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The application of microwave and ultrasound treatment on breadfruit flour for noodle fortification

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ABSTRACT

Breadfruit flour was subjected to treatment using either microwave radiation (1000 W, 16 min) or ultrasonic waves (20 kHz, 750 W, 16 min) before being combined with rice flour to produce dried rice–breadfruit noodles. Scanning electron microscopy and FT-IR spectroscopy were used to study alterations in the macrostructures and amylose/amylopectin arrangement of the treated flours, leading to changes in water adsorption and swelling power compared to originated flour. Noodles fortified with either microwave (M)- or ultrasound (U)-treated flour exhibited improved firmness and reduced cooking loss compared to those made with intact flour (Nf noodle), while noodles made from Nf combined with xanthan gum (Nf+X) demonstrated sufficient hardness and the lowest cooking loss. The addition of xanthan gum enhanced sensory score, whereas scores for M, U, and Nf noodles were comparatively lower. Although M treatment potentially enhanced the noodle texture and cooking properties, it also resulted in darkening due to pigment formation at high temperatures.

1. INTRODUCTION

Breadfruit (*Artocarpus altilis,* Moraceae) is a tropical species that originated in the Western Pacific and expanded into the Caribbean, Africa, Central/South America, India, and Southeast Asia [1,2]. A tree might provide 250–400 kg of fruits per year, which are food security candidates because of their high nutritional value; 100 g of fresh fruits contain 108–138 kcal, 27.12–33% carbohydrates, 1.48–2% fats, and 1.65–2% proteins together with high minerals, vitamins, and essential amino acids [3]. These properties have made breadfruits the greatest alternative to rice next to other carbohydrate sources such as cassava and sweet potato [4]. The fruits are mostly prepared and consumed by boiling, baking, and steaming. However, their shelf life is limited to a few days due to quick deterioration [5]. To enhance their fruits' storage properties, drying has been applied, and dried flour is widely used as an alternative ingredient in baking [6-9].

Rice noodles (rice vermicelli) are popularly served in Asia and have spread to Europe recently due to their gluten-free nature and good digestibility. Processing and types of ingredients used affect the strands' important properties such as color, uniformity, and eating quality [10,11]. Noodles have been fortified with various plant sources including breadfruit flour to enhance nutrition and consumer acceptance [4,12]. Up to 10–25% of rice flour has been substituted by breadfruit flour for successful utilization compared to other starch sources (potato and cassava) [13,14]. Breadfruit flour containing 18.2–27.68% starch displays low paste clarity, poor shear stress and thermal resistance, and high retrograded characteristics that cause the noodles to become sticky, less transparent, increase cooking loss, and decrease customer acceptance [15-17]. Therefore, many physical treatments such as heat, moisture, extrusion, radiation, sonication, and pressure have been applied to alter the breadfruit micro/macroscopic matrix and starch integrity, resulting in high viscosity and plastic materials for prospective thickening/gelling reagents [18].

Microwaves are electromagnetic radiation (frequency of 300–300,000 MHz) that provide heat through polar and ionizable components. The molecules absorb microwave energy and arrange themselves to the electrical field, resulting in heat generation within the food volumes due to friction [19]. This thermal treatment has enhanced the rheological and pasting properties of rice, corn, and breadfruit starches [16,19-21]. Low-frequency ultrasound (20–100 kHz), on the other hand, is a nonthermal technique that uses acoustic cavitation phenomenon, in which tiny bubbles are generated and collapsed under pressure variation. This technology insisted on changes in structural, crystallinity, and pasting characteristics of sweet potato, rice, and wheat flours [22-24]; however, the application to breadfruit powder has not been reported. Low-gluten noodles prepared with ultrasonically treated wheat dough showed promising textural and cooking quality [25], whereas the application of modified breadfruit flour to rice noodles has not yet been discussed. In this research, the morphologies and pasting properties of breadfruit flours treated by microwave and ultrasonic methods were compared to those of intact flour, and their substitution on rice vermicelli was also investigated.

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2. MATERIALS AND METHODS

2.1. Materials and Chemicals

Fresh, mature, and unripe breadfruits (0.5–1 kg/fruit) and Tai Nguyen rice were purchased from the local market in Can Tho City, Vietnam. The fresh fruits were stored at 15 ± 1°C for a maximum of 3 days, and the rice was kept in a tight bag at room temperature until used. Xanthan gum was purchased from a local store in Can Tho City, Vietnam. Distilled water was used throughout the experiment. Sodium metabisulfite ($Na_2S_2O_5$) was purchased from Xilong, China.

2.2. Breadfruit Flour Preparation

The flour was prepared according to the procedure developed by Tran et al. [26]. Fresh fruits were washed, peeled, coil removed, and cut into pieces (1.5 cm × 3.0 cm × 0.3 cm). The slices were soaked in sodium metabisulfite 0.45% (1:1, w:w) for 60 min to inhibit polyphenol oxidase and peroxidase hydrolase enzymes for flour color enhancement [8,26]; then slices were washed with water several times to remove the residual chemical; the blanching step was performed at 80°C for 2 min before air drying at 70°C until moisture content was under 13% (wet basic). The carbohydrate, starch, amylose, and amylopectin quantifications were done according to the Vietnamese National Standard method (TCVN 5716-2:2017, ISO 6647-2:2015) and the work of Tran et al. [26]. The dried flesh was milled to a fine powder (250 µm) and stored in tight plastic bags for modification and noodle preparation.

