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COMPREHENSIVE EVALUATION OF NUTRITIONAL ANTIOXIDANT FUNCTIONAL AND ANTINUTRITIONAL PROPERTIES OF BEETROOT *(BETA VULGARIS L.)* PEEL POWDER

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ABSTRACT

Beetroot *(Beta Vulgaris L.)* Peel is generally discarded during processing despite being a rich source of nutrients and bioactive compounds. This study aimed to evaluate the nutritional, phytochemical, antioxidant, functional, and antinutritional properties of beetroot peel powder to explore its potential use as a value-added food ingredient. The peels were cleaned, dried, and ground into a fine powder, and standard analytical methods were employed for analysis. The results showed that beetroot peel powder is rich in carbohydrates and dietary fiber, with moderate protein content and very low fat levels. Mineral analysis unveiled potassium as the predominant mineral, indicating its contribution to electrolyte balance. Antioxidant evaluation identified the presence of bioactive compounds such as phenolics, flavonoids, and vitamin C (14.20 ± 0.25 mg/100 g). The powder exhibited strong antioxidant activity, as supported by DPPH radical scavenging activity (66.36 ± 0.92%) and a FRAP value of 8.14 ± 0.32 mg ascorbic acid equivalents (AAE)/g extract. Functional property analysis revealed a bulk density of 0.42 ± 0.02 g/ml, water absorption capacity of 3.2 ± 0.15 g/g, swelling power of 4.8 ± 0.20 g/g, solubility of 14 ± 0.50%, and foam capacity of 9 ± 0.40%, suggesting good hydration behavior and suitability for incorporation into food formulations. The pH of the powder was 5.4 ± 0.10, indicating a slightly acidic nature compatible with various food systems. Qualitative antinutrient screening confirmed the presence of tannins, oxalates, and saponins. Collectively, the results suggest that beetroot peel is not merely a waste material but a nutritionally valuable, antioxidant-rich by-product with promising functional properties. Its utilization in food products may help reduce processing waste while enhancing the nutritional quality of foods.

KEYWORDS: beetroot, peel, antioxidant, functional, by-product.

1. INTRODUCTION

Beetroot *(Beta vulgaris L.)* is one of the widely consumed root vegetables in India and across the world. It is well known for its bright red color, characteristic earthy flavor, and significant nutritional and medicinal value. In recent years, there has been a growing shift among consumers toward natural, plant-based foods, and beetroot has gained considerable attention due to its richness in natural pigments, dietary fiber, vitamins, minerals, and bioactive compounds that support overall health (Chen & Ranawana, 2021; Clifford et al., 2015; Granato et al., 2020; Martirosyan & Singh, 2015; Esatbeyoglu et al., 2014; Zin et al., 2022; Sokolova & Ivanova, 2024). Although the edible flesh of beetroot is commonly used in domestic cooking and food processing, the peel is usually discarded as waste. However, numerous researchers have reported that beetroot peel contains higher concentrations of antioxidants and phytochemicals than the flesh, making it a promising raw material for functional food development (Zin et al., 2022; Bușterchi & Stoica, 2025; Stoica et al., 2025; Coimbra et al., 2023). In India, beetroot cultivation has increased steadily due to rising demand from the food processing sector. At the global level, beetroot is produced extensively for fresh consumption as well as for processed products such as

beetroot powder, juice, and natural color extracts. According to FAO (2021), global interest in beetroot-based products has increased, particularly due to the replacement of synthetic food colorants with natural alternatives. This trend has created opportunities for utilizing beetroot by-products such as peel, which is rich in betalains and phenolic compounds (Stoica et al., 2025).

Beetroot peel contains several valuable nutrients including vitamin C, potassium, dietary fibre, amino acids, and natural sugars (Abdo et al., 2022; Baião et al., 2017). Mutiple researchers have reported strong antioxidant activity in beetroot peel due to the presence of betalains, phenolic acids, and flavonoids (Esatbeyoglu et al., 2014; Zin et al., 2022). These bioactive compounds help reduce oxidative stress and may contribute to the prevention of chronic diseases (Chen et al., 2021). As a result, beetroot peel is increasingly being explored for incorporation into bakery products, beverages, snacks, and nutraceutical formulations (Constantin et al., 2025). Functional properties such as water absorption capacity, swelling power, foaming ability, solubility, and bulk density play an important role in determining the suitability of plant powders for food applications. Studies have shown that beetroot peel and pomace exhibit favourable functional properties, making them useful as food ingredients (Amoah et al., 2025; Ben-Othman et al., 2020; Adebowale et al., 2008; Elleuch et al., 2011). Utilizing beetroot peel not only enhances nutritional quality but also helps reduce agro-waste and promotes sustainable food processing. In recent years, there has been growing interest in the valorisation of agri-food waste materials, especially fruit and vegetable by-products (Ben-Othman et al., 2020; Gustavsson et al., 2011; Mirabella et al., 2014; Galanakis, 2012). Beetroot peel fits well into this concept due to its low cost, easy availability, and nutritional benefits (Stoica et al., 2025). Despite these findings, systematic evaluation of nutritional, antioxidant and functional properties using multiple laboratory techniques remains limited.

