Effect of Pretreatments on Nutritional, Functional and Physicochemical Properties of *Bauhinia variegata* Pod Peel Powder

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Abstract: The present study was conducted to evaluate the effect of different pre-treatments: blanching (K_1) and chemical treatment (K_2), before drying, on the physicochemical, functional, color, flow, and mineral properties of *Bauhinia variegate* pod peel powder. The results revealed significant variations among the treatments. K_2 showed lower moisture content (6.22%) and higher ash (7.46%), fat (2.24%), acidity (0.66%), and protein content (9.02%) compared to K_1. Functional properties such as water absorption capacity, oil absorption capacity, emulsifying activity, and foaming capacity were also influenced by the treatments. Colour analysis indicated higher lightness (L*) and hue values in K_2 samples, suggesting better color retention. Flow properties showed slight variations between treatments, while mineral analysis demonstrated higher calcium, potassium, magnesium, phosphorus, iron, zinc, and manganese contents in K_2. In the present study, K_2 was found to be more effective in preserving nutritional and functional quality characteristics of *Bauhinia variegata* pod peel powder.

Keywords: *Bauhinia variegata*, Functional properties, Mineral, FTIR analysis, Drying.

1. Introduction

Bauhinia variegate is a deciduous tree, native to tropical and temperate regions. It is a small-to medium-sized tree, brownish-grey in colour. It is an important medicinal plant belonging to the family Fabaceae, also known by various names like Kachanara (Hindi), Raktakanchan (Marathi), Mountain ebony or orchid tree (English) and Kanchana, which means "A glowing, beautiful lady" in Sanskrit [1]. It is a native of India, Burma, China, Malaysia, the tropics of South Africa, Zambia, and Zimbabwe. In India, some of the species of this genus are distributed, such as *B. tomentosa, B. purpurea* and *B. variegata* and grow well in the drier parts of tropical and subtropical regions. It is widely planted in gardens and parks as a decorative plant. The parts of this, that is, flowers, stem, bark, root, and seeds, are well known for their medicinal and therapeutic values. In Ayurveda, the plant parts are used in various medical formulations. Stem bark is used in treating disorders such as Galaganda, Gandamala, Arbuda, Kapha-Pitta, and Ashthila. Flowers are used for the treatment of conditions like Pitthaghna, Rakta pradaraghna, Kaasghna, and Kshyaghna. The pods are long, hard, flat, with dehiscent and 10-15-seeded. Buds, roots, pods and bark have good antioxidant properties. Besides this, the plant and its parts are used in many conventional activities, such as mosquito control, fibre production, the dyeing industry, and agricultural operations. *Bauhinia variegata* is rich in vital essential nutrients of vitamin C, B vitamins, key minerals of calcium, phosphorus, magnesium, iron, zinc, besides this, it also has macronutrients of reducing-sugar carbohydrates, dietary fibres, proteins and healthy unsaturated fats. Other than this, it contains ample amounts of several pivotal vitamins, minerals, proteins, carbs, and fats; it also illustrates a notable profile of bioactive phyto-nutrients with anti-inflammatory, antimicrobial, anti hyperglycemic, antiarthritic and cytotoxic, i.e., cancer-reducing properties. These bioactive constituents are very useful in the prevention, management and treatment of a host of disorders, including hypothyroidism, irregular periods and amenorrhea, high blood sugar levels in diabetes, mouth ulcers and digestive complications [2]. In many regions of India, curries and pickles are prepared by cooking, frying kachnar buds, seasoned with onions and spices, as a customary food, which is then eaten as vegetables or side dishes as part of the regular diet [3]. Therefore, the present study is justified to evaluate the nutritional composition, functional characteristics, and potential nutritional properties of *Bauhinia variegata* pods. This research may also contribute to promoting the sustainable use of locally available plant resources while enhancing the nutritional quality of foods. Ultimately, the findings of this study may support the incorporation of *Bauhinia variegata* pod powder into food systems aimed at improving metabolic health and overall well-being.