2.3. Microwave/Ultrasound Treatment and Noodle Preparation

2.3.1. Microwave treatment

The microwave treatment was performed following the work of Marta et al. [16] with minor modifications. An amount of 20 g breadfruit flour was weighed into a 100 mL beaker (the thickness of the flour layer was about 25 ± 2 mm), adjusted to 30% moisture content (wet basic), and treated in a household microwave (EM-G3650, Sanyo, Japan) at 100 W for 16 min (mixing every minute). The temperature after treatment was measured to be 70 ± 1°C. The sample was prepared freshly for analysis and noodle preparation.

2.3.2. Ultrasound treatment

The procedure was developed according to the research of Quin et al. [23]. An amount of 20 g breadfruit powder was weighed into a 100 mL beaker and adjusted to 30% moisture content (wet basic); the mixture was placed in an ultrasonic system (MC-031S, King Sonic, Vietnam) at a frequency of 20 kHz, 750 W for 16 min at room temperature; the temperature of the flour after treatment was recorded to be 60 ± 1°C. The flour was prepared freshly for analysis and noodling process.

2.3.3. Noodle preparation

Xanthan gum noodles (Nf+X): Wet rice flour was prepared by soaking the rice in water (1:2, w:v) for 24 h, decanting, and milling to a fine powder (28–30% moisture content). About 50 g of the (wet) rice flour was pre-gelatinized at 75°C for 5 min before being blended with 50 g wet rice flour, 20 g intact breadfruit flour, and 0.75 g xanthan gum. The mixture was kneaded thoroughly with water to prepare a dough of 35–40% moisture content. The 20-cm strand noodle was formed by a handle stainless steel extruder, steamed for 7 min, and dried at 70°C until the moisture content was less than 13%. The dried noodle was stored in tight plastic bags until analysis.

Intact noodle (Nf): The noodle was prepared similarly without xanthan gum. The dried noodle (Nf) was stored in tight plastic bags until analysis.

Modified noodles (M and U): The noodles fortified with either ultrasonic- or microwave-treated flour were processed as follows: 20 g of intact breadfruit flour was substituted with the microwave (M)- or ultrasonic (U)-treated flours, without the addition of xanthan gum. Subsequently, the dried noodles were stored in airtight plastic bags at room temperature until further analysis.

2.4. Properties of Modified Flour

2.4.1. Morphology

The SEM machine (JCM 7000, Joel, Japan) was used to observe the flour's microscopic appearances, while FT-IR spectroscopy (PerkinElmer Inc. Spectrum II) was applied to analyze the changes in FT-IR-characterized spectra of the native and treated flours in the frequency range 4000–400 cm^{-1}.

2.4.2. Gelatinizing characteristics

The gelatinizing properties of the native and modified flours were monitored by the differential scanning calorimetry (DSC) equipment (Netzsch DSC 200 F3, Germany). Approximately 3 mg of flour was mixed with distilled water (1:3, w/w) and heated from 20 to 100°C at a rate of 10°C/min. Onset temperature (T_o), peak temperature (T_p), and gelatinization enthalpy (enthalpy change, ΔH_g) were measured for the thermal transitions of the flours during gelatinization [19].

2.4.3. Water adsorption capacity and swelling powers

Water adsorption capacity (WAC): Approximately 2 g of flour was dissolved in 20 mL of water and mixed thoroughly, and the slurry was sedimented for 30 min, then centrifuged for 20 min at 4000 rpm, and decanted carefully. The remaining sediment was weighed. The WAC was calculated as the increased weight in percentage according to the study by Adepeju et al. [7]:

$$WAC\% = \frac{\text{Weight of sedimen– Weight of original sample}}{\text{Weight of original sample}} \times \text{WAC\%} \quad (1)$$

Swelling powers (SP): Approximately 3 g of sample was dissolved in 30 mL of distilled water and heated at the temperatures of 60, 70, and 90°C for 15 min with regular mixing. The heated slurries were then centrifuged at 3000 g for 10 min, the supernatant was removed, and the sediment was dried at 50°C for 30 min, cooled, and weighed for SP according to the study by Adepeju et al. [7].

$$Swelling\ power = \frac{\text{Weight of dried sediment}}{\text{Weight of original sample}} \times 100 \quad (2)$$

2.5. Noodles Properties

2.5.1. Cooking properties

Noodles' cooking time, cooking yield, and cooking loss were measured following the approved method AACC 66-50 (American Association of Cereal Chemists, 2000) with modification [27]. Approximately 5 g of noodles were cooked in 100 mL of boiling water until the strands' opaque part was gelatinized or the white core disappeared, and the optimal cooking time was recorded. The cooked noodles were drained for 5 min and weighed for the percentage increase during cooking (cooking yield). The cooked (drained) liquid was evaporated at 105°C until dryness and was weighed for cooking loss, which was calculated as a percentage of solid lost during cooking.

