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Research Article

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Effect of Acid Pretreatment on PhysicoChemical, Optical, Functional, Thermal, and Morphological Characteristics of Unripe Plantain and Banana Flour

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Abstract

Utilization of unripe plantain and banana flour can play a substantial role in economic sustainability and minimizing postharvest losses. Organic acids can play an essential role in preventing enzymatic browning and improving the properties of banana flour. Present work was conducted to study the effect of citric acid pretreatment on the physicochemical, functional, antioxidant, thermal, and morphological characteristics of unripe plantain (Bagner variety) and banana (Grand Naine variety) flour. Unripe plantain flour was found to have higher starch content than green banana flour. Citric acid treatment resulted in a decrease in the moisture content of dehydrated slices. Low moisture content indicates better storage quality and microbial stability. The Bagner variety had a higher swelling capacity than Grand Naine, possibly due to the higher starch content. Functional properties, namely water absorption capacity and swelling power, improved significantly after citric acid treatment. It also led to an improvement in total phenolic content and antioxidant activity. Citric acid treatment increased the gelatinization temperature and lowered peak viscosity. This might be due to the depolymerization of starch. Banana starch is observed to have a B-type crystal structure, a significant portion of which is resistant to digestion and thus can be used in developing various functional foods with a low-glycemic index.

Keywords

Banana, Plantain, Pretreatment, Dehydration, Composition, Pasting Properties

Introduction

With more than 25% (30.808 MMT) production share worldwide, India is a pioneer in banana production. Out of the total cultivated cropped area of 197.016 million hectares, 74.02% area is under the cultivation of food crops, 3.67% for fruits, and just 0.40% share for banana cultivation [1]. Although banana productivity in India (34.86 MT/ ha) is well below the global highest productivity of Indonesia (51.19 MT/ha) but the productivity of banana in many Indian states is above this productivity [2]. Following the cultivation practices of those states may further substantially improve banana production toward solving the global hunger problem to some extent [1]. Banana is among the top ten cultivated agricultural produce in India. Banana can be classified as plantain and dessert banana. Plantain is rich in starch when unripe and is usually consumed after cooking, whereas dessert banana is consumed after ripening [1, 3]. Banana is highly nutritious and possesses medicinal and therapeutic values. They are a rich source of carbohydrates, vitamins, and minerals such as potassium, phosphorus, and magnesium. Dopamine and catecholamine are found in banana pulp and peel, along

with other flavonoids and various antioxidant compounds that are found to have potential health benefits [4]. In their unripe stages, banana is an abundant source of dietary fiber and resistant starch. Starch is generally classified into three types based on its digestibility in the body: slowly digestible, rapidly digestible, and resistant starch. Thus, due to resistant starch, banana possesses prebiotic activity as it is not digested and gets fermented in the colon, leading to the growth of beneficial bacteria. Banana also provides various other health benefits, such as a role in bone, cardiovascular, and digestive health and in stress management [1, 5].

With increased awareness about health management, there has been an increasing trend for consuming nutraceutical and functional foods [6]. Thus, unripe plantain and bananas can be effectively utilized to develop various functional food products. Banana processing is slowly gaining importance, but banana is significantly consumed in raw and cooked forms.

The major constraint related to using banana is that around one-fifth of the total harvested fruit undergoes postharvest losses during transportation and handling [7]. Using culled or damaged green banana for further processing can substantially impact economic sustainability. By employing proper processing techniques, the unutilized and damaged banana can be used to develop banana flour as an intermediate processed food product for developing various functional food products [8]. Banana flour can be incorporated into other processed products to increase nutritional value. After peeling, the unripe banana and plantain undergo enzymatic browning, leading to the development of brown color; this can affect the optical characteristics of the dehydrated banana flour. So, the pretreatments with organic acids can effectively prevent the browning reaction [9, 10]. Organic acid pretreatment for the effective reduction in browning reactions improved bioactive components, and the antioxidant potential for preparing sweet potato, yam, and rice flours was reported [11-13]. The present study was carried out to develop unripe plantain and banana flours. In this study, banana slices were prepared and treated with citric acid to prevent browning, and then banana slices were dried. Dried slices were then used to prepare flour. This research investigates the effect of citric acid treatment on the characterization of unripe plantain and banana flour (Figure 1).