Therefore, the present study focuses on the nutritional, phytochemical, antioxidant, and functional analysis of beetroot peel powder. The study includes proximate composition, mineral content, phytochemical estimation, antioxidant activity calorific value, amino acid content, and functional properties. This research aims to highlight the potential of beetroot peel as a value-added functional ingredient for food and nutraceutical applications.

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

Fresh beetroot *(Beta vulgaris L.)* was purchased from a local vegetable market. The beetroots were washed thoroughly under running tap water to remove any adhering soil and impurities. The outer peel was carefully removed using a clean stainless-steel knife. The collected peels were rinsed again with distilled water to eliminate surface contaminants. The fresh beetroot peels were spread evenly on trays and dried in a hot air oven at 60°C for 2 days until the moisture was completely removed. This temperature was chosen because it helps in drying the sample uniformly without causing major loss of heat-sensitive nutrients. After drying, the peels were broken into smaller pieces and ground into fine powder using a grinder. The final beetroot peel powder was stored in airtight, zip bags at 4°C until further laboratory analysis.

2.2 Proximate Composition of beetroot peel

2.2.1 Total Moisture Content (%)

The moisture content of beetroot peel powder was determined using the hot air oven method. About 5 g of the sample was accurately weighed and transferred into a pre-weighed moisture dish. The sample was then dried in a hot air oven at 105°C for 3–4 hours until a constant weight was obtained. After drying, the dish was cooled in a desiccator and weighed again.

The loss in weight represented the moisture present in the sample.

$$\text{Moisture (\%)} = \frac{\text{Loss in Weight(g)}}{\text{Initial Weight of sample(g)}} \times 100$$

This method is commonly used for foods because it gives a direct estimate of water lost during heating and is widely applied in proximate analysis of plant-based materials, including beetroot by-products (Baião et al., 2017; Stoica et al., 2025; AOAC, 2019).

2.2.2 Total Ash Content (%)

Ash content was estimated by the dry ashing method. Approximately 2 g of beetroot peel powder was placed in a clean, dry crucible. The sample was first charred gently over a low flame to remove volatile organic matter. The crucible was then transferred to a muffle furnace at 550°C and kept for 4–6 hours until white or grey ash was obtained.

The crucible was cooled in a desiccator and weighed. The ash percentage was calculated using:

$$\text{Ash (\%)} = \frac{\text{Weight of Ash(g)}}{\text{Weight of Sample(g)}} \times 100$$

Ash represents the total mineral content of the sample, which is an important nutritional parameter in beetroot peels and other vegetable by-products (Amoah et al., 2025; Stoica et al., 2025; AOAC, 2019).

2.2.3 Total Carbohydrate Estimation (g/100g)

The total carbohydrate content of the beetroot peel powder was estimated using the anthrone method, which is one of the most widely used colorimetric techniques for carbohydrate determination. In this method, carbohydrates present in the sample first undergo acid hydrolysis, releasing simple sugars. When these sugars react with the anthrone reagent in a strongly acidic medium, they form a bluish-green colored complex. The intensity of this color is directly proportional to the

amount of carbohydrate present in the sample. For the analysis, a known quantity of the beetroot peel extract was mixed with freshly prepared anthrone reagent and heated in a boiling water bath to allow full color development. After cooling the tubes to room temperature, the absorbance of the solution was measured using a spectrophotometer at 620 nm. A standard glucose calibration curve was used to calculate the carbohydrate concentration in the sample. This method was selected because it is simple, sensitive, and suitable for plant materials containing both simple and complex carbohydrates, such as beetroot peels (Baião et al., 2017; Chen & Ranawana, 2021).

2.2.4 Total Protein Estimation (g/100g)

Protein content in beetroot peel powder was determined using the Lowry method, a sensitive biochemical assay widely used for quantifying proteins in food and plant samples. The Lowry method involves two major reactions. In the first step, proteins in the sample react with alkaline copper tartrate reagent, forming a complex under alkaline conditions (known as the biuret reaction). In the second step, this copper-protein complex reduces the Folin–Ciocalteu phenol reagent, resulting in a deep blue color whose intensity is proportional to the protein concentration. A measured amount of beetroot peel extract was mixed with the alkaline copper reagent and allowed to incubate, followed by addition of the Folin reagent. After the final incubation period, the absorbance was recorded at 750 nm using a spectrophotometer. A standard curve was prepared using bovine serum albumin (BSA), and the protein concentration in the sample was calculated from the calibration graph. The Lowry method is preferred for plant extracts due to its high sensitivity and suitability for samples containing phenolic compounds (Abdo et al., 2022; Amoah et al., 2025; Lowry et al., 1951).

