Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 57 Issue: 03:2024
DOI: 10.5281/zenodo.10792430

EFFECT OF FERMENTATION ON PHYSIOCHEMICAL, STRUCTURAL, RHEOLOGICAL, THERMAL AND PASTING PROFILE OF TARO STARCH

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Abstract

Starches present manufacturers with novel prospects to produce a diverse range of products characterized by appealing melt-in-mouth textures and robust, unadulterated flavors. The market segment has a growing preference for low-priced starches. The primary aim of modification is to facilitate the restricted utilization of starch across various applications. Lactic acid bacteria specifically *Lactobacillus Plantarum* are widely employed in the food industry due to their benefits and safety, and also the Food and Drug Administration (FDA) declared them generally recognized as safe (GRAS). The current study evaluated the impact of fermentation on the physicochemical characteristics of taro starch. The impact of fermentation through *Lactobacillus Plantarum* on samples was studied through dynamic characterization methods, including texture profile analysis (TPA), rapid visco analyzer (RVA), scanning electron microscope (SEM), Fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), rheometer, and physicochemical analyses. The unfermented samples exhibited a reduced moisture content compared to the fermented ones. The observed rise in moisture content after fermentation can be related to the introduction of water throughout the fermentation process, which facilitates the progression of microbial strains responsible for initiating and sustaining the fermentation process. Consequently, this extended duration of fermentation leads to a constant augmentation in moisture content. Fermentation results in more ash and lower fat and fiber. The protein contents of fermented samples are elevated compared to the non-fermented samples. Bacterial inoculation starts producing some extracellular enzymes known to be proteins. The amylose of fermented samples increases in all samples. The swelling of fermented samples decreased in all samples. Higher amylose results in lower swelling power and solubility attributed to granules' structural adjustment. Bioconversion of macro-molecules due to fermentation changes the gel structure of starch and decreases the leaching effect, ultimately improving the syneresis. Process stabilization governs product quality, and rheology is the crucial factor in defining the quality of any food. The unfermented samples showed lower rheological characterization as lower loss and storage modulus than the fermented samples. Fermentation results in better viscosity due to the degradation of macro-molecules into their building block, which enhances the applicability. Scanning electron microscope concluded a smooth surface for unfermented samples but irregular and sharp edges for fermented samples. This indicates that fermentation results in the degradation of particles, and small particles result in less water retention, while more water absorbing capacity ultimately leads to better rheology and highly compact dough. The FTIR peaks at 3422, 2918, 1570, 1382, 1325, 1162, 1022, 1045 and 765 cm^{-1} are associated with cellulose. The peak at 3422 cm^{-1} is attributed to O-H stretching. The absorption at 2918 cm^{-1} is credited to C-H stretching. A peak at 1570 cm^{-1} is linked with CH_2 symmetric bending. 1382 cm^{-1} is associated with C-H bending. 1325 cm^{-1} is associated with CH_2 bending of carbohydrates. The peak at 1162 cm^{-1} is attributed to C-O anti-symmetric stretching. The findings of our study indicate that the comprehensive categorization of starches enhances their practical utility by facilitating a thorough comprehension of their overall profile. The utilization of contemporary methodologies enables enhanced efficiency and heightened precision.

Keywords: Fermentation, Starch, Lactic Acid Bacteria, Modification, Rheology.

1. INTRODUCTION

Starches can be incorporated into many new products to attain desirable sensory, nutritional and overall acceptability characteristics. Many properties can be altered in dairy products by using starch, like improvement in mouthfeel, increase in viscosity and prevent syneresis. Due to many desirable physio-chemical textural and flavor properties like water holding capacity, swelling power, small particle size, more expansion and gel formation, it is useful in various foods (Yaqoob *et al*., 2019). Indigenous starches are cheaper and more beneficial to the manufacturers, and increasing the shelf life, producing new and innovative products, simplifying labels, which are more economical and reduce processing. Native starches give better output during manufacturing at a low cost and increase the product's shelf life. Many new products can be manufactured from gums and starches with many advantages, such as reducing recipe/production costs, simplifying label declaration, enhancing product aesthetics, and increase product throughput (Kushawa and Kaur, 2018).

In the market segment, there is a growing preference for low-price starches. Taro is a tropical tuber crop devoured and mainly cultivated for underground corms. Taro is characterized by its starch content, which typically ranges from 70% to 80%, and is composed of tiny granules (Ahmed *et al.*, 2013). Taro is cultivated worldwide in tropical as well as sub-tropical countries. It belongs to the family *Aracea.* The worldwide taro production is 9.2 million tons in the 1.57 million hectares (FAO, 2022). It is cultivated in different regions such as the West Indies, Southeast Asia, the Philippines, Hawaii, Africa, and some parts of South America, but also in many countries of the Pacific Island. It is of particular significance and forms the staple diet's part and it has been taken as a diet for more than nine centuries. In some countries like India and Pakistan, it is known as "arvi". It is a vegetable crop cultivated as a tuber due to its cormels, leaves, and corms. It has a higher price than cassava and sweet potato and contains starch, i.e., 15- 25%. The digestibility level of starch in cooked and raw taro is different, i.e., 72.98 and 75.5%, respectively but the irritation on the skin or oral tissue is caused by uncooked taro because calcium oxalate (0.03-0.46%) is present in it, so it should be boiled or cooked before eating (Singhal *et al*., 2021). However, raw taro is toxic and inedible but edible when it is cooked (Wang *et al.,* 2018).