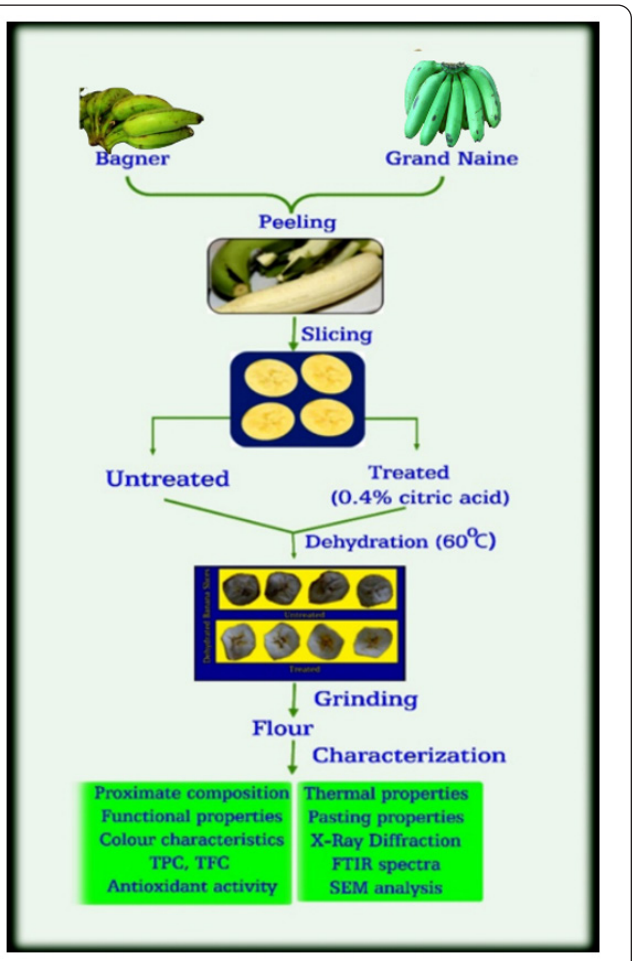

Figure 1: Schematic on the preparation and characterization of unripe plantain and banana flour.

Materials and Methods

Sample preparation

Unripe plantain and Cavendish banana, namely Bagner and Grand Naine, were procured from SLIET, Longowal, and the local banana merchant of Sangrur, respectively. Peeled banana were cut into slices of thickness 2 mm and then treated with citric acid before drying at 60 °C. Finally, the dried slices of untreated and treated samples were ground using a hammer mill to obtain the banana flour (Figure 1). Untreated and treated banana flour obtained from both varieties (Bagner and Grand Naine) were characterized on various parameters [14, 15].

Proximate composition

Moisture, ash, crude fat, crude protein, and crude fiber were estimated using the standard AOAC (Association of Official Analytical Chemists) methods [16]. Total carbohydrate content was calculated using the difference method.

Functional properties

Water and oil absorption capacity (WAC and OAC)

The WAC and OAC were determined by following the method [17]. Briefly, sample was mixed with 10 ml water in tubes and centrifuged at 4000 rpm for 15 min. The weight of the sediment was measured after decanting the supernatant from the tubes. The increase in weight was reported as WAC. Similarly, for OAC, 1 g sample was mixed with 10 ml of soyabean oil, and the same procedure was repeated for WAC. The following equation was used to calculate WAC and OAC using respective values for the weight of sediment.

$$WAC \text{ or } OAC = \frac{Weight\ of\ sediment - Weight\ of\ sample}{Weight\ of\ sample} X100 \quad (1)$$

Swelling power (SP) and water solubility index (WSI)

For determining the solubility and swelling power, a 0.5 g sample was mixed with 10 ml water and kept at 30 °C with continuous stirring for 30 min. After that, it was centrifuged at 4000 rpm. Supernatant by used to check the solubility, whereas sediment was used to determine the swelling power. The supernatant was collected and dried at 105 °C, and the weight of the dried supernatant was noted. The weight of wet sediment was also noted. Equations (2) and (3) were used to calculate

the WSI and SP, respectively [18].

$$WSI = \frac{W_2}{W_1} X100 \quad (2)$$

$$SP = \frac{W_3}{W_1 - W_2} \quad (3)$$

W_1 = weight of the sample

W_2 = weight of dried supernatant

W_3 = weight of wet sediment

Color analysis

The effect of citric acid treatment on the color of both samples was measured using a Hunter lab colorimeter (Hunter Associates Laboratory Inc., Resto VA, USA). Parameters, namely, L* (Lightness), a* (redness), b* (yellowness), and ΔE (color difference) were used to represent the color properties of the samples. Redness ranges from -a (green) to +a (red), and the yellowness value indicates the region ranging from -b (blue) to +b (yellow). The color differences (ΔE) were determined using the equation:

$$\Delta E = \sqrt{(L^* - L^*_0)^2 + (a^* - a^*_0)^2 + (b^* - b^*_0)^2} \quad (4)$$

Where, L^*_0, a^*_0, and b^*_0 is are the color parameters of fresh samples (control); L*, a*, and b* are the color parameters of dehydrated samples.

In addition, chroma (C*), hue angle (h°), and browning index (BI) of untreated and treated samples were calculated using the following equations.