2.2.5 Total Fat Estimation (%)

The fat content of beetroot peel powder was estimated using the Soxhlet extraction method. About 2g of sample was placed in a thimble and extracted with petroleum ether, which dissolves the fat fraction. Continuous refluxing allowed repeated solvent extraction cycles. After extraction, the solvent was evaporated and the remaining fat residue was dried and weighed. This method is widely used for determining crude fat in plant-based food materials and agri-food wastes (Ben-Othman et al., 2020; Baião et al., 2017; Soxhlet, 1879).

2.2.6 Total Dietary Fiber (%)

Dietary fiber in beetroot peel powder was estimated using the alkaline extraction method. In this method, non-fibrous components such as starch and proteins are solubilized under alkaline conditions, while fibrous components remain insoluble. The insoluble residue was filtered, washed, dried, and weighed to determine total dietary fiber content. This method is particularly suitable for beetroot peel, which is rich in cell wall polysaccharides such as cellulose and hemicellulose (Stoica et al., 2025; Constantin et al., 2025).

2.2.7 Total Amino Acid Estimation (µg/100g)

Amino acids in the beetroot peel extract were analyzed using the ninhydrin method, which is a classical colorimetric technique for detecting free amino acids. When amino acids react with ninhydrin reagent under heating, they form a deep purple-colored complex known as Ruhemann's purple. The intensity of this colour corresponds to the concentration of amino acids present in the sample. For the analysis, the sample extract was mixed with the ninhydrin reagent and heated in a water bath to allow full color development. After cooling, the absorbance was measured using a spectrophotometer at 570 nm. A standard curve prepared using a known amino acid (such as leucine or glycine) was used to quantify the amino acid content in the sample. This method is particularly useful for plant materials because it detects a wide range of free amino acids with good sensitivity (Chen et al., 2021; Stoica et al., 2025).

2.3 Antioxidant Activityof beetroot peel

2.3.1 Total Vitamin C Estimation (mg/100g)

Vitamin C content of the beetroot peel extract was determined using the dye titration method with 2,6-dichlorophenol indophenol (DCPIP) as the indicator dye. In this method, ascorbic acid present in the sample reduces the colored dye to a colorless form, and the endpoint appears as a faint pink color that persists for a few seconds. To prevent oxidation of vitamin C during extraction, the sample was treated with 8% metaphosphoric acid (HPO_3), which stabilizes ascorbic acid by inhibiting enzymatic and non-enzymatic degradation. The prepared extract was titrated with a standardized DCPIP solution, and the volume of dye required to reach the endpoint was noted. The amount of vitamin C was calculated using the dye factor and expressed as mg per 100 g of sample. This method is widely preferred for food samples because it is simple, accurate and effective for determining vitamin C in plant-based materials such as beetroot and its by-products (Chen &Ranawana, 2021; Zin et al., 2022).

2.3.2 Total Phenolics Content (TPC) (mg GAE/g)

The total phenolics content of beetroot peel extract was determined using the Folin–Ciocalteu method, which is one of the most widely used colorimetric techniques for estimating phenolic compounds in plant materials. In this method, phenolic molecules present in the extract react with the Folin–Ciocalteu reagent under alkaline conditions, resulting in the formation of a blue-colored complex. The intensity of this color is directly related to the amount of phenolics in the sample. For the analysis, the beetroot peel extract was mixed with Folin–Ciocalteu reagent followed by sodium carbonate solution and allowed to incubate for color development. After the reaction period, the absorbance was measured using a spectrophotometer at 765 nm. A standard curve prepared using gallic acid was used to express the results as

milligrams of gallic acid equivalents (mg GAE) per gram of sample. This method is widely applied for evaluating phenolic content in beetroot peel and other agri-food by-products due to its simplicity and reliability (Zin et al., 2022; Coimbra et al., 2023; Stoica et al., 2025; Singleton & Rossi, 1965).

2.3.3 Total Flavonoid Content (TFC) (mg QE/g)

The total flavonoid content of the beetroot peel extract was estimated using the aluminium chloride colorimetric method. Flavonoids react with aluminium chloride to form a yellow-colored complex, and the intensity of this color corresponds to the amount of flavonoids present in the sample. In this method, the beetroot peel extract was mixed with aluminium chloride reagent and allowed to incubate for a specific period to ensure complete formation of the colored complex. The absorbance was then measured at 415 nm using a spectrophotometer. A standard curve using quercetin was prepared, and the flavonoid content was calculated as milligrams of quercetin equivalents (mg QE) per gram of sample. This method is widely used because it is simple, sensitive and effective for quantifying flavonoids in plant materials, especially those rich in pigments and antioxidants like beetroot peel (Esatbeyoglu et al., 2014; Sokolova & Ivanova, 2024; Stoica et al., 2025; Chang et al., 2002).