2. MATERIALSANDMETHODS

2.1. Collection of Material

Fresh *Bauhinia variegate* mature tender seed pods were harvested from the university campus (GBU). The collected pods will be carefully selected to remove damaged, diseased, or immature samples. After collection, the pods will be transported to the laboratory and stored under clean and hygienic conditions until further processing and analysis.

2.2. Processing and Preparation of Samples

After washing, the pods were manually deseeded, and the peel portion was separated and cut into small uniform pieces to ensure uniform pre-treatment and drying. Different pre-treatments: steam blanching and chemical treatment (calcium chloride: 0.2% and citric acid: 0.3%), were applied before drying. For steam blanching (K_1), the peel pieces were steamed blanched at 80°C for 5 min in water containing 0.5% sodium chloride, followed by draining to remove excess surface moisture. For chemical treatment (K_2), the peel slices were immersed in an aqueous solution containing 0.3% citric acid and 0.2% calcium chloride for 30 min at room temperature. The pre-treated samples were uniformly spread on stainless steel trays and dried in a tray dryer maintained at 45°C until constant weight was achieved. The dried samples were cooled to room temperature, ground into fine powder using a laboratory grinder, and sieved through a 60 BSS sieve to obtain a uniform particle size. The prepared powder was packed in airtight containers and stored under ambient conditions for further analysis [4]. Each treatment (K_1 and K_2) was prepared independently in triplicate, and all analyses were performed on three replicate samples (n = 3). Results are expressed as mean ± standard deviation.

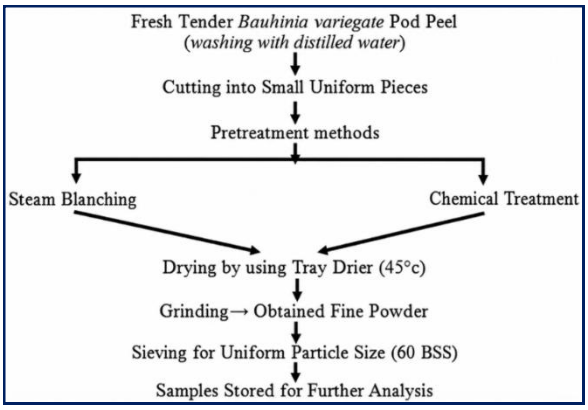

Fig. 1. Processing of *Bauhinia variegate* Powder

2.3 Physicochemical Analysis

Moisture, ash and fat content of the sample were evaluated by using standard method. Crude fibre and protein were analyzed used by using automatic extraction unit (Kelpus pelican) whereas pH determined using digital pH meter (Biogen Scientific, India) [5,6,7].

2.4 Functional Properties

Functional properties, including water absorption capacity and oil absorption capacity, were evaluated using standard analytical methods [8,9.10]. Briefly, 1 g of sample was dispersed in 30 ml of distilled water, heated at 50°C for 30 min, and centrifuged (Biogen Scientific, India) at 4500 rpm for 15 min. Swelling power (SP) and solubility index (SI) were calculated at 80^0 c following the standard analytical procedure.

2.5 Bulk and Tapped density

BD was determined by measuring the volume occupied by 50 g of the sample in a graduated cylinder where as tapped density was measured after mechanically tapping the cylinder until a constant volume was obtained [11].

2.6 Flow properties

It was calculated using Carr's Index (CI) and Hausner Ratio (HR) were used to assess flowability [12]. CI values below 15% and HR values <1.25 indicate good flowability.

$$CI (\%) = [(Tapped – Bulk) / Tapped] \times 100$$
$$HR = Tapped / Bulk$$

2.7 Color Analysis

Color characteristics of samples were measured by using hunter color lab colorimetery (Hunter Associates Laboratory Inc., Reston, VA, USA) were expressed in terms of L* (lightness), a* (redness), b* (yellowness), C* (chroma) and h° (hue) [13].

2.8 Elemental Analysis

A 0.25 g aliquot of each dried sample underwent acid digestion with 6 mL of nitric acid (HNO_3) and 1 mL of hydrogen peroxide (H_2O_2) in a microwave digestion apparatus. The digested samples were diluted to 50 mL with deionised water and subsequently diluted 1:10 before analysis. Elemental concentrations were determined using Inductively Coupled Plasma Optical Emission Spectroscopy (Thermo Scientific iCAP 7000 Series), and results were expressed in mg/kg [14].