2.5.2. Texture (firmness) and color

The firmness of cooked noodles was measured by a texture analyzer (TMS Pro, USA) following the method of Srikaeo et al. [28]. Five strands of cooked noodles were put next to each other for measurement, and the compression mode with 75% deformation was applied using a knife blade probe (10 cm × 5.0 cm × 0.2 cm) at a test speed of 1 mm/s. The highest force (N) to compress the noodle was firmness. The texture was measured immediately after cooking (fresh) and after 24 and 48 h of storage under 5°C to compare noodles' retrogradation. The color of cooked noodles was recorded by a lab colorimeter (Cielab sph870, Germany) using the standard CIELAB Color System (L*: brightness to darkness; a*: redness to greenness; b*: yellowness to blueness, and ΔE: color difference). The yellowness index (YI) associated with product color degradation by processing was also calculated according to the study by Pathare et al. [29].

$$YI = \frac{142.86 \times b^*}{L^*} \qquad (3)$$

2.5.3. Sensory evaluation

Sensory tests for the cooked noodles were done by 15 third-year students from the Food Technology Department, Can Tho University of Technology, Can Tho City, Vietnam using a nine-point hedonic scale. The scale runs from 1 to 9, with 1 representing "dislike extremely" and 9 representing "like extremely." Each noodle (Nf, Nf+X, U, M) was cooked at optimal cooking time, drained, and served.

2.6. Data Analysis

All measurements were conducted in duplicates, and the data were analyzed by variance analyses (ANOVA) followed by a Fisher's least significant difference (LSD) test with 95% confidence, using the Statgraphics Centurion XVI software.

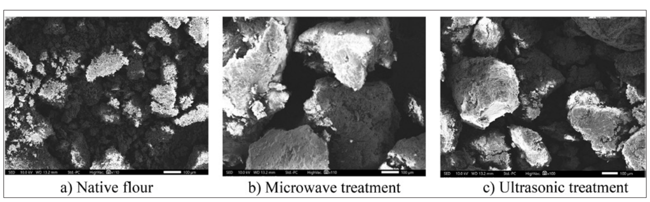

Figure 1: SEM micrographs of native **(a)**-, microwave **(b)**-, and ultrasonic-treated-**(c)** flour.

3. RESULTS AND DISCUSSION

3.4. The Flour Properties

3.4.1. Morphology

SEM: The morphologies of native and modified flours were examined by SEM to compare the cluster macromolecule structures, and the micrographs are presented in Figure 1. The native starch granules exhibit typical spherical, elliptical, and polyhedral shapes, whereas the starches treated with microwave and ultrasonic methods display notable deformation, appearing as irregular shapes next to the other components such as proteins and fibers. Microwaves cause the molecules to collide and gelatinize, resulting in losses in conjunction and physical integrity, while also generating the porous surface of breadfruit starch [16]. Meanwhile, there are few spherical structures found in ultrasonic-treated flour next to the changes in surface roughness due to the collision of the granules. The ultrasonic process destroys the starch structures by inducing frictional, shear forces, and heat, depending on the treatment time and intensity, and a similar partial gelatinization was seen in the treatment of the sweet potato and wheat flour before [22].

FT-IR: The modification of starch structures caused by microwave and ultrasonic processes is observed through the FT-IR characteristic spectra [Figure 2], and the results are summarized in Table 1. Generally, the three flours showed identical adsorption bands at 3500–3200, 2929–2850, 1030–990, 1450–1200, and 1600–1500 cm^{-1}, which are attributed to hydrogen bonding of –OH, C–H, O–C, and C–O–H stretching, respectively, which is consistent with the report of Otemuyiwa and Aina [30]. The intensities of the major peaks were changed following the treatments; noticeably, the rise in the –OH absorption band observed in the microwave-treated sample shifted toward higher wave numbers (3421.2 vs. 3419.2), similar to the effect seen in the treatment of rice flour. This phenomenon is attributed to the rapid movement of polar molecules during the microwave process [23].

Besides, the minor peak ranges at 995, 1047, and 1022 cm^{-1} represent the vibrations of C–OH bending, amorphous, and crystalline regions of starch. These bands slightly declined under microwave heating but enhanced under ultrasonic radiation. Qin et al. [23] explained that these changes are caused by the quick boiling and evaporation of water under the microwave process and the hydrogen bonds broken by ultrasonic treatment. The changes in the ratios of 1022:995 and 1047:1022 give information about the double helices and short-range crystallinity of