2.3.4 DPPH (2,2-diphenyl-1-picrylhydrazyl) Radical Scavenging Activity (%)

The antioxidant activity of the beetroot peel extract was evaluated using the DPPH radical scavenging method, which is one of the most commonly used assays for measuring free radical–quenching ability. DPPH (2,2-diphenyl-1-picrylhydrazyl) is a stable free radical that shows a deep violet color in solution. When antioxidants present in the beetroot peel extract donate a hydrogen atom or electron to the DPPH radical, the violet color fades to yellow, indicating the reduction of DPPH. For this analysis, different concentrations of the extract were mixed with the DPPH solution and allowed to incubate in the dark to prevent photodegradation. The decrease in absorbance was then measured spectrophotometrically at 517 nm. The extent of color reduction reflected the radical scavenging capacity of the sample and was expressed as percentage inhibition. This method is widely used to assess the free radical-quenching ability of beetroot peel extracts and has been reported as an effective indicator of antioxidant potential due to phenolics, flavonoids, and betalains (Esatbeyoglu et al., 2014; Zin et al., 2022; Coimbra et al., 2023; Brand-Williams et al., 1995).

2.3.5 FRAP (Ferric reducing antioxidant power) Assay (mg AAE/g)

The ferric reducing antioxidant power (FRAP) assay was carried out according to the method described by (Benzie and Strain 1996) with slight modifications. The FRAP reagent was freshly prepared by mixing 300 mM acetate buffer (pH 3.6)**,** 10 mM TPTZ (2,4,6-tripyridyl-s-triazine) solution prepared in 40 mM HCl**,** and 20 mM ferric chloride ($FeCl_3 \cdot 6H_2O$) in the ratio of **10**:1:1 (v/v/v). An aliquot of 0.1 mL of beetroot peel extract was mixed with 3.0 mL of FRAP reagent and incubated at 37°C for 4 minutes. The absorbance was measured at 593 nm using a UV–Visible spectrophotometer against a reagent blank. A calibration curve was prepared using ascorbic acid**,** and the results were expressed as mg ascorbic acid equivalents (AAE)/g extract (Benzie & Strain, 1996)

2.4 Functional Properties of beetroot peel

2.4.1 Bulk Density (g/ml)

Bulk density was measured to understand how the beetroot peel powder behaves during packaging and storage. A graduated cylinder (10 or 25 mL) was weighed and filled with a known weight of sample without compacting. The bottom of the cylinder was gently tapped 2–3 times to settle the powder.

Bulk density was calculated as

$$\text{Bulk Density (g/ml)} = \frac{\text{Weight of Sample(g)}}{\text{Volume of Sample(ml)}} \quad (3)$$

Bulk density is an important functional property that influences packaging efficiency, handling, and storage behavior of powdered food materials, particularly fruit and vegetable by-products (Amoah et al., 2025; Stoica et al., 2025).

2.4.2 Water Absorption Capacity (WAC) (g/g)

The water absorption capacity of beetroot peel powder was determined to understand how much water the powder can retain under hydration. The sample was mixed with distilled water and allowed to stand for a period to enable absorption of water by the fibers and polysaccharides present in the powder. After equilibration, the mixture was centrifuged to separate the unabsorbed water, and the weight of the hydrated sample was recorded. The increase in weight indicated the amount of water absorbed by the sample. This property is particularly important because high water absorption helps improve the texture and moisture retention of foods such as bakery products, porridges and dough-based formulations. Beetroot peel, being rich in dietary fiber, is expected to show good water absorption capacity (Ben-Othman et al., 2020; Amoah et al., 2025).

$$\text{WAC (g/g)} = \frac{Weight\,after\,water\,absorption(g) - Initial\,Dry\,Weight(g)}{Initial\,dry\,weight(g)} \quad (4)$$

2.4.3 Foaming Capacity and Foam Stability (%)

Foaming capacity and foam stability were evaluated to assess the aeration properties of beetroot peel powder. A suspension of the powder in water was blended to incorporate air, and the volume of foam formed immediately after whipping indicated foaming capacity. Foam stability was determined by allowing the foam to stand for a specific period and recording the remaining foam volume. These properties are influenced mainly by

protein and soluble fiber content. Although beetroot peel is not protein-rich, its fiber components may contribute to foam structure.

Foam (%) = $\frac{Volume\ after\ whipping(ml) - Initial\ volume(ml)}{Initial\ volume(ml)} \times 100$ (5)

Similar observations regarding limited but measurable foaming properties of vegetable by-product powders have been reported in earlier studies (Baião et al., 2017; Stoica et al., 2025).

