and nutraceutical formulations (Mirabella *et al.,* 2014; Beres *et al.,* 2017). This aligns with circular economy principles by reducing waste and generating value-added products.

In summary, the results of this study are in agreement with existing literature, confirming that grape pomace powder is a nutritionally and functionally valuable material. Its antioxidant capacity, mineral composition, fiber content and diverse bioactive compounds make it a promising ingredient for functional food and nutraceutical applications. The effective utilization of grape pomace not only contributes to improved human health but also supports sustainable agro industrial practices.

5. Conclusion

This study demonstrates the effective valorisation of paneer grape waste from the Cumbum region into a nutraceutical rich pomace powder with measurable recovery efficiency and functional significance. From 10 kg of fresh grapes, 1.5 kg (15%) of fresh pomace was recovered after juice extraction and subsequent drying yielded 473 g of pomace powder, representing 4.73% of the total grape weight with a drying yield of 31.53%, indicating substantial moisture removal and improved storage stability. The reduced moisture content enhances shelf-life, while the retained bioactive compounds contribute to functional properties. Analytical evaluation confirmed the presence of dietary fibre, carbohydrates, minerals and phenolic compounds responsible for antioxidant activity, suggesting its potential role in combating oxidative stress. The considerable recovery percentage and stability of the final powder highlight its practical applicability as a value added functional ingredient. The novelty of this study lies in the integrated evaluation of locally sourced paneer grape waste, combining yield optimization, nutritional profiling and advanced analytical techniques (FTIR and GC-MS), thereby offering a region specific and sustainable approach to agro industrial waste valorization.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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