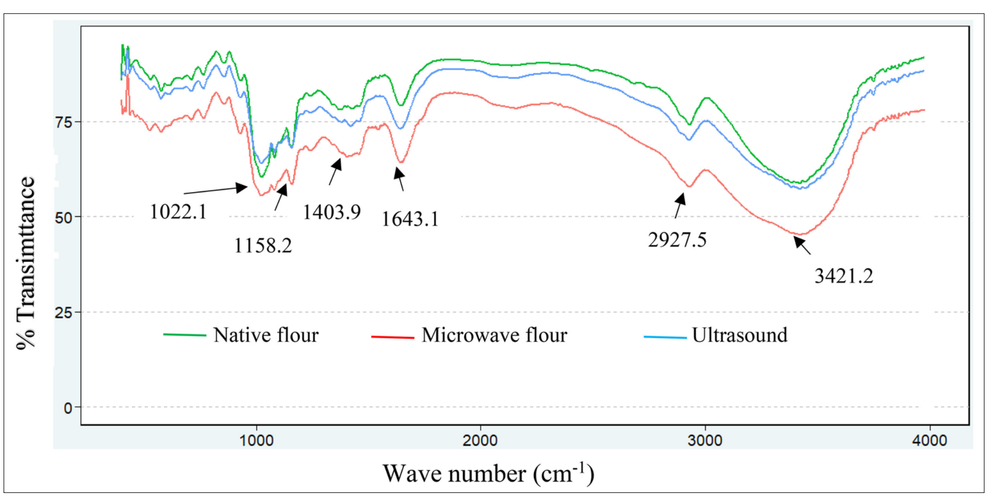

Figure 2: FT-IR characteristic spectra of native, microwave-, and ultrasonic-treated flours.

the crystallites [24]. In this study, the ratio 1047:1022 declined slightly, indicating a lower relative crystallinity, while the ratio 1022/995 increased significantly, referring to a higher proportion of amorphous material under both treatments, in which the ratios of ultrasonic treatment are slightly higher than those of microwave treatment.

3.4.2. Gelatinizing characteristics

The thermal properties of native and modified flours were evaluated by DSC technology, where the endothermic peak represents the gelatinization transition of the starch occurring under heating [Figure 3]. The results of onset temperature (T_o), endothermic peak gelatinization (T_p), and gelatinization enthalpy change (ΔH_g) are summarized in Table 2.

The microwave heating slightly enhances the gelatinization mechanism (T_o, T_p, and T_e temperatures increased by 0.5–1°C compared to that of native flour) and significantly reduces the ΔH_g to more than four times. The higher gelatinization temperatures and lower enthalpy energy resulted from the alteration of starch crystal structures, the improved macromolecules' stability, and homogeneity, while very low ΔH_g indicated the complete gelatinization of the starch granules under microwave treatment. Besides, the interaction of starch with other components present in the flour could also raise the pasting temperature, which is consistent with the microwave-treated wheat and corn flour reported before [31]. Mehta et al. [32] also summarized that high-temperature processes enhance pasting temperatures by forming complex bonds between amylose and amylopectin in the crystalline and amorphous regions.

The sonication, on the other hand, has decreased the gelatinization temperature (from 73 to 71.3°C) and the enthalpy energy (nearly three times) due to the weakening of the starch granules' crystalline structures and the deformation of the amorphous regions under cavitation effects [25]. These declines are in agreement with the study of Vela et al. [24].

Table 1: FT-IR diagnostic bands and frequencies of the functional groups of the three flours.

Bands (cm^{-1})	Vibration Mode	Native	Microwave	Ultrasound
3500–3200	OH stretch of starch	3419.5	3421.2	3419.2
2929–2850	C-H stretch (-CH_3)	2928.9	2927.5	2927.5
1030–990	-O-C (glycosidic) stretch	1022.6	1022.1	1022.1
1450–1200	C-OH stretch	1370.1	1403.9	1419.4
1600–1500	OH stretch of water	1641.1	1643.1	1641.2

3.4.3. WAC and SP

The pasting properties of the flour depend on its composition and morphology, which changes with the fruit's maturity, production methods, environmental conditions, and analysis methods [33]. In this study, the carbohydrate and starch contents of the intact flour were 55.22 and 35.83%, respectively [26]. The starch includes 27.19% amylose and 72.81% amylopectin, which are comparable to the report of Marta et al. [16]. WAC and SP indicate the flour's capacity to absorb water and swell in bulk, which is correlated to their amorphous and crystalline interactions. Table 3 shows the WAC and SP of the intact and two modified flours. Both processes enhanced the flour's hydration properties, and the values of the microwave sample were lower than those of the ultrasound sample. The increases in starch's WAC and SP under these physical treatments were seen in the studies of Marta et al. [16] and Vela et al. [24], which was explained by the dissociation of proteins' binding sites together with the re-arrangement of the amylose and amylopectin within the starch structures. These hydrophilic properties significantly depend on flour sources and treatment times, which caused the damage to starch crystalline and amorphous regions, allowing the exposure of hydrophilic groups to water. Besides, the significant rise of SP at around 80°C is similar to the report of Adepeju et al. [7] on breadfruit flesh flour.

3.5. Noodles Properties

3.5.1. Cooking properties

The cooking time, cooking yield, and cooking loss of noodles fortified with native flour (Nf), native flour and xanthan gum (Nf+X), microwave (M)-, and ultrasound (U)-treated flours are presented in Table 4.