The limited applications of starch can be enhanced by enabling the modification via several methods. Recently, biotechnological modification like fermentation or enzymolysis through different bacteria, yeast and mold is of keen interest because it improves the applicability and more specificity in results (Yaqoob *et al.*, 2022).

During the last decade, stupendous attention has been given to microbial biotechnology, especially in the food industry. Among them, lactic acid bacteria (LAB) have gained more attention due to their incorporation in fermented food products like yogurt and cheese (Martinez *et al*., 2013). Traditional approaches such as hydro-distillation, Soxhlet extraction, and maceration have been utilized for polyphenolic compounds extracted from plant material. Many drawbacks have been associated with the above-mentioned methodologies, for example, high solvent consumption, high-temperature conditions, and more time, which ultimately can destroy polyphenolic compounds (Reyes *et al*., 2016). Ultrasonication is an innovative technology and has gained much attention in the food industry because it provides higher quality and safe food with cost effective industrialization and an eco-friendly environment. It is a non-destructive technique that ensures the functionality of processed foods and is known to be an effective approach to modifying food components (Wang *et al.*, 2023).

To run over these drawbacks, innovative approaches such as fermentation have been adopted that allow the starches to be used in food industries and better extraction of bioactive components without nutrient loss or degradation from plant materials. Consequently, this research is an attempt to use taro starch in the food industry and improve their whole profile by modification.

2. MATERIALS AND METHOD

2.1 Procurement of raw materials

Taro were procured from the local market of Faisalabad, Pakistan, while all the chemicals and reagents were acquired from a local supplier of Sigma Aldrich, USA. *Lactobacillus plantarum (L. plantarum),* were purchased from DuPont China Holding Co. Ltd (Shanghai, China) and propagated on Man Rogosa Sharp broth (MRS) (Sinopharm Chemical Co. Shanghai, China) medium at 37°C and stored at 4°C.

2.2 Extraction of Starch

Starche were purified and extracted by adopting the method prescribed by Hoover and Hadzigev (1981) with some modifications.

2.2.1 Extraction procedure of starch from taro

The extraction process includes rinsing, peeling, and blending in 0.2% sodium hydroxide solution using a domestic blender (CB15E, Essex, UK). A 200-mesh sieve was used to filter the mixture. The filtrate was left to stand at 4 °C overnight. The precipitate was then collected. The starch sediment was treated with 0.1 g/100 mL sodium hydroxide solution and then centrifuged at 6000 g. When the pH of the starch reached nearly 7.0, the precipitate was collected and washed multiple times with distilled water. Then, the starch was washed using chloroform: methanol (2:1) solution to remove fat. The precipitates were evaporated and dried at 40 °C overnight in a conventional oven and ground into fine powder. The resulting starch powder was collected, bagged in polyethylene freezer bags, and stored in a freezer (Haier, Qingdao, China).

2.3 Fermentation

Lactobacillus plantarum was used for fermentation according to the method of Yaqoob *et al.* (2019). Isolated *L. plantarum* was cultured in De Man, Ragosa and Sharper (MRS) medium (liquid) in an incubation chamber (HZQ-F160, Shanghai, China) to a bacterial concentration of 10^7-10^8 cfu/mL. A 20% bacterial suspension was placed into the samples, which were then kept in an incubator at 37 °C for 24 hours.

Table 1: Codes for different treatment

Codes	Treatments
NFT	Non-fermented taro
FFT	Fermented taro

2.4 Physico-chemical analysis

2.4.1 Proximate analysis

The proximate composition of starches was determined by the method of AACC, 2000.

2.4.2 Swelling power (SP)

Sample SP was measured using a previous report by Yang *et al.* (2019). A (500 mg) dry basis of the sample was previously heated in 20 mL water for 30 minutes at temperatures of 50, 60, 70, 80, and 90 °C. After cooling to room temperature, the samples were centrifuged at 3000 g for 15 minutes. The supernatant was collected, and the remaining material was weighed to determine SP. The supernatant was put into a glass dish, dried to a constant weight at 105 °C, and weighed.

$$\mathrm{SP} = \text{sediment weight}/\text{sample weight}$$

2.4.3 Water retention capacity

Samples (fermented and non-fermented) were mixed with 10 mL H_2O and centrifuged for 15 minutes at 4000 rpm (TG16-WS centrifuge, Hitachi, Japan). The supernatant was collected and weighed to calculate the water retention capacity (Yang *et al*., 2019).

$$\text{Water rentention} = \text{supernatant weight}/\text{sample weight}$$

2.4.4 Amylose content

Standard samples of amylose and amylopectin were placed in hot water (2 mg/mL, carefully preventing caking while dissolving), and the solutions were mixed in varying amounts to generate amylose concentrations of 0, 10, 20, 25, 30, and 35%. One mL of each of these amylose solutions or samples was combined with one mL of 0.01 N I_2-KI solution, and the absorbance of the mixture was measured at 720 nm using a spectrophotometer (7200 type, Unico, Shanghai, China); water was used as a control sample (Yang *et al*., 2019).

2.4.5 Syneresis

Starch suspension (2%, w/v) was heated at 85°C for 30 minutes in a temperature-controlled water bath followed by rapid cooling in an ice water bath to room temperature.