2.9 FTIR Analysis

FTIR spectra of the powder samples were recorded using an FTIR spectrometer in the spectral range of 4000–400 cm⁻¹. Spectra were collected at a resolution of 4 cm⁻¹ with 32 scans per sample. The obtained spectra were used to identify the major functional groups present in the samples.

2.10 Statistical Analysis

All experiments were performed in triplicate and results were expressed as mean ± standard deviation. Statistical analysis was carried out using one-way analysis of variance (ANOVA) using SPSS software to determined significant differences among drying methods at $p < 0.05$ level of significance.

3. Result and Discussion

3.1 Effect on Physicochemical Properties

The physicochemical characteristics of K_1 were recorded as 7.33%, whereas K_2 showed lower moisture content (6.22%). The reduction in moisture content in K_2 may be attributed to the osmotic effect of calcium chloride and the tissue-firming action of calcium ions, which enhanced water diffusion during drying [15]. Similar findings were documented by [16] in treated jackfruit bulb powder, where the moisture content was observed to be 6.92% and 5.8%, due to enhanced drying efficiency after acid treatment. Lower moisture content indicates improved shelf stability and reduced microbial spoilage potential in pod peel powders.
The ash content of K_1 and K_2 ranged from 5.11% to 7.46%, with the highest value observed in K_2 , which could be due to the incorporation and retention of calcium ions from calcium chloride treatment within pod peel tissues [17]. Similar results were reported by [78] in carrot peel powder, where chemically treated samples showed ash values of 7.1–7.4%, while blanched samples showed lower values of 5.2–5.8%.
The fibre content of K_2 (11.12%) was higher than that of K_1 (9.23%). The increase in crude fibre may be due to the stabilization of structural polysaccharides, including cellulose and hemicelluloses and greater moisture loss and stabilization of structural polysaccharides during chemical treatment [18]. A similar trend was followed by [19] who observed fibre content of treated drumstick pod powder ranging from 13.5% to 16.8% and 11.4% to 15.7%. [20] also observed higher dietary fibre retention (11.02%) in acid-treated vegetable peel powders than in untreated samples (9.14%). Fat content slightly increased from 2.12% in K_1 to 2.24% in K_2. The increase may be related to concentration effects caused by the consequent concentration of lipid fractions [21].

Table 1. Effect on Physicochemical Properties

Parameter (s)	Sample			
	K_1	**K_2**	**CD (%)**	**CV (%)**
Moisture (%)	7.33 ±0.02	6.22 ±0.23	0.41	2.99
Ash (%)	5.11 ±0.02	7.46 ±0.02	0.11	0.95
Fibre (%)	9..23 ±0.07	11.12 ±0.03	0.20	0.69
Fat (%)	2.12 ±0.01	2.24 ±0.02	0.05	1.08
Protein (%)	8.41 ±0.02	9.02 ±0.02	0.05	0.32
Acidity (%)	0.46 ±0.02	0.66 ±0.32	0.03	2.64
pH	5.75 ±0.02	6.25 ±0.03	0.05	0.32
Carbs (%)	62.86± 0.11	57.87 ±0.36	0.59	0.46
Energy (k/cal)	304.2 ±0.25	287.7 ±1.15	2.02	0.32

Values expressed are ± SD (n=3)
K_1= Blanched *Bauhinia variegate* Pod Peel Powder
K_2 = Chemical *Bauhinia variegata* Pod Peel Powder
CD = Critical Differences
CV= Coefficient of variation

Protein content values ranged from 7.46±0.01% to 9.02±0.02%, with K_2 showing the highest protein content. The higher protein content in the chemically treated sample may be due to reduced protein denaturation and minimized leaching losses during processing, which was similarly observed by [22] in calcium chloride-treated legume powders. Citric acid pre-treatment may additionally inhibit enzymatic protein degradation during drying [23].