Cooking yield and cooking loss are the main quality properties of the noodles, which are calculated according to the AACC 66-50 (2000) [27]. The cooking yield indicates the water-holding capacity of the noodles, whereas cooking loss correlates to amylose leaching and protein

Table 2: Gelatinization properties (melting temperatures) of native-, microwave-, and ultrasonic-treated flours.

Melting Temperatures	T_o (°C)	T_p (°C)	T_e (°C)	ΔH_g (J/g)
Native flour	70	73	76.5	6.984
Microwave flour	71	73.5	77.5	1.521
Ultrasonic flour	67	71.3	73.5	2.486

The melting temperatures [onset temperature (T_o), endothermic peak gelatinization (T_p)], and gelatinization enthalpy change (ΔH_g).

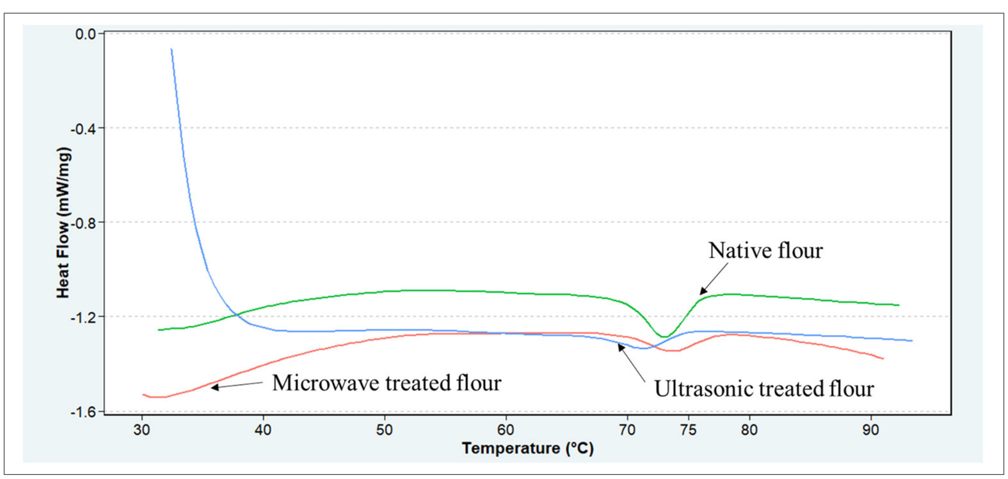

Figure 3: DSC thermograms of native, microwave-, and ultrasonic-treated flours.

Table 3: The WAC and SP of the native-, microwave-, and ultrasonic-treated flours.

		Native	Microwave	Ultrasound
WAC (%)		253.10 ± 3.3^{a}	276.10 ± 1.9^{b}	259.04 ± 1.3^{a}
SP (g/g)	60°C	2.18 ± 0.07^{a}	2.66 ± 0.02^{a}	2.92 ± 0.09^{b}
	70°C	2.32 ± 0.01^{a}	2.83 ± 0.01^{b}	2.97 ± 0.005^{b}
	80°C	5.50 ± 0.14^{a}	5.73 ± 0.07^{a}	5.80 ± 0.04^{a}

The letters in the same row represent the significant ($p < 0.05$) differences in data.

Table 4: Cooking time, cooking yield, and cooking loss of noodles fortified with native (Nf), microwave (M)-, and ultrasonic (U)-treated flour, native flour with xanthan gum (Nf+X).

	Nf	Nf+X	M	U
Cooking time (min)	10.3 ± 0.2^{d}	6.83 ± 1.2^{a}	7.0 ± 0.2^{c}	6.96 ± 0.1^{b}
Cooking yield (%)	250.2 ± 1.5^{a}	302.77 ± 1.0^{b}	395.8 ± 0.9^{d}	351.1 ± 1.7^{c}
Swelling (%)	220 ± 2.9^{a}	500 ± 1.6^{d}	310 ± 3.8^{b}	350 ± 2.6^{c}
Cooking loss (%)	13.25 ± 0.2^{d}	6.61 ± 0.4^{a}	12.02 ± 0.2^{b}	13.1 ± 0.1^{c}

The different letters in the same row represent the significant ($p < 0.05$) differences in data.

solubility and high cooking loss causes turbid cooking solutions and a low consumer acceptance rate [34]. In this study, the M sample has the highest cooking yield (355.1%), followed by U, Nf+X, and Nf samples. On the other hand, the highest cooking loss (13.25%) was found in Nf noodles next to U and M ones, while Nf+X noodles lost the least (6.61%). The increased cooking yield and reduced cooking loss due to starch and protein macrostructure disruption under an ultrasonic wave were also seen in gluten noodles before [25]. Xanthan gum is generally used to improve noodle-eating qualities such as viscosity, firmness, and mouth feel by enhancing the interaction between amylopectin and water [28]. For swelling power, the value of the Nf sample is the lowest, followed by M, U, and Nf + X, and this swelling behavior depends on starch granules' dimension, the level of protein, and amylose. These components strongly affect the flour's functional properties, and the damage to amylose structures under microwave and ultrasonic treatments might cause the rise of flour swelling power [15].