The starch was stored for 24, 48 and 120 hours at room temperature. Syneresis was measured as percentage amount of water released after centrifugation at 3200 rpm for 15 min.

2.5 Pasting characterization through rapid visco analyzer (RVA)

RVA (RVA 4800, Perten, UK) was used to evaluate the visco and pasting parameters of different samples by the method formerly described by Wani *et al.* (2012). RVA parameters were obtained, including peak viscosity, final viscosity, trough viscosity, breakdown, setback, and peak temperature. Briefly, 25 mL water was mixed with a 3 g sample and placed on RVA. The total time for one sample was about 13 minutes, and the temperature was 30-95 °C.

2.6 Micromorphological analysis

The micromorphological characterization was done through a Scanning electron microscope (G2-PhenonTM, Scoreby VIC, Australia) (Yaqoob *et al.,* 2022). The dried sample was fixed on holding tape and placed for gold plating at 5 kv in a vacuum to make the net charge zero for better pictorial views. Micrographs of each sample were taken at ×5000.

2.7 Molecular structure of samples through Fourier-transformed infrared (FTIR) spectra

FTIR spectra of samples can be determined according to the previously reported method of Yaqoob *et al*. (2019). The spectra were recorded in the infrared range of 400-4000 cm^{-1}. The alteration in molecular structure in samples was measured by scanning the pellet through FTIR (Bruker, Vertex-70, Massachusetts, USA). 100 mg potassium bromide and 1 mg sample were placed under vacuum pressure to make a tablet and placed in FTIR to get the peaks.

2.8 Textural analysis

Textural analysis was done by textural analyzer TA-XT Plus (Stable-Micro Systems, Godalming, Surrey, UK) using a compression plate by the method explained by Yang *et al*. (2017). Briefly, 50 mL water and the samples were mixed and kneaded until a smooth texture was attained, followed by one hour of rest at room temperature. The following conditions were used for analysis: test velocity is 0.5 mm, test distance is 10 mm, and the probe is P/0.5.

2.9 Rheological characterization

A rheometer was used to measure the rheological properties (Yu *et al*., 2016). Rheological properties were measured using a rheometer (Anton Paar, Modulus compact rheometer MCR-302, Graz, Austria). Samples were placed on the machine through a spatula, and excessive were removed. A frequency sweep test was adopted by maintaining the plates at a gap of 1 mm and 25 °C. Silicone oil was added to the sample to avoid evaporation, and 10 minutes of rest was given to equilibrate the stresses. A strain sweep test was performed to define the viscoelastic region. The frequency ranges between 0.1 to 10 Hz. Three basic parameters were obtained: storage, loss modulus, and tan delta.

2.10 Thermal characterization through differential scanning calorimetry (DSC)

DSC (DSC, TAQ 2000, Newcastle, USA) was used to evaluate the thermal properties of fermented and non-fermented samples through the method previously used by Yaqoob *et al.* (2022). An empty aluminum pan was used as a reference standard for samples. 0.006 mL H_2O was mixed with a 3 mg sample and placed in the DSC pan. The optimum temperature range was set at 30-90 °C at a constant increase of 10 °C min^{-1}.

2.11 Statistical analysis

Statistical analysis of obtained data for all the parameters was done through statistical software origin pro-8.5. The significance level (95%) was determined through Analysis of variance (ANOVA), and a completely randomized design (CRD) was applied to perform the analysis. All the analysis were performed thrice to check the significance.