Acidity increased from 0.46% in K_1 to 0.66% in K_2. The higher acidity observed in K_2 powder may be due to the infusion of chemicals during pre-treatment that leading to enhanced organic acid concentration in the powder [24]. Organic acid penetration into peel tissues during soaking increases titratable acidity and improves microbial stability of the dried powder [4]. Similar findings were reported by [25] who studied citric acid-treated pomegranate, carrot and tomato peel powder, where acidity increased with 0.82, 0.63 and 5.50% as compared to blanching.

The increase in pH of K_2 (6.25) may be associated with ionic interactions between calcium salts and naturally occurring organic acids present in pod peel tissues [26]. A similar trend, followed by [27] reported pH values ranging from 6.1–6.3 and 5.1-6.4 in chemically treated pea and pumpkin peel powder, observed high values as compared to blanched samples.

Similar carbohydrate content ranged from 55% to 70% in fruit residue powders, as investigated by. Carbohydrate content decreased from 62.86% in K_1 to 57.87% in K_2. That decrease comes from soluble sugars washing away and some carbs breaking down during the acid treatment, as reported by [28].The energy value decreased from 304.2 kcal in K_1 to 287.7 kcal in K_2. The reduction in calorific value may be associated with lower carbohydrate concentration in chemically treated pod peel powder, as carbohydrates contribute significantly to total energy content [29]. Similar findings were found by [30] in osmotic dehydrated turnip and radish.

All the parameters had low coefficient of variation (CV) and critical difference (CD) values under 5% that strongly indicates statistical significance due to the pre-treatment methods used, and the variations show good consistency among observations.

3.2 Effect on Functional Properties

The functional properties of pre-processed K_1, K_2 and are presented in Table 2. The results revealed marked variability among treatments, likely due to structural changes, protein functionality, and macromolecule interactions.

WAC values ranged from 2.42g/g in K_2 and 2.66 g/g in K_1. K_1 had significantly higher WAC than K_2 due to thermal disruption of cellular structure and may partially gelatinise carbohydrates and denature proteins, leading to improved hydration properties and enhancing the exposure of hydrophilic groups [46]. The lower WAC in K_2 may result from thermal pretreatments increasing water absorption due to structural loosening of plant tissues [47]. Similar findings were documented by [43], who studied the pretreated beetroot peel powder, which showed higher WAC (2.71 g/g) than chemically treated samples (2.38 g/g).

Table 2. Effect on Functional Properties

Parameter (s)	Sample			
	K_1	**K_2**	**CD (%)**	**CV (%)**
WAC (g/g)	2.66 ±0.03	2.42 ±0.02	0.04	0.95
OAC (g/g)	1.97 ±0.01	1.81 ±0.26	0.04	1.21
SP (g/g)	4.33 ±0.05	3.21 ±0.02	0.11	1.45
SI (%)	26.81 ±0.10	23.38 ±0.09	0.24	0.50
EA (%)	50.24 ±0.03	55.20 ±0.05	0.16	0.15
ES (%)	45.17 ±0.04	50.65 ±0.25	0.45	0.47
FC (%)	28.27 ±0.11	24.08 ±0.06	0.26	0.51
FS (%)	21.26 ±0.12	25.29 ±0.10	0.15	0.35

Values expressed are ± SD (n=3)
K_1= Blanched *Bauhinia variegate* Pod Peel Powder
K_2 = Chemical *Bauhinia variegata* Pod Peel Powder
CD = Critical Differences
CV= Coefficient of variation

The present study showed OAC of K_1 was1.97 g/g and K_2 was 1.81. The lower OAC in chemically treated samples may result from structural modifications in proteins, reducing their lipid-binding sites. The higher OAC observed in K_1 may result from the availability of non-polar side chains of proteins, which accelerate lipid binding, whereas K_2 had slightly reduced oil binding due to structural alterations of proteins, as reported by [13]. Similar data were reported by [48], who studied blanched pumpkin peel powder, which exhibited higher OAC (2.04 g/g) than chemically treated samples (1.76 g/g).