The cooking times of both M and U noodles are slightly longer than Nf+X but significantly lower than Nf. The enhancement of water uptake and reduction in the cooking time of noodles fortified with microwave pre-gelatinized flour were consistent with the study of Xue et al. [35] on wheat noodles.

3.5.2. Firmness, color, and sensorial evaluation of the noodles

The treatment appeared to alter the texture, color, and sensorial scores of the fortified noodles, and the results are summarized in Table 5.

In terms of texture [Table 5a], the hardness of all fresh samples was different and then changed significantly during cold storage ($p < 0.05$) due to the starch retrogradation, except for the Nf+X sample. The hardness of Nf+ X is also the highest after cooking (0.63 N), and it remains almost stable after 48 h, due to the addition of a hydrocolloid that maintains water and starch interactions. Meanwhile, the texture of freshly cooked noodles was significantly influenced by the type of flour (0.43 N, 0.29 N, and 0.284 N for M, U, and Nf noodles, respectively) and storage time. The hardness of the Nf noodles showed the largest increases of 1.6 and 2.04 times after 24 and 48 h of cooling due to significant retrogradation. The increases in hardness for M and U samples are not sufficiently different after 24 h (1.4 times). However,

Table 5: The firmness (a), color (b), and sensorial scores (c) of noodles fortified with native (Nf), microwave (M), and ultrasonic (U)-treated flour, native flour with xanthan gum (Nf-X).

a)	Firmness (N)		
	Fresh	24h	48h
Nf	0.284 ± 0.04^{aX}	0.473 ± 0.04^{aY}	0.592 ± 0.08^{abZ}
Nf + X	0.632 ± 0.07^{cX}	0.654 ± 0.06^{bX}	0.634 ± 0.09^{bX}
M	0.434 ± 0.04^{bX}	$0.594 \pm 0.09a^{bY}$	0.637 ± 0.09^{bX}
U	0.290 ± 0.02^{aX}	0.415 ± 0.03^{aY}	0.480 ± 0.07^{aZ}

b)	Color				
	L*	a*	b*	ΔE	YI
Nf	58.2 ± 1.6^{b}	1.39 ± 0.3^{b}	1.45 ± 0.8^{a}	51.08 ± 1.6^{a}	5.45 ± 0.3^{a}
Nf + X	48.03 ± 0.8^{a}	1.24 ± 0.4^{a}	1.93 ± 0.9^{b}	53.25 ± 5.2^{ab}	8.14 ± 0.4^{a}
M	41.93 ± 3.8^{a}	1.75 ± 0.2^{c}	2.86 ± 0.9^{c}	57.26 ± 3.2^{b}	12.61 ± 0.8^{b}
U	42.48 ± 2.5^{a}	1.89 ± 0.8^{c}	3.12 ± 0.8^{d}	56.67 ± 1.9^{b}	13.58 ± 0.5^{b}

c)	Overall Acceptability
Nf	5.29 ± 0.3^{a}
Nf + X	8.45 ± 0.6^{d}
M	7.26 ± 0.5^{c}
U	6.16 ± 0.4^{b}

The X, Y, Z letters represent the significant ($p < 0.05$) differences in data of the same row; the a, b, c letters represent the significant ($p < 0.05$) differences in data of the same column.

after 48 h, the firmness of U noodles increased to 1.7 times compared to 1.5 times of M noodles. This texture alteration is in agreement with the study of Huang et al. [36] on the increase of breadfruit starch retrogradation under a high-temperature process.

The color of four noodles was distinguished by the CIELAB system, where the brightness, redness, yellowness, and total color difference of the samples were represented by L^*, a^*, b^*, and ΔE values. In general, the noodles fortified with different treated flours exhibited significant color changes compared to the blank noodles, and tissue shrinkage and browning during heating treatment are considered reasons for the high ΔE values of M and U samples. This finding aligns with the effects of ultrasound and microwave treatments on various flours reported before [22,29]. The lowest L^* value was observed in the M and U samples (41.93 and 42.48) due to the darkness of breadfruit flour resulting from these two treatments. The Nf + X noodles was lightly brighter ($L^* = 48.03$), whereas the non-treated noodle Nf exhibited the highest L^* value (58.2). The increase of dough darkness under heat treatment such as microwaves and ultrasound has been confirmed in a study by Rao et al. [37] on foxtail millet. The high temperatures might promote the Maillard reaction, leading to the formation of brown pigments. This observation is consistent with the sufficiently high b^* and YI values of the noodles modified with treated flours, where the YI values of U and M were two times higher than that of Nf (13.58, 12.61 vs. 5.45). The YI of food products is known to vary based on radiation intensity or heating effects [29].

There were significant differences in the sensory scores of all samples, in which the noodles fortified with native flour added xanthan gum (Nf+X) and native flour (Nf) had the highest and lowest likeness (8.45 vs. 5.29, respectively), and the M and U noodles were better evaluated compared to Nf (7.26 vs. 6.16). This could be related to the soft, sticky, and crumbling appearance of the U and N noodles, which is highly relevant to their excessive cooking loss.