3. RESULTS AND DISCUSSION

3.1 Physicochemical analysis

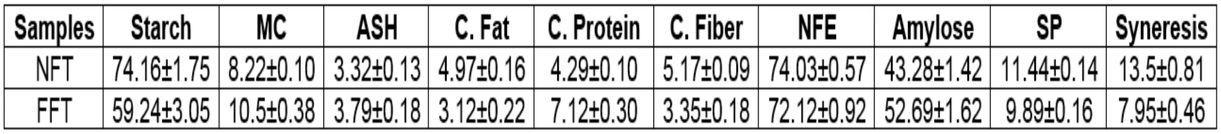
The most important and globally used phenomenon in the testing and processing foods is the moisture content. A small amount of moisture affects the overall product quality, and suitable moisture levels differ between constituents (Young, 2015). Moisture characterization of starches is very important as it describes the stable quality of the end product. The moisture content of fermented and non-fermented samples is depicted in table 2. The results showed a significant effect ($p<0.05$) on moisture percentage. The results show that non-fermented and fermented taro moisture content is 8.22 and 10.5%, respectively. The moisture content of non-fermented samples was lower than fermented samples, as reported by Ogodo *et al*. (2017). This increase in moisture content after fermentation may be attributed to adding water during fermentation to carry out the process. Moreover, microbial strains initiate the fermentation process and continue for longer, continuously increasing moisture content (Terefe *et al*., 2021). The ash contents generally represent the total amount of minerals in the biomass. Ash measurement is the most important parameter for quality that is routinely conducted in lab tests, which measure biomass to evaluate the composition and nutritional contents of ash. Ash comprises organometallic compounds, extraneous solids, iron, magnesium, sodium, aluminum, nickel, vanadium, and calcium salts (Maj, 2018). The substance remaining after igniting any food product is called ash. These components consist of inorganic matter, which is present in food commodities. The ash content of fermented and non-fermented samples is depicted in table 2. The results showed a significant effect ($p<0.05$) on ash. The results show that the ash content of non-fermented and fermented taro is 3.32 and 3.79%, respectively. Fermentation conditions and time also significantly impact ash contents, and it was observed that ash contents increased with fermentation time when compared with unfermented (control) samples (Paul-Ndubuisi *et al.,* 2023). The fat content of fermented and non-fermented samples is depicted in table 2. The results showed a significant effect ($p<0.05$) on fat percentage. The results show that non-fermented and fermented taro fat content is 4.97 and 3.12%, respectively. The fat content of unfermented samples was higher than fermented samples, as reported by Opeifa *et al.,* 2015 and Gernah *et al.,* 2011. The protein content of fermented and non-fermented samples is illustrated in table 2. The results showed a significant effect ($p<0.05$) on protein percentage. The fermented samples have more crude protein than the non-fermented samples (4.29 and 7.12%). The protein content of fermented samples is higher than the non-fermented samples, which agrees with the previous study by Anaemene and Fadupin, 2020. The previous study concludes that after a certain time of inoculation, the LAB produces some extracellular enzymes known as proteins (Oseni and Akindahunsi, 2011). The non-fermented samples have more crude fiber than the fermented samples (5.17 and 3.35%), respectively. Fiber characterization of starches is very important as it describes the stable quality of the end product. The crude fiber contents of fermented samples decreased in all samples, aligning with the previous results reported by Anaemene and Fadupin, 2020. The percentage of fiber content decreases significantly after LAB inoculation, as reported by Ogodo *et al.* (2017). The decrease in crude fiber could be due to the release of enzymes by microorganisms that hydrolyze carbohydrates. The results of the NFE of samples showed a decreasing trend when samples were fermented and reported that fermentation decreased the NFE content of wheat (Bledzki *et al*., 2010).

The starch content of fermented and non-fermented samples is depicted in table 2. The results showed a significant effect ($p<0.05$). The results show that the starch content of non-fermented taro is 74.16% while fermented taro is 59.2%. Starch obtained from taro is 74.16%, followed by research results of Aboubakar *et al.* (2008) published in his results that starch %age in taro powder is 66.5%. The starch of fermented samples decreased in all samples; some LAB strains produce amylases that break down starches isolated from cassava flour, which agrees with the previous results reported by Sotomayor *et al.* (1999). The decrease in starch could be due to the release of enzymes by microorganisms that hydrolyze the starch. It is also reported that the bacteria, specifically *L. plantarum,* produce ß-D-glucosidase, which ultimately hydrolyzes the non-reducing sugars (Minnaar, 2017). The amylose contents of fermented samples increased in all samples, which agrees with the previous results reported by Yaqoob *et al.* (2019). This increase may be due to the conversion of amylopectin into amylose due to the action of enzymes produced by microorganisms during fermentation. Oke and Bolarinwa (2011) suggested similar results while fermenting cocoyam flour. Amylose changes also directly affect Chinese chestnut's rheological properties (Yu *et al.,* 2016). Previous studies suggested that higher amylose results in lower swelling power and solubility attributed to granule structural adjustment (Chan *et al.,* 2009).

The swelling of fermented samples decreased in all samples, which agrees with the previous results reported by Yaqoob *et al.* (2019). Previous studies suggested that higher amylose results in lower swelling power and solubility attributed to granule structural adjustment (Chan *et al*., 2009). Temperature also affects the swelling power of starches, like an increase in temperature from 50 to 90ºC. Swelling power increases with the increase in temperature as it increases in cassava starches (fermented and unfermented). This increase is mainly related to starch gelatinization (Oyeyinka *et al.,* 2015). Samson *et al.* (2020) found a decrease in the swelling power of starches in fermented cassava tubers. He reported that this reduction is due to the more solubility and presence of fibrous residues, which resist swelling. As the fermentation proceeded, the pH went down, and an acidic environment prevailed, which caused a reduction in the swelling power of starches (Alonso-Gomez *et al.,* 2016).

The syneresis of fermented and non-fermented samples are depicted in table 2. The results showed a significant effect ($p<0.05$) on syneresis. The results show that the syneresis of non-fermented and fermented taro is 13.5 and 7.95%, respectively. Bioconversion of macromolecules, due to fermentation, changes the gel structure of starch and decreases the leaching effect, ultimately improving the syneresis. Water holding capacity is linked with starch retrogradation, which involves the collapse of granules with crystalline and amorphous regions, ultimately improving the syneresis (Mirmoghtadaie *et al.,* 2009).