The present study showed the SP and SI in K_1 ranged 4.33 g/g, 26.81 %, and K_2 ranged 3.21 g/g, 23.38 %, respectively. K_1 showed significantly higher SP than K_2, along with SI values that were higher in K_1 as compared to K_2 due to breakdown of cell wall structures and increased availability of starch and fibre components to enhanced water uptake, leading to greater swelling behavior [40]. Similar findings were observed by [42] in papaya peel powder, where blanched samples showed higher swelling capacity (4.51 g/g) than chemically treated samples (3.34 g/g). The present study revealed that the powders exhibit goods welling behaviour, which plays a key role in texture development in food applications.

EA values in K_1 and K_2 ranged from 50.24% to 55.20%, while ES ranged from 45.17% to 50.65%, respectively. K_2 exhibited significantly higher EA (55.20) and ES (50.65) as compared to K_1 (50.24% and 45.17%, respectively). Due to improved protein–protein interactions and the formation of cohesive, viscoelastic interfacial films that prevent coalescence of oil droplets and reduce thermal denaturation during pretreatment [14]. Recent studies have shown that structural modification of proteins enhances interfacial adsorption and improves film-forming ability, resulting in emulsion stability in food systems, as demonstrated by [50]. Similar findings were reported by [40] in moringa leaf powder, where chemically treated samples exhibited higher EA (57.42%) and ES (52.14%) than blanched samples.

FC values ranged from 24.08% to 28.27%, while FS ranged from 21.26% to 25.29%. K_2 showed significantly higher FC and FS compared to K_1, which may be due to improved protein flexibility and film-forming ability around air bubbles, there by stabilising foam structure [51]. Similar findings were reported by [45], who studied mango peel powder, where chemically treated samples showed higher foam stability (26.41%) than blanched samples (22.13%). Recent studies suggest that moderate thermal treatments improve protein flexibility and reduce aggregation, thereby enhancing the foaming properties of plant proteins, according to. Accordingly, the higher FC in blanched samples shows beneficial structural modifications that promote foam formation. Therefore, FS values reflect the role of protein structural integrity in maintaining foam structure over time.

3.3 Effect on Flowability Properties

The flowability of both sample showed significant differences ($p < 0.05$) among the drying methods as presented in Table 3. Parameters such as bulk density, tapped density, Carr's index, Hausner's ratio, and angle of repose are important indicators of powder handling behaviour, flow characteristics, packaging efficiency, and storage stability.

The bulk density of both K_1 and K_2 was recorded as 0.51 g/cc, indicating no significant difference between treatments; however, the tapped density (TD) was slightly higher in K_2 (0.62 g/cc) than in K_1 (0.60 g/cc). Bulk density is influenced by particle size, porosity, and packing behaviour of powder particles under loose conditions [31]. The increase in tapped density may be attributed to improved particle compactness and inter-particle void spaces in the powder [32]. Similar findings were reported by [33,34], who also observed negligible differences in BD and TD of pre-treated pumpkin, beetroot and sweet potato peel powder.

Table 3. Effect on Flow Properties

Parameter (s)	Sample			
	K_1	K_2	CD (%)	CV (%)
BD (g/cc)	0.51 ±0.01	0.51 ±0.02	N/A	7.76
TD (g/cc)	0.60 ±0.15	0.62 ±0.06	N/A	N/A
CI (%)	14.96 ±1.41	17.13 ±4.04	N/A	30.84
HR	1.17 ±0.02	1.21 ±0.05	N/A	N/A
AR (^{0})	33.73 ±0.56	33.83 ±1.35	N/A	5.779

Values expressed are ± SD (n=3)
K_1= Blanched *Bauhinia variegate* Pod Peel Powder
K_2 = Chemical *Bauhinia variegata* Pod Peel Powder
CD = Critical Differences
CV= Coefficient of variation

Carr's Index (CI) was higher in K_2 (17.13%) compared to K_1 (14.96%), indicating comparatively lower flowability in the chemically treated sample. The increase in CI of K2may be due to enhanced cohesiveness and stronger inter-particle interactions [31]. Powders with higher CI values generally exhibit greater compressibility and moderate flow behaviour. CI differences are due to variations in particle size distribution and moisture content, which affect friction and cohesion between particles, as reported by [35]. [36] reported CI values of 15.4–18.3% in chemically treated papaya peels powder.