2.4.4 Swelling Power (g/g)

Swelling power was determined to assess the ability of beetroot peel powder to absorb water and expand. About 1 g of sample was mixed with distilled water and heated at controlled temperature, followed by centrifugation. The weight of the swollen sediment was recorded after discarding the supernatant.

Swelling Power (g/g) = $\frac{Weight\ of\ swollen\ sediment(g)}{Weight\ of\ dry\ sample(g)}$ (6)

Swelling power reflects the hydration behavior of fiber-rich powders and is an important functional characteristic for their application in food formulations (Amoah et al., 2025; Stoica et al., 2025).

2.4.5 Water Solubility Index (WSI) (%)

WSI was measured using the same supernatant obtained during the swelling power test. After centrifugation, the supernatant was collected in a pre-weighed dish and dried at 105°C to a constant weight. The dried residue represented soluble components.

WSI (%) = $\frac{Weight\ of\ dried\ supernatant(g)}{Weight\ of\ dry\ sample(g)} \times 100$

WSI shows how much of the sample dissolves in water, which is important for applications in beverages and instant foods. Similar approaches have been used for evaluating solubility of beetroot by-products and plant-based powders (Amoah et al., 2025; Constantin et al., 2025).

2.4.6 pH Measurement

The pH of the beetroot peel sample was measured using a standard digital pH meter. To prepare the sample, a small amount of the peel powder was mixed with distilled water (1:10 w/v) and allowed to stand so the solution could settle properly. Before taking any readings, the pH meter was calibrated with pH 4.0 and pH 7.0 buffer solutions to ensure accuracy. After calibration, the electrode was gently placed in the sample, and the pH was recorded once the meter showed a stable value. All measurements were taken at room temperature for consistency. pH is an important parameter influencing stability, shelf life, and functional behavior of food powders and plant-derived materials (Chen & Ranawana, 2021; Stoica et al., 2025).

2.5 Antinutrient Detection of beetroot peel

2.5.1 Detection of Tannins

Tannins were detected using the ferric chloride test. An aqueous extract of the sample was prepared, and 1–2 ml of the extract was taken in a test tube. A few drops of ferric chloride solution were added to the extract. The formation of a greenish black coloration indicated the presence of tannins in the sample. This qualitative test is commonly used for the detection of tannins in plant-based foods and by-products and is based on the ability of tannins to form colored complexes with ferric ions (Chung et al., 1998; Gemede & Ratta, 2014).

2.5.2 Detection of Oxalates

Oxalates were detected by the calcium precipitation method. An aqueous extract of the sample was prepared, and 1–2 ml of the extract was taken in a test tube. Calcium chloride solution was added to the extract, leading to the formation of a white precipitate due to calcium oxalate, which confirmed the presence of oxalates in the sample. This method is widely used for qualitative detection of oxalates in plant foods due to its simplicity and reliability (Gemede & Ratta, 2014).

2.5.3 Detection of Saponins

Saponins were detected using the foam test. Two grams of beetroot peel powder were mixed with 20 ml of distilled water in a test tube and shaken vigorously for 1–2 minutes. The formation of stable and persistent foam indicated the presence of saponins in the sample. The foam test is a commonly employed qualitative method for saponin detection in plant materials and is based on their surface-active properties (Shi et al., 2004; Gemede & Ratta, 2014).

2.6 Total Mineral Estimation of beetroot peel (mg/g)

The minerals sodium (Na) and potassium (K) present in beetroot peel powder were estimated using a flame photometer, which is a simple and widely used analytical tool for quantifying alkali metals. For the analysis, the sample was first subjected to dry ashing in a muffle furnace, and the ash obtained was dissolved in dilute hydrochloric acid to prepare a clear mineral solution. This solution was fed into the flame photometer, where the sodium and potassium atoms become excited in the flame and emit light at characteristic wavelengths. The emitted light intensity is proportional to the concentration of the respective element. Standard solutions of Na and K were used to prepare calibration curves, and the mineral content of the sample was calculated from the instrument readings. Flame photometry is commonly used for mineral analysis in plant-based foods and beetroot by-products due to its simplicity, rapidity, and reliability (Amoah et al., 2025; Stoica et al., 2025; Baião et al., 2017; AOAC, 2019).

2.7 Determination of Calorific of Value beetroot peel (kcal/g)

The calorific value of beetroot peel powder was determined using a bomb calorimeter, which measures

the total energy released during complete combustion of the sample. A small, accurately weighed amount of the dried sample was placed in the combustion cup of the bomb calorimeter, which was then filled with oxygen under high pressure. The bomb was immersed in a known volume of water, and the sample was ignited electrically. As the sample burned completely, the heat released increased the temperature of the surrounding water. The rise in temperature was recorded and used to calculate the energy content of the sample. The calorific value was expressed in kilocalories per gram. This method provides a direct and accurate measurement of the energy potential of food materials and has been widely applied in nutritional evaluation of plant-based foods and agricultural by-products (Ben-Othman et al., 2020; Stoica et al., 2025; Chen et al., 2021; Parr Instrument Co., 2015).