4. CONCLUSION

The cooking and sensory qualities of dried rice–breadfruit noodles were enhanced by fortifying them with breadfruit flour pre-treated using either ultrasonic or microwave processes. The structural and physicochemical characteristics of the treated flour were altered compared to the intact flour. The heating effect of the microwave reduces the crystallinity and swelling power, and increases the gelatinization temperature of the breadfruit flour. In contrast, the cavitation formed under ultrasonic waves led to a decline in the pasting temperature. Noodles fortified with the treated flour exhibited better texture and taste compared to noodles made with intact flour. These ultrasound and microwave irradiation methods are modern and environmentally friendly techniques that modify breadfruit flour effectively and in a reduced amount of time, making them suitable for noodle fortification. Therefore, further research is necessary to optimize these mechanical modification processes for high-quality dried rice–breadfruit noodles.

6. ACKNOWLEDGMENTS

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7. AUTHORS' CONTRIBUTIONS

TT: Concept and Design, Data Acquisition, Data Analysis/ Interpretation, Drafting Manuscript, Critical Revision of Manuscript, Statistical Analysis, Admin, Technical or Material Support, Supervision, Final Approval. TTV: Data Acquisition, Data Analysis/ Interpretation, Drafting Manuscript, Statistical Analysis. PL: Data Analysis/ Interpretation, Drafting Manuscript, Statistical Analysis. TNV: Data Analysis/ Interpretation, Drafting Manuscript, Statistical Analysis.

8. CONFLICT OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

9. ETHICAL APPROVALS

The sensorial analyses of this research were approved by the Institutional Ethics Committee of the Department of Food Technology, Faculty of Biological, chemical and Food Technology, Can Tho University of Technology, Can Tho City, Vietnam.

10. DATA AVAILABILITY

The data availability could be accessed upon email request (email: ttmthu@ctuet.edu.vn).

11. USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

12. PUBLISHER'S NOTE

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REFERENCES

1. Fosberg FR. Introgression in Artocarpus (Moraceae) in micronesia. Brittonia. 1960;12:101–3. https://doi.org/10.2307/2805210
2. Ragone D. Breadfruit, *Artocarpus altilis* (Parkinson) Fosberg. Promoting the conservation and use of underutilized and neglected crops. vol. 10. Rome: Bioversity International; 1997.
3. Liu Y, Ragone D, Murch SJ. Breadfruit (*Artocarpus altilis*): a source of high-quality protein for food security and novel food products. Amino Acids. 2015;47(4):847–56. https://doi.org/10.1007/s00726-015-1914-4
4. Histifarina D, Purnamasari NR. The prospect of developing breadfruit as an alternative source of food to support food diversification. Proceedings of the IOP Conference Series: Earth and Environmental Science; 2022 Apr 1 (Vol. 1012, No. 1). IOP Publishing; 2022. p. 012023.
5. Amusa NA, Kehinde IA, Ashaye OA. Bio-deterioration of breadfruit (*Artocarpus communis*) in storage and its effects on the nutrient composition. Afr J Biotechnol. 2002;1:57–60.
6. Arinola SO, Akingbala JO. Effect of pre-treatments on the chemical, functional and storage properties of breadfruit (*Artocarpus altilis*) flour. Int Food Res J. 2018;25:109–18.
7. Adepeju AB, Gbadamosi SO, Adeniran AH, Omobuwajo TO. Functional and pasting characteristics of breadfruit (*Artocarpus altilis*) flours. Afr J Food Sci [Internet]. 2011;5(9):529–35.
8. Aderinola TA. Effects of processing techniques on the functional properties of wheat- breadfruit composite flour. Int Food Res J. 2016;23:2759–62.
9. Tijani AO, Oke EK, Bakare HA, Tayo TR. Quality evaluation of instant noodles produced from composite breadfruit flour. Researcher. 2017;9(1):20–6.
10. Ross AS. Instrumental measurement of physical properties of cooked Asian wheat flour noodles. Cereal Chem. 2006;83(1):42–51.
11. Jeong S, Kim Y, Ko S, Yoon MR, Lee JS, Lee S. Physicochemical characterization and in-vitro digestibility of extruded rice noodles with different amylose contents based on rheological approaches. J Cereal Sci. 2016;71:258–63.
12. Charutigon C, Jitpupakdree J, Namsree P, Rungsardthong V. Effects of processing conditions and the use of modified starch and monoglyceride on some properties of extruded rice vermicelli. LWT Food Sci Technol. 2008;41(4):642–51.
13. Minh NP, Nguyen DK. Cooking quality attributes of rice (*Oryza sativa* L.) noodle substituted by different carbohydrate sources. Res Crops. 2022;23(1):235–42.
14. Aulia SR, Heriyadi SA, Maharani D. Breadfruit (*Astocarpus altilis*) noodle as a local food for improving food diversification in Indonesia. Proceedings of the B. 7th Asian Acad. Soc. Int. Conf; 2019 Nov 14; 2019. p. 235–241.
15. Adebowale KO, Olu-Owolabi BI, Olawumi EK, Lawal OS. Functional properties of native, physically and chemically modified breadfruit (*Artocarpus artilis*) starch. Ind Crops Prod. 2005;21(3):343–51.
16. Marta H, Cahyana Y, Arifin HR, Khairani L. Comparing the effect of four different thermal modifications on physicochemical and pasting properties of breadfruit (*Artocarpus altilis*) starch. Int Food Res J. 2019;26(1):269–76.