Table 2: Physicochemical analysis of fermented and non fermented taro



Samples	Starch	MC	ASH	C. Fat	C. Protein	C. Fiber	NFE	Amylose	SP	Syneresis
NFT	74.16±1.75	8.22±0.10	3.32±0.13	4.97±0.16	4.29±0.10	5.17±0.09	74.03±0.57	43.28±1.42	11.44±0.14	13.5±0.81
FFT	59.24±3.05	10.5±0.38	3.79±0.18	3.12±0.22	7.12±0.30	3.35±0.18	72.12±0.92	52.69±1.62	9.89±0.16	7.95±0.46

3.2. Pasting properties:

In Table 3, the pasting parameters of native and fermented samples are summarized. The overall modification substantially alters the shape of the RVA visco profile. Fermentation decreases pasting parameters such as PV, PT, FV, and setback. This could be attributed to the significant decrease in macromolecule degradation during the procedure. The obtained results are from the findings of Ilowefah *et al.* (2015). Different food items of different categories, like corn, sweet potato, and potatoes, are used as a source of starch, which is regarded as part of macromolecule carbohydrates. In their explanation, they elaborated that acidification renders starch granules more vulnerable and susceptible to rupture. Results of the RVA presented in the table 3 demonstrate that changes in the viscosity of starch suspension occur during heating. Different trends like increase and decrease both are found in different parameters like trough viscosity, final Viscosity, viscosity

of starch after spontaneous fermentation, peak viscosity, break down viscosity, and LP fermentation of starch samples of non-fermented starch, except for SB viscosity at a high level. Results align with Navarro *et al.* (2016), who reported that different parameters of pasting properties were higher in non-fermented samples than fermented ones, and results of rice starch and sweet potato starch agree with our findings. The results of the experiments on the pasting properties are also comparable to those of earlier researchers, who reported that rice flour fermented with lactic acid had less breakage and setback (Yang & Tao, 2008).

Table 3: Pasting properties of fermented and non fermented taro

Test	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)	Pasting temp (°C)
NFT	2110±16.50	1302±11	808±8.50	2259±14	957±6.02	4.86±0.03	75.1±0.07
FFT	1810±18.52	1420±13.50	390±9	2093±13.50	673±7.50	5.4±0.07	85.5±0.02

3.3. Structural characterization of samples

The FTIR spectra of fermented and non-fermented flour had almost a mixture of profiles, as shown in Fig 1. The peaks at 3422, 2918, 1570, 1382, 1325, 1162, 1022, 1045 and 765 cm^{-1} are associated with cellulose. The peak at 3422 cm^{-1} is attributed to O-H stretching. The absorption at 2918 cm^{-1} is credited to C-H stretching. A peak at 1570 cm^{-1} is linked with CH_2 symmetric bending. 1382 cm^{-1} is associated with C-H bending. 1325 cm^{-1} is associated with CH2 bending of carbohydrates. The peak at 1162 cm^{-1} is attributed to C-O antisymmetric stretching. A band at 1022 cm^{-1} is related to C-OH skeletal vibration. A peak at 1045 cm^{-1} is due to the C-O-C pyranose ring skeletal vibration. The peak at 765 cm^{-1} corresponds to the glycosidic C_1-H deformation with ring vibration contribution, which is a characteristic of glycosidic linkages between glucose molecules in cellulose. Furthermore, the crystalline and amorphous structures are linked to FTIR absorbance bands 1045 and 1022. It has been proposed that increasing the absorbance ratio increases conformational alterations in these regions (Monroy *et al*., 2018). Yaqoob *et al*. (2019) observed similar outcomes and concluded that the fermentation and multiple freezing/thawing treatments improved the dough's quality and applicability. These modifications improved the maize dough's physicochemical, structural, rheological, morphological, and thermal properties (Yaqoob *et al*., 2019). The peak at 1430 cm^{-1} corresponds to a strong bending vibration of CH_2 in crystalline cellulose and a feeble vibration in amorphous cellulose (Boukir *et al.,* 2019). The decreased intensity of the peak at 1250 cm^{-1} corresponding to the C-O stretching signal in lignin and hemicelluloses indicates a decrease in lignin and hemicelluloses (Gao *et al.,* 2021). Moreover, the peak at 897 cm^{-1} corresponds to the glycosidic C_1-H deformation with ring vibration contribution, typical of β-glycosidic linkages between glucose molecules in cellulose (Makarem *et al.*, 2019). The fingerprint region exhibited distinct absorbances primarily attributable to C-O bond elongation. As a result of fermentation, initial peaks appeared primarily at 568 and 765 cm^{-1}, indicating the vibration of CH_2. Starch comprises most of the corn flour and as a glucose polymer, with each glucose unit comprising CH_2, starch is the predominant component of taro flour. BeMiller (2019) concluded that fermentation can result in hydrolysis, increasing amylose content, decreasing crosslinking, and improving rheological properties. By modifying the structure, fermentation increases crystallinity and decreases the amount of amorphous material.