3. RESULTS AND DISCUSSION

3.1 Proximate Composition of Beetroot Peel Powder

The proximate composition of beetroot peel powder (BPP) presented in Table 1 reflects its potential as a nutritionally valuable plant by-product. The moisture content of BPP was 7.20 ± 0.10%, which is within the range reported for dried beetroot peel and pomace powders (approximately 7–9%), indicating effective dehydration and suggesting good storage stability (Amoah et al., 2025; Bușterchi & Stoica, 2025). The ash content of 9.38 ± 0.08% observed in this study is comparable to values reported in earlier studies on beetroot peels (around 8–10%), confirming that the outer tissues of beetroot are rich in mineral constituents due to their physiological role in nutrient accumulation (Zin et al., 2022; Stoica et al., 2025). The fat content of BPP was low (1.42 ± 0.05%), which agrees with previous findings that beetroot peels and related by-products typically contain less than 2% fat, making them suitable for low-fat food formulations (Baião et al., 2017; Chen & Ranawana, 2021). A notably high dietary fiber content (16.80 ± 0.25%) was recorded, which is consistent with literature reporting fiber values in the range of 14–18% for beetroot peel-based ingredients, attributable to the presence of cellulose, hemicellulose, and pectic polysaccharides (Ben-Othman *et al.*, 2020; Constantin et al., 2025). Carbohydrates constituted the major macronutrient fraction in BPP (53.95 ± 0.65 g/100 g), comparable to values reported for beetroot pomace and peel powders (approximately 50–60 g/100 g) following dehydration (Amoah et al., 2025; Abdo et al., 2022). The protein content of 11.25 ± 0.18 g/100 g was within the range reported for beetroot peels and peel-enriched formulations (9–12 g/100 g), highlighting the contribution of beetroot by-products to plant-based protein enrichment strategies (Abdo et al., 2022; Stoica et al., 2025). In addition, the detection of free amino acids (7.56 ± 0.11 µg/100 g) aligns with previous reports indicating the presence of bioavailable amino acids in beetroot tissues, which may contribute to both nutritional quality and physiological functionality (Chen et al., 2021; Clifford et al., 2015). Overall, the results demonstrate that the proximate composition of beetroot peel powder obtained in this study is in close agreement with literature values, supporting its sustainable utilization as a functional food.

Table 1: Proximate Composition of Beetroot Peel Powder

Parameters	Moisture (%(w/w))	Ash (%)	Fat (%(w/w))	Dietary Fiber (%(w/w))	Carbohydrate (g/100g)	Protein (g/100g)	Amino acid (µg/100g)
BPP	7.20 ± 0.10	9.38 ± 0.08	1.42 ± 0.05	16.80 ± 0.25	53.95 ± 0.65	11.25 ± 0.18	7.56 ± 0.11

(*BPP = Beetroot Peel Powder)

3.2 Antioxidant Activity of Beetroot Peel Powder

The antioxidant activity of beetroot peel powder (BPP) is presented in Table 2 and demonstrates its richness in bioactive compounds with antioxidant potential. The vitamin C content of BPP was 14.20 ± 0.25 mg/100 g, which is comparable to values reported for beetroot peels and related by-products, where vitamin C levels typically range between 10 and 20 mg/100 g depending on processing and drying conditions (Chen & Ranawana, 2021; Chen et al., 2021). The total phenolic content (TPC) of BPP was 12.78 ± 0.18 mg GAE/g, falling within the range reported for beetroot peel and pomace extracts, which are known to contain higher phenolic concentrations than beetroot flesh due to the accumulation of protective secondary metabolites in the peel (Zin et al., 2022; Stoica et al., 2025). Similarly, the total flavonoid content (TFC) recorded in this study (15.93 ± 0.21 mg QE/g) is consistent with values reported in beetroot peel-based products and snacks, where flavonoid content commonly ranges from approximately 12 to 18 mg QE/g (Bușterchi & Stoica, 2025; Constantin et al., 2025). The DPPH radical scavenging activity of BPP was 66.36 ± 0.92%, indicating a strong free radical inhibition capacity, comparable to reported DPPH inhibition values (60–75%) for beetroot peel and peel-enriched formulations (Abdo et al., 2022; Zin et al., 2022). Furthermore, FRAP value of beetroot peel extract was 8.14 ± 0.32 mg ascorbic acid equivalents (AAE)/g extract, indicating strong ferric reducing and antioxidant activity. Comparable FRAP values ranging from 6.0 to 9.5 mg AAE/g have been reported for beetroot peel and other vegetable by-product extracts, mainly due to their high phenolic and vitamin C content. These findings are consistent with earlier studies that highlight beetroot peel as a promising natural antioxidant source (Benzie & Strain, 1996; Coimbra et al., 2023). Overall, the antioxidant profile of beetroot peel powder obtained in

this study is in close agreement with literature values and confirms that beetroot peel is a concentrated source of natural antioxidants with potential applications in functional and value-added food products.