HR increased slightly from 1.17 in K_1 to 1.21 in K_2, further indicating a moderate increase in cohesiveness of the chemically treated powder. The increase in HR may be associated with increased cohesiveness and reduced inter- particle mobility caused by finer particles in chemically treated samples. Nevertheless, the HR values remained within acceptable limits for good flowing powders. [37] reported Hausner ratio values between 1.18 and 1.23 in chemically treated banana peel powder. Similar findings were also observed by [38] in citrus peel powder after citric acid treatment. The higher HR value may be associated with moisture

redistribution and increased surface adhesion among particles after chemical pretreatment [16]. A Hausner ratio under 1.25 signals good flowability, while higher numbers point to more cohesiveness. Similar HR values from 1.15 to 1.30 in food powders were reported by [39]. This behaviour may result from stronger inter-particle interactions and denser packing caused by calcium chloride treatment [32]. However, both samples remained within acceptable flowability limits for food powders.
The flow property analysis showed that all samples had good to fair flowability, based on Carr's Index, Hausner ratio, and angle of repose values. Angle of repose values ranged from 33.73° to 36.83°, indicating acceptable flowability of all powder samples. According to [33], irregular particle morphology increases frictional resistance and consequently raises angle of repose values in dehydrated powders. Similar observations were reported by [34] in spray-dried fruit powders, where angle of repose values ranged from 32.8° to 37.4° after blanching and acid treatment. The present study showed that K_2 demonstrated slightly higher compressibility and cohesiveness than K_1, while both powders maintained acceptable flow properties suitable for powder handling and functional food applications.

3.4 Effect on Mineral Composition

Mineral composition represents a key nutritional parameter affecting the health value and functional value of plant-based powders. K_2 showed higher retention of all minerals as compared to K_1, indicating better preservation of nutrients during drying. The calcium content ranged from 120.85 to 152.60 mg/100 g. K_2 showed higher calcium content, which may be due to absorption of calcium ions from calcium chloride during pretreatment and reduced mineral leaching during drying, whereas K_2 showed low calcium content, which may cause loss of soluble minerals into blanching water. Similar findings were reported by [52] in mango peel powder, where chemically treated samples showed higher calcium content (148.42mg/100g) than blanched samples (118.65mg/100g). Potassium content varied from 642.10 to 705.80 mg/100 g, with a higher value observed in K_2 (705.80 mg/100 g) as compared to K_1 (642.10 mg/100 g).
The lower magnesium content in blanched powder may be due to heat-induced leaching of mineral content during processing. Higher sodium, iron and zinc content were observed in K_2, ranging 30.95, 5.90, 2.10 mg/100 g, as compared to K_1 24.85,4.85, 1.62 mg/100g. Blanching may reduce sodium content because of the dissolution of salts into the blanching water, as reported by [43].

Table 4. Effect on Mineral Contents

Parameter (s) (mg/100g)	Sample	
	K_1	K_2
Calcium	120.85	152.60
Potassium	642.10	705.80
Magnesium	79.40	95.20
Sodium	24.85	30.95
Iron	4.85	5.90
Zinc	1.62	2.10
Copper	0.60	0.82
Manganese	1.48	1.95
Phosphorus	94.60	112.75

Values expressed are ± SD (n=3)
K_1= Blanched *Bauhinia variegate* Pod Peel Powder
K_2 = Chemical *Bauhinia variegata* Pod Peel Powder
CD = Critical Differences
CV= Coefficient of variation

Similar findings were observed by [40] in moringa leaf powder, where chemically treated samples retained higher iron content than blanched samples. Similar findings were reported by [53] in citrus peel powder. K_2 showed higher copper (0.82 mg/100 g), manganese (1.95 mg/100 g), and phosphorus (112.75 mg/100 g) content than K_1 (0.60, 1.48, and 94.60 mg/100 g). The increase in phosphorus content in chemically treated samples may be attributed to reduced leaching and concentration effects during drying and enhanced mineral retention, thereby improving the nutritional quality of the developed powders. Enhanced retention in K_2 results from reduced leaching and preserved tissue structure during processing. Similar values have been reported in fruit powders (90–130 mg/100 g) [23]. K_2 showed improved mineral stability and reduced oxidative losses during drying, and showed a reduction in K_1 due to the leaching process during blanching.