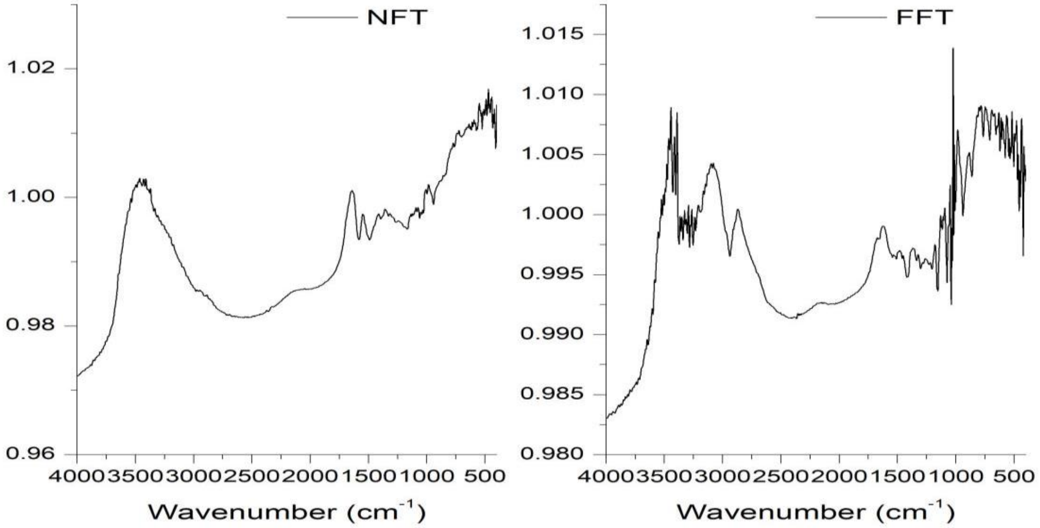


Figure 1: Structural characterization of fermented and non fermented taro

3.4. Textural characterization of samples

Textural parameters such as hardness, cohesiveness, gumminess, chewiness, springiness, and resiliency were investigated, and the results are shown in Table 4. Significant differences were observed between the interventions and between fermented and unfermented samples. Due to the conversion of components during fermentation, the hardness decreases. Similar patterns can be observed in all other parameters. Incorporating bacteria enhanced textural properties during fermentation by reducing hardness and increasing cohesiveness, chewiness, and springiness. Previous studies also included that bacterial incorporation in corn flour enhanced the textural properties by reducing hardness and increasing cohesiveness, gumminess, chewiness, and springiness, thereby facilitating flour processing into the dough (Yaqoob *et al.,* 2022). Yang *et al.* (2017) investigated the amylase-rich fermented maize-fortified flour and concluded that the fermented flour had a superior texture, consistent with our findings. Gelation involves a fast development via chain enlargement, while amylopectin involves slow crystallinity (Li & Gong, 2022). Therefore, the increase in bacterial texture may be associated with the retrogradation phenomenon (Tao *et al.,* 2016).

Table 4: Textural characterization of fermented and non fermented taro

Treatment	Hardness (g)	Adhesiveness (g.sec)	Springiness (mm)	Cohesiveness	Gumminess (g)	chewiness	Resilience
NFT	94.83±1.68	−46.67±0.39	0.99±0.04	0.26±0.05	25.45± 0.43	25.34±0.46	0.12±0.01
FFT	68.83±1.88	−31.67±0.49	1.09±0.04	0.43± 0.05	15.85± 0.43	18.34± 0.46	0.08±0.01

3.5. Thermal characterization of samples:

Thermal characterization of non-fermented and fermented starch samples was done through DSC techniques. Results are presented in Table 5. Results showed significant differences between fermented and non-fermented samples. Thermodynamic properties, including the onset (T_O), peak (T_P), conclusion (T_C), melting temperature (T_C -T_O), and gelatinization enthalpy ΔH of starch samples, were determined by DSC. Results showed that fermentation increases the values for all the parameters mentioned above. Values of taro for non fermented were 70.95, 76.33, 85.17, 12.55, 3.90 for T_O, T_P, T_C, T_C -T_O, and ΔH during fermentation due to bacterial action the values of parameters for taro were recorded as increased like 73.15, 79.33, 91.17, 14.51, and 4.95 for T_O, T_P, T_C, T_C -T_O, and ΔH, respectively. Well-ordered granules and a high degree of crystallinity are due to an increased transition temperature and gelatinized enthalpy, which results in high temperature and ultimately leads to delayed gelatinization (Tao *et al.,* 2015). Different parameters like degree of branching, phosphorus content, amylose to amylopectin ratio, length, and molecular conformation directly affect the enthalpy and gelatinized temperature (Kaur *et al.,* 2004).

Table 5 Thermal characterization of fermented and non fermented taro

Treatment	T_O (^{O}C)	T_P (^{O}C)	T_C (^{O}C)	T_C -T_O (^{O}C)	ΔH (J/g)
NFT	70.95± 0.09	76.33 ± 0.37	85.17 ± 0.45	12.55 ± 0.39	3.90 ± 0.06
FFT	73.15 ± 0.08	79.33 ± 0.33	91.17 ± 0.41	14.51 ± 0.32	4.95± 0.06

3.6. Micromorphology of samples:

SEM micrographs permit direct observation of various samples treated as fermented and unfermented to explain the different properties of unfermented and fermented taro samples. As shown in Fig. 2, SEM micrographs of various fermented and unfermented samples were captured at various magnifications (A) NFT, (B) FFT. Similar to the findings of Yaqoob *et al.* (2019), fermented maize flour had much smaller particles with sharp and irregular edges, whereas unfermented corn flour retained a smooth surface. Using a scanning electron microscope, it was determined that fermented taro and corn share similar characteristics. Having smaller irregular particles resulted in a higher water-absorbing capacity and a lower water-retention capacity, which ultimately led to a more compact dough and improved rheology (Oh *et al*., 2008). Starch produced during the dormant period had a greater proportion of double helix, a more stable and well-organized crystalline structure, and a larger amount of short-range order than starch produced during the growth stage (Zou *et al.*, 2020). Similar to the findings of Siano *et al.,* 2018 fermented maize flour had particles with sharper and more regular margins than unfermented corn flour, which had a smooth surface. Smaller and irregularly shaped fermented flour particles led to a greater water-absorbing capacity and a lesser water-retention capacity, resulting in a more manageable and compact dough and improved rheology. Multiple cycles expose more fissures and indentations. Due to a phase transformation, the particles may have shrunk and fractured during fermentation (Szymonska *et al*., 2000; Yaqoob *et al.*, 2019). High-pressure compression of starch yielded comparable outcomes (Vallons *et al*., 2010; Buckow *et al*., 2007). It is concluded that starch properties like pasting property, swelling property, and gelling can be improved by fermentation. This affects and benefits fermentation and modifies the fermentation methods for better use of fermentation to improve nutritional and functional characteristics.