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (5)$$

$$h = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (6)$$

$$BI = \left(\frac{x - 0.31}{0.17}\right) X100 \quad (7)$$

$$\text{where } x = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} \quad (8)$$

Particle size analysis

Particle size analysis of flour samples was carried out using a Laser diffraction particle size analyzer (SALD-2300, Shimadzu, M/S Shimadzu Corporation, Kyoto, Japan). For the analysis, samples were dispersed (1%) in isopropyl alcohol and added in the cuvette dropwise until a 20 to 40% refractive index was reached. The average diameter of the particles is reported.

Total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activity (AAA)

For the determination of TPC, TFC, and AA, the samples were prepared in an 80% aqueous methanolic solvent. One gram of sample was dispersed in 10 ml of solvent, kept overnight, then centrifuged, and the supernatant was collected. TPC was measured using gallic acid as the standard. Briefly, 1 ml of the extract was mixed with 5 ml Folin-Ciocalteau reagent and 4 ml sodium carbonate (7%). Absorbance was measured at 765 nm after incubating the samples for 1.5 h [19]. Results were reported as mg Gallic acid equivalent/ sample.

For TFC estimation, quercetin was used as a standard. 1ml extract was mixed with 4 ml distilled water in a test tube. 0.3 ml sodium nitrite (5%) was added, and after 6 min, 0.3 ml of aluminum chloride (10%) was added, following the addition of sodium hydroxide (1 M) after resting for 5 min and finally making the volume up to 10 ml using distilled water. The absorbance was measured at 510 nm after incubating the samples for 15 min at room temperature.

Antioxidant activity was measured regarding DPPH free radical scavenging following [20] 3.9 ml of 0.15 mmol/L of DPPH solution was mixed with 0.1 ml of extract, samples were incubated for 30 min, and absorbance was measured at 517 nm. The control was prepared by adding 0.1 ml 80% methanol to the 3.9 ml DPPH solution. The following equation was used to calculate the % scavenging activity:

$$\%Scavenging\ activity = \left(1 - \left(\frac{Absorbance\ of\ sample}{Absorbance\ of\ control}\right)\right) X\ 100 \quad (9)$$

Thermal properties

Thermal properties of green banana flours were determined using the Pyris Perkin Elmer scanning calorimeter, USA. Precisely weighed banana flour was mixed with distilled water, sealed in an aluminum pan, and allowed to equilibrate for 1 h. An empty aluminum pan was used as a reference, and the sample was heated from 30 - 150 °C with a constant rate of 10 °C/min. Onset temperature (T_O), peak temperature (T_P), conclusion temperature (T_C), and enthalpy (ΔH) were obtained from the heat flow curve.

Pasting properties

The pasting properties of banana flour were analyzed using a rapid visco analyzer (RVA, Perten Instruments, Newport Scientific Pvt. Ltd., Warriewood, Australia). A flour sample of 2.86 g was added to 25 g of deionized water and mixed in an RVA canister, followed by homogenization at 960 rpm. The temperature profile initiates withholding at 50 °C for 1 min, then heated from 50 to 95 °C followed by holding at 95 °C for 4 min, then cooling to 50 °C over 3 min (Figure 2). Pasting parameters such as peak viscosity, setback viscosity, final viscosity, and breakdown viscosity were determined [21].

X-ray diffraction pattern (XRD)

XRD of untreated and treated flour were obtained at a wavelength of 1.54 Å, 30 mA current, and 40 kV acceleration potential using an X-ray diffractometer (XRD-D8 Advance, Bruker, Germany). Data was recorded for a diffraction angle range of 5 - 50°.

Fourier transform infrared spectroscopy (FTIR)

FTIR was used to observe the changes in functional groups of untreated and treated Bagner and Grand Naine flour.

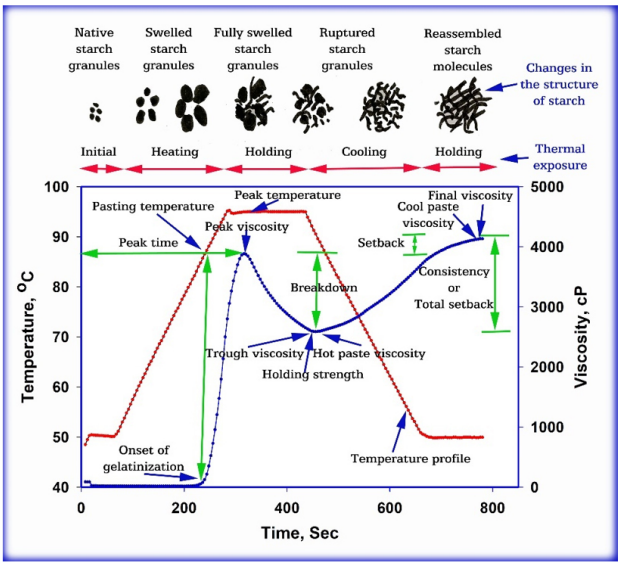

Figure 2: Typical rapid visco analysis (RVA) profile of pretreated unripe plantain flour.