3.5 Effect on Color Properties

The color quality of food powders is an important quality attribute because it directly influences consumer acceptability and reflects pigment stability during processing. In the present investigation, significant differences were observed in the color parameters of K_1 and K_2, indicating that the pretreatment methods markedly affected pigment retention and browning behaviour. The L* value indicates the whiteness level; zero represents black, while one hundred represents white color. The increased lightness in chemically treated samples may be associated with the inhibitory effect of citric acid on enzymatic browning and the stabilising action of calcium ions on plant tissues, which contribute to the retention of preserved color pigments as reported by [35]. L* values ranged from75.38 to 79.84 in K_1 and K_2, which exhibited significantly higher L* values, may be attributed to the anti-browning effect of citric acid, which lowers pH and inhibits polyphenol oxidase activity responsible for enzymatic browning reactions. Calcium chloride additionally helps in maintaining cellular integrity and reducing pigment degradation during dehydration [36] who stated that acid-based pretreatments effectively reduce browning and improve color stability in dehydrated products. [37] Further explained that calcium chloride treatments preserve tissue firmness and reduce oxidative darkening during dehydration. Similar findings were demonstrated by [38] who studied citric acid-treated sweet potato peel powder, showing significantly higher L* value (82.16, 79.45) than blanched samples (73.84, 70.26), indicating superior brightness retention after chemical pretreatment.

K_1 showed a positive a* value (1.09), whereas K_2 exhibited a negative a* value (−2.90), indicating better retention of green pigments in K_2. The deviation in a* values may be associated with pigment degradation and transformation during processing, including chlorophyll degradation, generation of pheophytins, and non-enzymatic browning reactions, and preserve greenness as described by [39]. Comparable findings were observed by [40] who studied pretreated moringa leaf.

The b* values ranged in K_1 (23.76) and K_2 (19.66), with significantly higher b* values indicating increased yellowness in K_1. The lower b* value in K_2 may be attributed to carotenoid pigment degradation during processing; higher values in blanched samples may be associated with better retention of natural yellow pigments as reported by [41]. Similar findings were recorded by [42] in papaya peel powder, where blanched samples exhibited a higher b* value (29.15) than citric acid-treated samples (22.48).

The chroma (C*) values of K_1 showed significantly higher chroma values (23.79) than K_2 (19.88). Similar findings were observed by [43] in beetroot peel powder, where blanched samples recorded a higher chroma value (26.37) compared to chemically treated samples (21.14). The lower chroma in K_2 may indicate stabilisation of pigments and reduced oxidative color changes. K_2 exhibited significantly higher hue angle (98.43) than K_1 (87.40), indicating better retention of natural yellow-green color characteristics.

Table 5. Effect on Color Quest

Parameter (s)	Sample			
	K_1	**K_2**	**CD (%)**	**CV (%)**
L*	75.38 ±0.41	79.84 ±0.84	0.4	0.6
a*	1.09 ±0.11	-2.90 ±0.13	0.8	0.9
b*	23.76 ±0.17	19.66 ±0.63	0.6	0.3
C*	23.79 ±0.17	19.88 ±0.64	0.7	0.4
h°	87.40 ±0.23	98.43 ±0.28	0.5	0.3

Values expressed are ±SD (n=3)
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K_1= Blanched *Bauhinia variegate* Pod Peel Powder
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CD = Critical Differences
CV= Coefficient of variation

In the present study, the increase in ho in K_2 may be attributed to improved chlorophyll stability due to chemical treatment help topreserve natural color, whereas K1showed a slightly lower value due to thermal conversionof chlorophyll into yellowish-brown compounds [44]. Similar findings were reported by [45] in mango seed coat powder, where chemically treated samples exhibited a higher hue angle value (99.26) than blanched samples (88.43).