Table 2: Antioxidant Activity of Beetroot Peel Powder.

Parameters	Vitamin C (mg/100g)	Total Phenolic Content (TPC) (mg GAE/g)	Total Flavonoid Content (TFC) (mg QE/g)	DPPH Inhibition (%)	FRAP Activity (mg AAE/g)
BPP	14.20 ± 0.25	12.78 ± 0.18	15.93 ± 0.21	66.36 ± 0.92	8.14 ± 0.32

(*BPP = Beetroot Peel Powder)

3.3 Functional Properties of Beetroot Peel Powder

The functional properties of beetroot peel powder (BPP), as shown in Table 3, provide insight into its potential behavior in food formulations. The bulk density of BPP was 0.42 ± 0.02 g/ml, which is comparable to values reported for dried beetroot peel and vegetable by-product powders (approximately 0.35–0.50 g/ml), indicating a relatively light material that may contribute to improved texture and reduced product weight in formulated foods (Amoah et al., 2025; Ben-Othman *et al.*, 2020). The water absorption capacity (WAC) of BPP was 3.20 ± 0.15 g/g, reflecting its ability to retain water, which can be attributed to the high dietary fiber and polysaccharide content of beetroot peels; similar WAC values ranging from 2.5 to 4.0 g/g have been reported for beetroot pomace and peel-based composites (Amoah *et al.*, 2025; Constantin et al., 2025). Foam capacity was relatively low (9.00 ± 0.40%), which is consistent with previous reports indicating limited foaming ability in beetroot-derived powders due to their moderate protein content and the predominance of non-surface-active components (Abdo et al., 2022; Chen & Ranawana, 2021). The swelling power of BPP was 4.80 ± 0.20 g/g, falling within the range reported for plant-based peel powders (approximately 4–6 g/g), suggesting the presence of both soluble and insoluble polysaccharides that contribute to hydration and thickening properties (Ben-Othman *et al.*, 2020; Stoica et al., 2025). The water solubility index of BPP was 14.00 ± 0.50%, indicating partial solubility of low-molecular-weight components such as sugars and soluble fibers; comparable solubility values (10–20%) have been reported for beetroot peel and pomace powders (Bușterchi & Stoica, 2025; Constantin et al., 2025). The pH of BPP was 5.4 ± 0.10 indicating a slightly acidic nature, which is consistent with reported pH values (approximately 5.0–6.0) for beetroot-derived products and reflects the presence of organic acids and phenolic compounds (Chen et al., 2021; Clifford et al., 2015). Overall, these functional properties suggest that beetroot peel powder possesses favorable hydration, swelling, and stability characteristics, supporting its potential application as a functional ingredient in bakery, snack, and formulated food products.

Table 3: Functional Properties of Beetroot Peel Powder.

Parameters	Bulk Density (g/ml)	Water Absorption Capacity (g/g)	Foam (%)	Swelling Power (g/g)	Water Solubility Index (%)	pH Measurement
BPP	0.42 ± 0.02	3.20 ± 0.15	9.00 ± 0.40	4.80 ± 0.20	14.00 ± 0.50	5.4 ± 0.10

(*BPP = Beetroot Peel Powder)

3.4 Qualitative Detection of Antinutrient in Beetroot Peel Powder

Qualitative screening of beetroot peel powder confirmed the presence of tannins, oxalates, and saponins using standard detection methods (Table 4). The appearance of a greenish black coloration in the ferric chloride test indicated the presence of tannins, which are polyphenolic compounds commonly reported in plant peels and outer tissues (Chung et al., 1998). Oxalates were detected by the formation of a white calcium oxalate precipitate during the calcium precipitation test, suggesting the presence of oxalic acid derivatives that are known to chelate calcium and reduce mineral bioavailability when consumed in excess (Noonan and Savage, 1999). The formation of stable and persistent foam in the foam test confirmed the presence of saponins, which are glycosidic compounds widely distributed in plant materials and reported to exhibit both antinutritional and functional properties (Shi et al., 2004). The detection of these antinutrients is consistent with previous studies reporting that vegetable by-products and peels often contain higher levels of secondary metabolites compared to edible portions (Gemede and Ratta, 2014; Chung et al., 1998; Noonan & Savage, 1999; Shi et al., 2004; Kumar et al., 2012; Gemede & Ratta, 2014). Although tannins, oxalates, and saponins may negatively affect nutrient absorption at high concentrations, their presence at low levels is common in plant-based foods and can be reduced through appropriate processing methods such as blanching, cooking, or fermentation (Arjeh et al., 2015). Therefore, the results suggest that while beetroot peel powder contains detectable antinutrients, suitable processing strategies may improve its nutritional suitability for use as a value-added food ingredient.