Attenuated total reflectance type FTIR (L1600300 Spectrum Two-LIT-a FTIR, UK) was used to record the spectrum in the range of 4000 - 400cm^{-1}. The surface of the Attenuated total reflectance plate was completely covered with a powdered sample to obtain the spectra.

Morphological characteristics

The microstructure of green banana flour was analyzed using scanning electron microscopre (SEM) (JEOL, Japan) with a voltage of 10 kV and a current of 80 mA. A sample of green banana flour was sprinkled on adhesive tape, and a blower was used to remove the excess particles on the tape. The sample was then covered with gold in a gold coater before scanning.

Statistical analysis

All the experiments were carried out in triplicates, and results were reported in mean ± SD. SPSS software was used to carry out the statistical analysis. Analysis of variance (ANOVA) and Duncan test ($p \leq 0.05$) to determine the significant difference between the mean values of different samples.

Results and Discussion

Proximate composition

The proximate composition of control and citric-treated Bagner and Grand Naine flours is shown in table 1. The moisture content of Bagner control flour (BCF) was found to be lower as compared to Grand Naine flour, whereas after citric acid treatment, moisture content was found to decrease in both cases. The low moisture content of banana flour indicates the reduced potential for microbial growth, thus, higher stability and shelf life. Similar results have been reported for oven-dried green banana flour [22]. Protein, fat, ash and crude fiber content of GNCF were higher, whereas carbohydrate content was lower than BCF. After citric acid pretreatment, protein content improved, whereas fat and ash content decreased in both varieties. The variation observed in protein content may be due to varietal differences or non-enzymatic browning due to the condensation of reducing sugars with amino groups because of the Maillard reaction.

Table 1: Proximate composition of control and citric acid treated Bagner and Grand Naine flour (% Dry Basis).

Parameters	BCF	BTF	GNCF	GNTF
Moisture	5.85 ± 0.08^{b}	5.34 ± 0.05^{c}	6.05 ± 0.05^{a}	5.75 ± 0.08^{b}
Crude Protein	3.37 ± 0.06^{b}	3.53 ± 0.13^{b}	5.03 ± 0.19^{a}	5.24 ± 0.05^{a}
Crude Fat	0.47 ± 0.02^{b}	0.43 ± 0.04^{b}	0.51 ± 0.03^{a}	0.48 ± 0.05^{b}
Crude Fiber	5.73 ± 0.05^{d}	5.87 ± 0.35^{c}	6.50 ± 0.26^{b}	6.62 ± 0.35^{a}
Ash	2.41 ± 0.04^{b}	2.34 ± 0.25^{b}	2.54 ± 0.06^{a}	2.45 ± 0.07^{ab}
Carbohydrate	81.55 ± 0.42^{b}	82.72 ± 0.11^{a}	78.88 ± 0.04^{d}	79.46 ± 0.31^{c}

Results are expressed as mean ± standard deviation. Means with different superscript letters within same row differ significantly ($p < 0.05$).
*BCF= Bagner Control Flour, BTF=Bagner Treated Flour, GNCF= Grand Naine Control Flour, GNTF= Grand Naine Treated Flour

Furthermore, the leaching effect of minerals in the CA solution may also be responsible for its lower ash content [12]. Starch content was around 70%, with 30% of resistant starch in the plantain and banana flours (unpublished data). An increase in the fiber content of treatment flour may be due to the starch modification [23]. The protein and ash content values of plantain flour agree with those reported in the literature [24]. There was a significant increase in carbohydrate content in the case of citric acid-treated samples. The differences in the proximate composition of banana flours can be attributed to varietal differences.

Functional properties

The functional properties of untreated and treated Bagner and Grand Naine flour are depicted in table 2. WAC was found to increase significantly after citric acid pretreatment.

Table 2: Antioxidant and functional properties of control and treated Bagner and Grand Naine flour.

Parameters	BCF	BTF	GNCF	GNTF
Total phenolic content (mg/100 g)	93.17 ± 1.64^{d}	101.38 ± 1.52^{b}	94.87 ± 1.05^{c}	103.30 ± 1.52^{a}
Antioxidant activity (%)	8.91 ± 0.16^{d}	10.48 ± 0.21^{b}	9.65 ± 0.14^{c}	10.84 ± 0.23^{a}
Total Flavonoid content (mg/100 g)	68.08 ± 0.46^{d}	73.03 ± 0.47^{c}	77.40 ± 0.75^{b}	83.85 ± 0.83^{a}
Water Absorption Capacity (g/g)	6.10 ± 0.06^{d}	6.56 ± 0.05^{b}	6.38 ± 0.02^{c}	7.23 ± 0.03^{a}
Oil Absorption Capacity (g/g)	2.69 ± 0.01^{a}	2.50 ± 0.02^{b}	2.06 ± 0.02^{c}	1.81 ± 0.03^{d}
Water Solubility Index (g/g)	6.55 ± 0.04^{b}	6.15 ± 0.03^{d}	7.40 ± 0.06^{a}	6.35 ± 0.07^{c}
Swelling Power (g/g)	3.07 ± 0.05^{a}	3.10 ± 0.04^{a}	2.56 ± 0.09^{b}	3.02 ± 0.25^{a}

Results are expressed as mean ± standard deviation. Means with different superscript letters within same row differ significantly ($p < 0.05$).