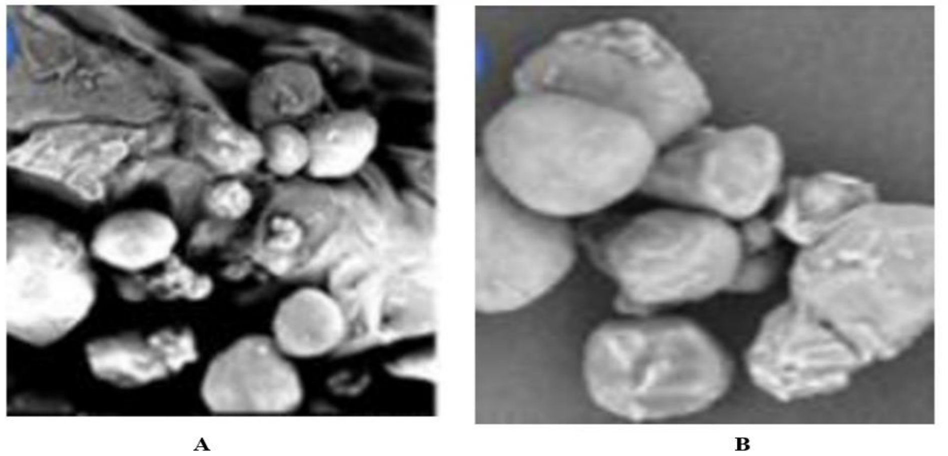
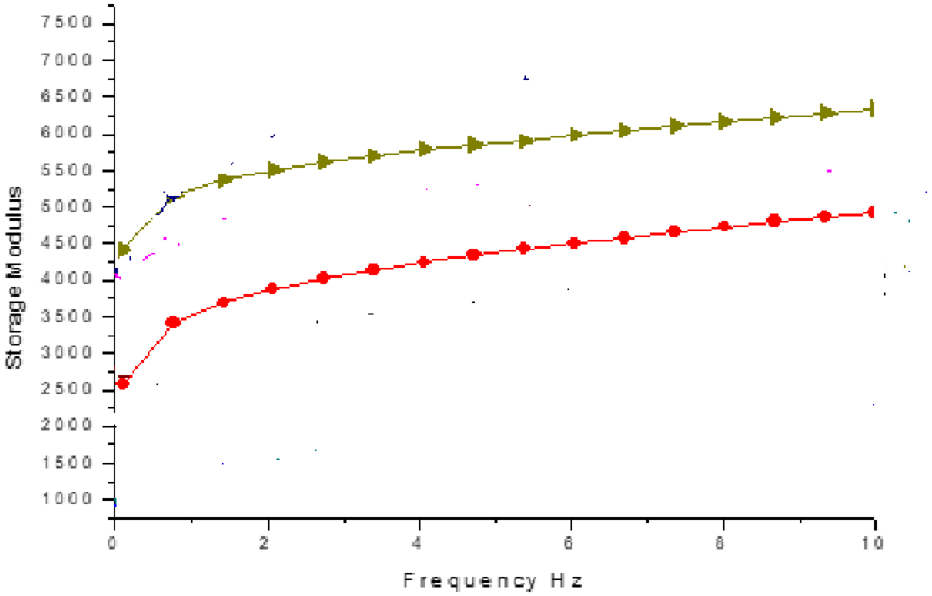
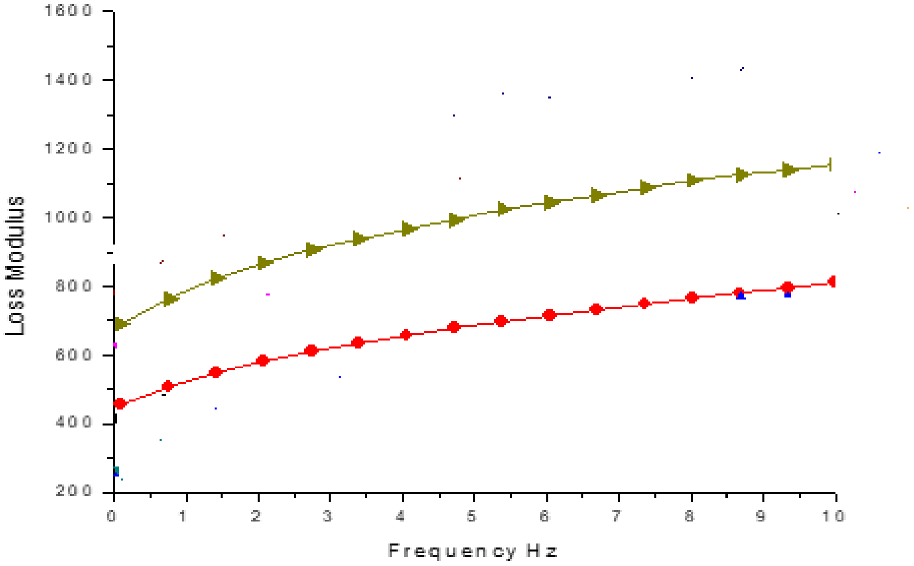