Table 4: Qualitative Detection of Antinutrients in Beetroot Peel Powder.

Antinutrient	Tannins	Oxalates	Saponins
Present / Absent (BPP)	Present	Present	Present
Observation	Greenish black color	White precipitation formation	Stable foam formation

(*BPP = Beetroot Peel Powder)

3.5 Total Mineral Estimation of Beetroot Peel Powder

The mineral composition of beetroot peel powder (BPP) showed a sodium content of 1.85 ± 0.03 mg/g and a substantially higher potassium content of 24.60 ± 0.17 mg/g (Table 5). The relatively low sodium level and high potassium concentration are consistent with reported values for beetroot peels and by-products, where potassium is the predominant mineral due to its role in plant metabolism (Zin *et al.*, 2022; Stoica *et al.*, 2025). Similar potassium ranges (approximately 20–30 mg/g) have been reported in earlier studies, confirming beetroot peel as a potassium-rich material (Chen *et al.*, 2021; Clifford *et al.*, 2015). This favorable potassium-to-sodium ratio enhances the nutritional value of beetroot peel powder and supports its potential application in health-oriented and functional food formulations.

Table 5: Total Mineral Estimation of Beetroot Peel Powder.

Parameters	Sodium (mg/g)	Potassium (mg/g)
BPP	1.85 ± 0.03	24.60 ± 0.17

(*BPP = Beetroot Peel Powder)

3.6 Calorific Value of Beetroot peel Powder

The calorific value of beetroot peel powder (BPP) was 2.736 kcal/g (273.6 kcal/100 g), indicating a moderate energy contribution mainly from carbohydrates and dietary fiber. This value falls within the range reported for dried beetroot peels and beetroot-derived by-products (approximately 250–300 kcal/100 g), as documented in earlier studies (Amoah et al., 2025; Baião et al., 2017). Similar calorific values have also been reported for beetroot peel-enriched formulations, reflecting less fat content and carbohydrate-dominated composition of beetroot by-products (Abdo et al., 2022; Stoica et al., 2025). These findings suggest that beetroot peel powder can be incorporated into functional foods without substantially increasing the overall energy density.

4. CONCLUSION

The present study demonstrated that beetroot peel powder (BPP), commonly discarded during processing, possesses considerable nutritional, antioxidant, functional, and mineral potential. Proximate analysis showed that BPP is rich in carbohydrates (53.95 ± 0.65 g/100 g) and dietary fiber (16.80%), with moderate protein content (11.25 ± 0.18 g/100 g) and low fat (1.42%), which is comparable to values reported for beetroot peels and by-products in earlier studies (Abdo et al., 2022; Amoah et al., 2025). The low moisture content (7.20%) suggests good storage stability. Mineral analysis confirmed potassium as the predominant mineral (24.60 ± 0.17 mg/g), with a favorable sodium–potassium ratio, consistent with previous reports on beetroot by-products (Zin et al., 2022; Chen et al., 2021). Beetroot peel powder exhibited strong antioxidant potential, as indicated by its vitamin C content (14.20 mg/100 g), appreciable phenolic and flavonoid contents, and high DPPH radical scavenging activity (66.36%) along with FRAP value (8.14 mg ascorbic acid equivalents (AAE)/g extract). These findings are consistent with earlier studies that highlight beetroot peel as a promising natural antioxidant source (Benzie & Strain, 1996; Coimbra et al., 2023). Functional properties such as bulk density (0.42 g/ml), water absorption capacity (3.2 g/g), and swelling power (4.8 g/g) indicate favorable hydration behavior suitable for food formulations. Although qualitative screening confirmed the presence of antinutrients such as tannins, oxalates, and saponins, these compounds are commonly present in plant-based foods and may be reduced through appropriate processing methods. Future studies may focus on the quantitative estimation of antinutrients, evaluation of bioavailability of nutrients, and assessment of processing techniques such as blanching, fermentation, or extrusion to reduce antinutritional factors. Further work on product development, sensory evaluation, shelf-life studies, and in vivo assessment of antioxidant activity would help in validating the practical applicability of beetroot peel powder in functional and commercial food products. Overall, the findings support the sustainable utilization of beetroot peel powder as a value-added ingredient, contributing to waste reduction and improved nutritional quality.

Conflict of Interest

The authors declares that there is no conflict of interest related to the present research work.

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