WAC of Bagner flour was found to be 6.10 ± 0.06 g/g, and it increased to 6.56 ± 0.05 g/g after treatment. WAC represents the capacity of flour to bind with water, and it depends on the presence of pectin and other polysaccharides [25]. The particle size of the flour is also found to affect the WAC, and smaller particle size leads to higher water binding capacity [26]. The Grand Naine flour showed smaller particle sizes and thus had slightly higher WAC than Bagner flour. In contrast, OAC was found to more in Bagner flour than in Grand Naine. Treatment with citric acid led to a decrease in OAC in both samples. The OAC of citric acid-treated Bagner flour (BTF) was 2.50 ± 0.02 g/g; for GNTF, it was found to be 1.81 ± 0.03 g/g. OAC of various banana cultivars varied from 1.93 to 2.21 g/g in the conducted study [27]. It depends on starch, protein, and hydrophobic amino acids [28].

SP and WSI increased and decreased after citric acid pretreatment. The SP of Bagner flour was slightly higher than Grand Naine flour. This mainly depends on starch, the amylose content, and its interaction with other flour components [27]. An increase in the water-holding capacity of Amritsagar banana powder after citric acid and potassium metabisulphite treatment has also been reported [29].

Color analysis

The color characteristics of treated and untreated Bagner and Grand Naine flour are shown in table 3. The citric acid treatment resulted in significant differences in most of the color parameters, but it did not significantly affect the a* and b* values. The lightness of the samples increased after the treatment in both varieties. Citric acid-treated Bagner flour was lighter in color as compared to other samples. The results of the browning index and color difference also support this. Untreated Grand Naine flour had the highest browning index and decreased after citric acid treatment, whereas BTF had the lowest browning index. Color difference was measured by comparing it with fresh samples, and BTF showed the least color difference. This can be attributed to the anti-browning effect of citric acid. Similar observations have been made regarding unripe banana flour treated with ascorbic, citric, and lactic acid [30]. Citric acid prevents enzymatic browning by reducing the pH, which leads to the inactivation of the enzyme polyphenol oxidase, which is responsible for browning. Drying temperature also improves the effectiveness of citric acid treatment as it allows the acid to diffuse rapidly into the cells [31].

Table 3: Color characteristics of control and treated Bagner and Grand Naine flour.

Parameters	BCF	BTF	GNCF	GNTF
L*	81.81 ± 1.50^{b}	89.64 ± 0.29^{a}	75.58 ± 0.75^{c}	81.99 ± 0.93^{b}
a*	1.62 ± 0.10^{c}	2.02 ± 0.04^{b}	2.44 ± 0.07^{a}	2.45 ± 0.27^{a}
b*	8.48 ± 0.27^{b}	8.60 ± 0.30^{b}	9.21 ± 0.25^{a}	9.59 ± 0.29^{a}
ΔE	13.48 ± 0.08^{c}	10.84 ± 0.09^{d}	20.51 ± 0.67^{a}	15.08 ± 0.20^{b}
C	8.64 ± 0.25^{a}	8.83 ± 0.29^{b}	9.53 ± 0.26^{c}	9.90 ± 0.35^{bc}
h°	79.17 ± 0.94^{b}	76.82 ± 0.24^{b}	75.21 ± 0.01^{a}	75.69 ± 1.10^{a}
BI	12.15 ± 0.04^{c}	11.50 ± 0.42^{d}	15.07 ± 0.27^{a}	14.34 ± 0.46^{b}

Results are expressed as mean ± standard deviation. Means with different superscript letters within same row differ significantly ($p < 0.05$).

Particle size analysis

The Particle size of untreated and treated Bagner and Grand Naine flour is depicted in table 4. The particle size of the Bagner flour was larger than Grand Naine flour and increased significantly after citric acid pretreatment. Particles with larger particle sizes (more than 100 µm are considered free-flowing, whereas smaller particles are responsible for cohesiveness and poor flow properties. Smaller particles have a high surface area, more contact locations, and thus more interparticle bonding leading to cohesive behavior [32]. Thus, it can be interpreted from the results that citric acid treatment increased particle size, thus improving the flow behavior of the samples.

Table 4: Particle size of control and treated Bagner and Grand Naine flour.