Figure 2: SEM phoromicrographs of fermented and non fermented taro. A: Non fermented taro, B: Fermented Taro

3.7. Rheological characterization of samples:

Rheology is the most important factor in determining the quality of any food. However, process stabilization ultimately determines the quality of the product. When food ingredients are subjected to physical pressures and made to flow, the rheological properties of those food ingredients play a significant role in determining their texture and behavior. Various techniques can be used to investigate the rheological properties of basic materials, intermediate products such as batters and doughs, and final products. The rheology of fermented and unfermented samples consists of storage, loss modulus, and tan delta. Utilizing a frequency sweep test, the quality of carbohydrates was evaluated. A thorough understanding of rheology was required for product quality control and manufacturing (Letang *et al.,* 1999). The storage modulus, loss modulus, and tan delta are the sample rheology parameters illustrated in Figure 3. Frequency has a direct relationship with both the storage modulus and loss modulus. The loss modulus was always less than the storage modulus, indicating that the samples were more elastic than viscous (Narsimhan, 1994). The storage and loss modulus of fermented samples was greater than that of unfermented samples. The extraction of amylose and amylopectin chains from the granules, which drastically altered the starch structure through enzymatic hydrolysis, led to the formation of extremely viscous material during gelatinization (Tao *et al.,* 2016). Earlier research indicates that phase transformation causes water to expand, forming a coarse surface. This surface could enhance the water absorption rate, an important factor in determining the rheology (Zhang *et al.*, 2021). In another important investigation, Yuan *et al.* (2008) isolated starch from spontaneously fermented corn to investigate fermentation’s effect on the physical properties of corn starch and the suitability of fermented corn. Fermented corn had substantially less swelling power and solubility than control samples at temperatures above 75 °C ($p<0.05$). With fermentation time, peak viscosity and breakdown initially increased and then decreased, whereas final viscosity and setback decreased progressively. The gel strength of fermented samples was notably greater ($p<0.05$). According to the toxin test results, the spontaneous fermentation was safe (Yuan *et al.*, 2008). In turn, the partial fragmentation of the flour caused by enzymatic hydrolysis, specifically the action of amylolytic enzymes, influences the dough's rheology. The maximum value of tan for mango kernel starch indicated that both starches were more elastic than viscous (Thory & Sandhu, 2017).





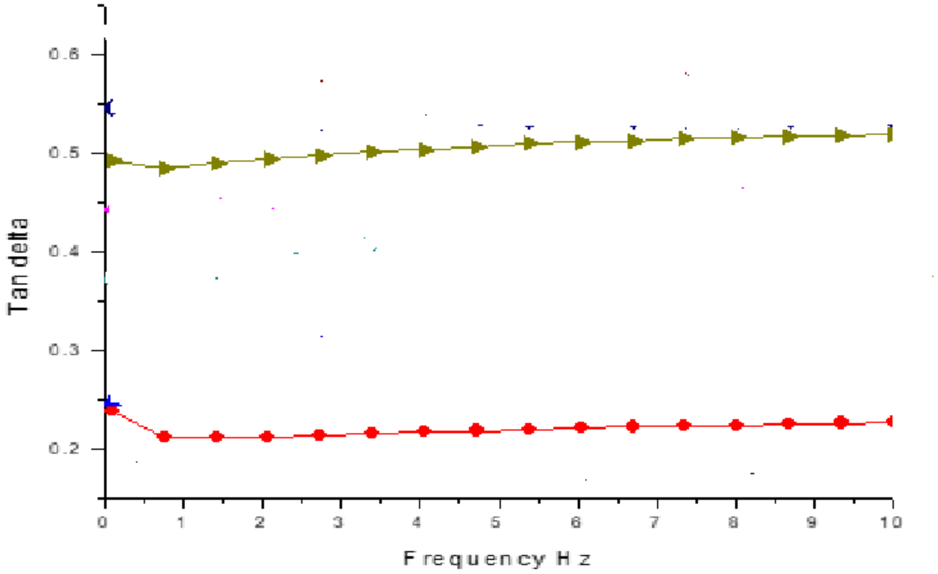


Figure 3: Rheological characterization of fermented and non-fermented taro

4. CONCLUSION

The current study examined a large variance in the nutritional profile of taro starch. LAB carried great industrial importance and hydrolyzed the flour, leading to improved characteristics. Bacterial inoculation results in better rheology, texture, thermal, and structural profile of samples. Although significant variation has been seen among different samples, the results are satisfactory overall. LAB positively impacts the starch profile, ultimately improving its applicability. Fermentation treatment directly disturbs the integrity of starch, disrupting various components. However, the damage is less due to improved shelf life and easy handling of materials. These results provided a noble insight into the deeper characterization of starches. To date, enough knowledge has been gleaned from this work to examine the alteration of starches in various food systems, although additional research will be required.

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