3.6 Effect on FTIR

The FTIR spectra of *Bauhinia variegata* pod peel powder revealed several characteristic absorption bands associated with carbohydrates, dietary fibre, organic acids, phenolic compounds, and mineral-associated constituents. The absorption peak at 2921.29 cm⁻¹ corresponds to C–H stretching vibrations of polysaccharides and structural carbohydrates, confirming the carbohydrate-rich nature of the pod peel powder. The peak observed at 1734.13 cm^{-1} is attributed to C=O stretching vibrations of pectic substances and organic acids, supporting the acidity values obtained in the physicochemical analysis, particularly in the chemically treated sample (K_2). The band at 1241.93 cm^{-1} corresponds to C–O stretching vibrations of phenolic compounds and lignin-related constituents, suggesting the presence of bioactive compounds that may contribute to improved colour retention and nutritional quality.

Table 6. FTIR with Functional Group

ṽ (cm⁻¹)	**K_1**	**K_2**	**Vibration Functional Group**
2921.29	Present	Present	Stretching C–H
1734.13	Present	Present	Stretching C=O
1241.93	Present	Present	Stretching C–O
1030.91	Strong	Very strong	Stretching C–O–C
516.81	Present	Present	Bending Metal–O / Skeletal

A strong absorption peak at 1030.91 cm⁻¹ represents C–O–C stretching vibrations of cellulose and hemicellulose, confirming the fibre-rich composition of the powder and supporting the higher fibre content observed in K_2 (11.12%). The peak around 516.81 cm⁻¹ may be associated with mineral-linked compounds and complex polysaccharide structures, which is consistent with the appreciable levels of calcium, potassium, magnesium, iron, zinc, and manganese detected through ICP-OES analysis. Furthermore, K_2 exhibited comparatively sharper and more intense absorption bands than the K_1, indicating better preservation of structural polysaccharides and bioactive constituents following citric acid–calcium chloride pretreatment. These observations agree well with the higher mineral retention, protein content, emulsifying properties, and colour stability recorded for K_2. Similar FTIR observations in peel powders and chemically treated plant products were also reported by [10].

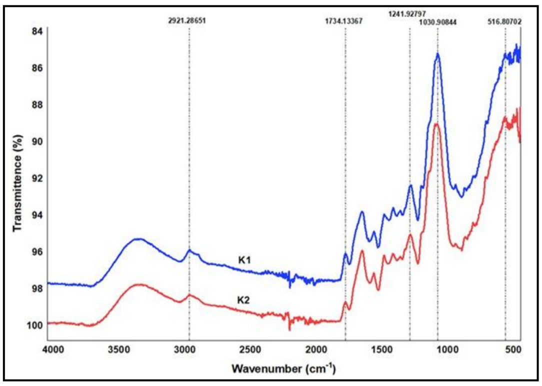

Fig. 2. FTIR Spectra of K_1 and K_2

Conclusion

The present study revealed that the pre-treatment methods significantly influenced the physicochemical, functional, mineral and color characteristics of *Bauhinia variegata* pod peel powder. K_2 showed higher retention of minerals, protein, fibre, acidity, emulsion properties, foaming characteristics and color stability than K_1. The chemical pretreatment also improved lightness, preserved natural pigments, and reduced enzymatic browning, resulting in improved visual quality and nutritional stability of the powder. K_1 had relatively higher WAC, OAC, SC, SI, and chroma values, indicating better hydration and texture-related functional properties. Both treatments presented flowability characteristics suitable for powder handling and storage applications. FTIR analysis showed the presence of important functional groups related to carbohydrates, phenolics, fibre, and organic acids, and sharper peaks in K_2, so it shows indicated improved preservation of bioactive compounds after chemical pretreatment. The low moisture content and adequate physicochemical properties also indicate a good shelf stability of the developed powders. The present study suggests that the under utilised by-product, *Bauhinia variegate* pod peel, has considerable nutritional and functional potential for incorporation into value-added functional foods, nutraceuticals formulations and food powder applications. Chemical pretreatment with calcium chloride and citric acid was found to be better for retention of nutritional quality as well as overall powder stability during drying and storage.

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