Sample	Particle size (µm)
BCF	77.32 ± 1.69^{b}
BTF	85.52 ± 3.10^{a}
GNCF	64.25 ± 4.94^{c}
GNTF	75.44 ± 3.79^{b}

Results are expressed as mean ± standard deviation. Means with different superscript letters within same row differ significantly ($p < 0.05$).

TPC, TFC, and AA

Antioxidant properties of food products are one of the most important properties beneficial for health and are also dependent on the presence of polyphenols and flavonoids. The TPC of untreated and treated flour varied from 93.17 ± 1.64 to 103.30 ± 1.52 mg/100 g. The TPC of plantain was slightly lower than Grand Naine, a Cavendish banana. Citric acid treatment increased phenolic content, and the highest amount of TPC was found in GNTF. The highest concentration of citric acid and the lowest drying temperature reduced the oxidation rate of polyphenol compounds, which might increase the polyphenolic content [12]. Previous studies also supported these results, where the organic acid pretreatment with lactic acid, citric acid, and ascorbic acid increased TPC [30]. TFC was higher in Grand Naine than in Bagner flour and increased significantly after citric acid pretreatment. The TFC of untreated Grand Naine flour was 77.40 ± 0.75, increasing to 83.85 ± 0.83 mg/100 g. In previous studies by other researchers, the TFC of different banana cultivars varied from 103.54 - 177.13 mg/100 g [27] and 53.52 - 85.23 mg/100 g [7]. Free radical scavenging activity was determined using the DPPH assay. A similar trend was observed for AA for TPC and TFC, as antioxidant oxidants are directly related to TPC and TFC content. So, with an increase in both properties, AA of banana flour increased with citric acid treatment [12]. These properties are significantly affected by cultivar, ripening stage, and pretreatment [33].

Thermal properties

Table 5 shows the DSC analysis for a single endothermic reaction for control and citric acid pretreated banana flour. From the results, the Onset temperature (T_O), There was a significant increase in gelatinization temperature of both Bagner and Grand Naine flour after citric acid pretreatment, in the case of Bagner flour, it increased from 82.50 to 86.79 °C and

Table 5: Effect of pretreatment on thermal properties of Bagner and Grand Naine flour.

Parameters	BCF	BTF	GNCF	GNTF
T_O (°C)	39.27 ± 0.65^b	34.26 ± 0.41^d	44.61 ± 0.96^a	36.72 ± 0.52^c
T_P (°C)	82.50 ± 0.16^b	86.79 ± 0.17^a	74.90 ± 0.70^d	81.73 ± 0.41^c
T_C(°C)	137.55 ± 0.10^a	132.65 ± 0.27^b	112.84 ± 0.07^d	127.58 ± 0.35^c
ΔH (J/g)	240.53 ± 0.44^a	224.80 ± 0.31^b	202.65 ± 1.44^c	197.42 ± 0.54^d

Results are expressed as mean ± standard deviation. Means with different superscript letters within same row differ significantly ($p < 0.05$).

from 74.90 to 81.73 °C in case of Grand Naine flour. A significant difference was observed in the T_O, T_P, T_F, and ΔH of control and citric acid pretreated banana flour. The higher peak temperature (gelatinization temperature) of pretreated banana flour as compared to the control might be due to the interaction of citric acid with the banana flour matrix, which causes the release of water molecules and hardening of the matrix. Furthermore, higher transition temperatures in pretreated banana flour might be attributed to the high degree of crystallinity, making the starch granules more resistant to gelatinization [34]. The T_P in this study was similar to that reported for green banana flour (75.9 °C) dried in a hot air oven at 50 °C [22]. The high gelatinization enthalpy occurred due to the partial melting of amylopectin crystals or the variation in the stability of crystals linked amid the size of starch granules [7]. Compared to Grand Naine flour, Bagner's high gelatinization enthalpy may be due to the higher starch content. Similar observations have been made in other studies conducted on unripe banana flour [35].

Pasting properties

The results of the RVA for the unripe plantain and banana flour are shown in table 6. The peak, trough, breakdown, and final viscosity of control banana flour was higher than pretreated banana flour (Figure 2). The pasting properties of treated banana flour were significantly different from those of untreated flour.

Pasting temperature indicates the minimum temperature required for cooking the sample [36], and a slightly higher temperature was seen in treated samples compared to control banana flour. The pasting temperature obtained by RVA was slightly different from the peak temperature obtained by DSC, possibly due to the difference in the technological phenomenon and different sampling requirements in both cases. The increased viscosity is due to the swelling of starch granules and is reflected by the pasting temperature. The transition into the solid/liquid phase is reflected through the onset temperature (T_O). This indicates that pasting temperature depends on starch concentration, and the interaction among starch components is related to the onset temperature [37]. Thus, a higher pasting temperature was observed in Bagner flour as compared to Grand Naine flour. Citric acid pretreatment resulted in a significant decrease in the samples' peak and final viscosity. This can be attributed to starch depolymerization induced by even small concentrations of weak organic acids, leading to differences in pasting behavior [35]. These results are in agreement with those reported in a study where a decrease in viscosity was observed as a result of acid pretreatment [38].

XRD pattern

XRD detected the crystalline and amorphous structure of green banana flour. As per the XRD pattern, starches from different sources are categorized mainly into A, B, and C- types. A type XRD pattern is mainly observed for cereals starches, B type pattern in the tuber, amylose-maize, and retrograded starch. C-type crystallinity is a combination of A and B type and is found mainly in root and seed starches like peas and beans [39]. In our study, three distinct diffraction peaks at 15°, 17°, and 22° were seen in both banana flour and citric acid-treated banana flour, indicating a B-type pattern of banana starch. Green banana starches mainly show evidence of B-type XRD patterns in different varieties and regions [40-42]. It could be noticed that starches prepared from chemically pretreated root samples did not show any significant change. However, there was a shift of peaks in both treated and control banana flour concerning the intensity, indicating a partial change in crystalline phases (Figure 3). Several factors such as the ratio of amylose and amylopectin, presence of an amorphous region of starch, extent of hydrolysis, and average chain length also influence the relative crystallinity of different starches [42]. B-type structures are resistant to digestion, and this characteristic makes bananas a potentially valuable fruit [39-43].

FTIR spectra

FTIR spectra of treated and untreated plantain and green banana flour are shown in figure 4. Information regarding the functional groups present in flour is obtained from FTIR spectra by matching the transmittance of bands with vibrational modes of various chemical bonds and bond stretching [44]. Conformational changes due to the citric acid pretreatment can be predicted from differences in peak intensity. The

Table 6: Effect of pretreatment on pasting properties of Bagner and Grand Naine flour.

Parameters	BCF	BTF	GNCF	GNTF
Peak Viscosity (cP)	4167.33 ± 7.01^a	3735.00 ± 7.00^b	3256.67 ± 16.01^c	2809.67 ± 13.05^d
Trough Viscosity (cP)	2635.00 ± 7.21^b	2600.67 ± 11.67^b	2862.00 ± 43.86^a	2081.67 ± 22.72^c
Breakdown Viscosity (cP)	1561.67 ± 16.04^a	1115.33 ± 6.65^b	922.67 ± 11.50^d	761.33 ± 10.59^c
Final Viscosity (cP)	4125.00 ± 10.14^a	4085.33 ± 16.25^a	3326.67 ± 43.98^b	3073.67 ± 32.56^c
Setback Viscosity (cP)	1492.00 ± 4.58^a	1461.00 ± 10.53^b	1051.67 ± 10.06^c	985.33 ± 7.09^d
Pasting Temperature (°C)	83.94 ± 0.18^b	84.63 ± 0.41^a	77.02 ± 0.46^d	78.41 ± 0.10^c

Results are expressed as mean ± standard deviation. Means with different superscript letters within same row differ significantly ($p < 0.05$).

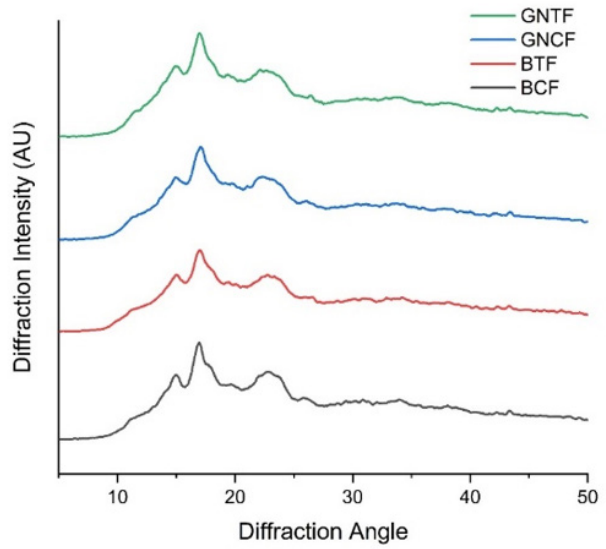

Figure 3: XRD pattern of control and treated Bagner and Grand Naine flour (BCF= Bagner Control Flour, BTF=Bagner Treated Flour, GNCF= Grand Naine Control Flour, GNTF= Grand Naine Treated Flour).

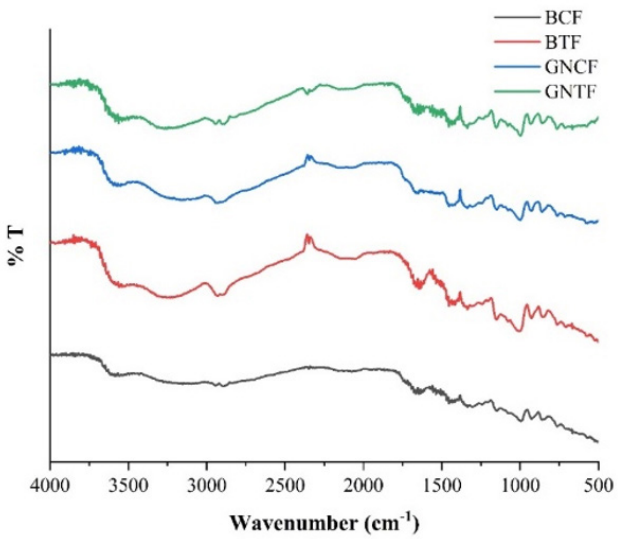

Figure 4: FTIR spectra of control and treated Bagner and Grand Naine flour (BCF= Bagner Control Flour, BTF=Bagner Treated Flour, GNCF= Grand Naine Control Flour, GNTF= Grand Naine Treated Flour).

peaks around 1500 and 1650 cm^{-1} represent the C=O bond stretching, and the intensity of this peak was found to increase in the case of citric acid-treated flours. The bond stretching around 3000 - 3500 cm^{-1} is mainly due to the presence of carboxylic acid and water molecules and represents the O-H group. Variations in the intensity of peak around 2800 - 3000 cm^{-1} might be due to the flour's difference in amylose and amylopectin content [45].

Morphological characteristics

SEM images are used to retrieve critical information about the characterization of starch granules, including size and shape, presence of other compounds, structural integrity, and surface morphology. figure 5 shows the surface morphology of native and treated plantain and green banana flour. In the case of untreated Bagner flour (Figure 5a), starch molecules appeared as large, elongated, and irregularly shaped molecules, along with some small spherical molecules. Whereas in untreated Grand Naine flour (Figure 5c), mostly irregularly shaped, flattened starch molecules were observed, and very few spherical molecules (unpublished data). The material that appears on the surface of the granules is most likely to be amyloplast membranes, which enclose starch granules in the banana fruit cell [46]. Pretreatment with citric acid resulted in cracks over the surface of starch granules and loss of smoothness. Because of the loose structure of the amorphous region, acid penetration becomes more accessible and is attacked by hydrogen ions, which leads to alterations in the surface structure [47]. Citric acid treatment did not result in any changes in the shape of molecules. Instead, it led to the loss of surface smoothness. Similar observations have been made [48].

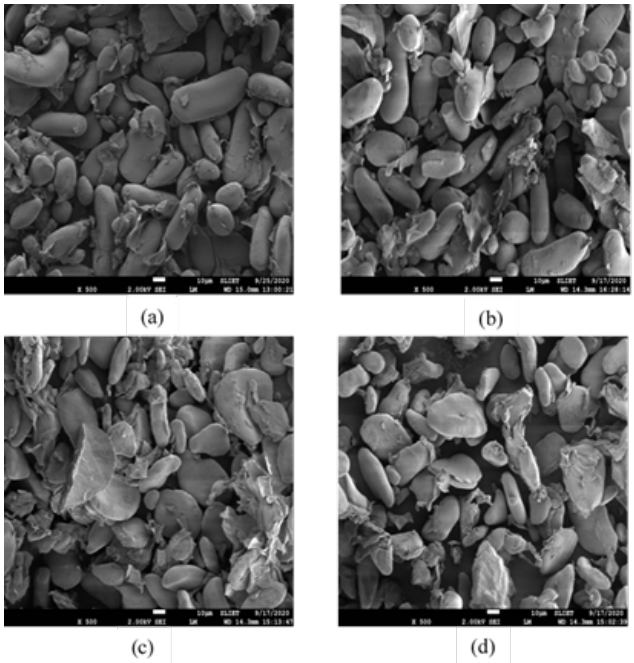

Figure 5: Effect of pretreatment on morphological characteristics of (**a**) BCF= Bagner Control Flour, (**b**) BTF= Bagner Treated Flour, (**c**) GNCF= Grand Naine Control Flour, and (**d**) GNTF= Grand Naine Treated Flour.

Conclusion

The physicochemical, functional, and technological characteristics of Bagner and Grand Naine were significantly different, and citric acid treatment improved the characteristics of flour, making it more suitable for its utilization in food products. The Bagner variety was found to have higher carbohydrate content as compared to Grand Naine. Citric acid pretreatment resulted in changes in flour's functional properties and showed high water absorption and swelling capacity. Banana starch shows a B-type structure as per XRD data. Citric acid treatment significantly affected the gelatinization temperature and viscosity of the flour. Citric acid-treated plantain flour can be effectively used to develop low-glycemic foods. Plantain is consumed in the form of chips as festive food. So, the acid-treated plantain flour can be effectively used to develop various festive food products such as vermicelli and pasta.

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None.

Conflict of Interest

None.

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