17. Wang D, Fan DC, Ding M, Ge PZ, Zhou CQ. Characteristics of different types of starch in starch noodles and their effect on eating quality. Int J Food Prop. 2015;18(11):2472–86.
18. Nwokocha LM, Williams PA. Comparative study of physicochemical properties of breadfruit (*Artocarpus altilis*) and white yam starches. Carbohydr Polym [Internet]. 2011;85(2):294–302. https://doi.org/10.1016/j.carbpol.2011.01.050
19. Román L, Martínez MM, Rosell CM, Gómez M. Effect of microwave treatment on physicochemical properties of maize flour. Food Bioproc Tech. 2015;8(6):1330–5.
20. Villanueva M, Harasym J, María Muñoz J, Ronda F. Microwave absorption capacity of rice flour. Impact of the radiation on rice flour microstructure, thermal and viscometric properties. Food Hydrocoll. 2018;224:156–64.
21. Villanueva M, Harasym J, Ma Muñoz J, Ronda F. Rice flour physically modified by microwave radiation improves viscoelastic behavior of doughs and its bread-making performance. Food Hydrocoll. 2019;90:472–81.
22. Cui R, Zhu F. Effect of ultrasound on structural and physicochemical properties of sweetpotato and wheat flours. Ultrason Sonochem. 2020;66:105118. https://doi.org/10.1016/j.ultsonch.2020.105118
23. Qin W, Xi H, Wang A, Gong X, Chen Z, He Y, et al. Ultrasound treatment enhanced semidry-milled rice flour properties and gluten-free rice bread quality. Molecules. 2022;27(17):5403. https://doi.org/10.3390/molecules27175403
24. Vela AJ, Villanueva M, Solaesa GA, Ronda F. Impact of high-intensity ultrasound waves on structural, functional, thermal and rheological properties of rice flour and its biopolymers structural features. Food Hydrocoll. 2021;113(1):106480. https://doi.org/10.1016/j.foodhyd.2020.106480
25. Zhang H, Chen G, Liu M, Mei X, Yu Q, Kan J. Effects of multi-frequency ultrasound on physicochemical properties, structural characteristics of gluten protein and the quality of noodle. Ultrason Sonochem. 2020;67:105135. https://doi.org/10.1016/j.ultsonch.2020.105135
26. Thu TTM, Ngoc NTB, Linh TTT, Phuong LVL, Thu NTN, Nhu YNT. Study the effect of pre-treatment condtitions on the peroxidase enzyme activity and quality of breadfruit (*Artocarpus altilis*) flours. Vietnam J Agricult Rural Dev. 2022;445:54–61.
27. American Association of Cereal Chemists. Approved Methods Committee. Approved methods of the American association of cereal chemists (Vol. 1). American Association of Cereal Chemists; 2000.
28. Srikaeo K, Laothongsan P, Lerdluksamee C. Effects of gums on physical properties, microstructure and starch digestibility of dried-natural fermented rice noodles. Int J Biol Macromol. 2018;109:517–23. https://doi.org/10.1016/j.ijbiomac.2017.12.121
29. Pathare PB, Opara UL, Al-Said FAJ. Colour measurement and analysis in fresh and processed foods: a review. Food Bioproc Tech. 2013;6(1):36–60.
30. Otemuyiwa IO, Aina AF. Physicochemical properties and in-vitro digestibility studies of microwave assisted chemically modified breadfruit (*Artocarpus altilis*) starch. Int J Food Prop. 2021;24(1):140–51.
31. Lewandowicz G, Jankowski T, Fornal J. Effect of microwave radiation on physico-chemical properties and structure of cereal starches. Carbohydr Polym. 2000;42(2):193–9.
32. Mehta KA, Quek YCR, Henry CJ. Breadfruit (*Artocarpus altilis*): processing, nutritional quality, and food applications. Front Nutr. 2023;10:1156155. https://doi.org/10.3389/fnut.2023.1156155
33. Jones AMP, Ragone D, Tavana NG, Bernotas DW, Murch SJ. Beyond the bounty: breadfruit (*Artocarpus altilis*) for food security and novel foods in the 21st Century. Ethnobotany Res Appl. 2011;9:129–49.
34. Han HM, Cho JH, Koh BK. Processing properties of Korean rice varieties in relation to rice noodle quality. Food Sci Biotechnol. 2011;20(5):1277–82.
35. Xue C, Sakai N, Fukuoka M. Use of microwave heating to control the degree of starch gelatinization in noodles. J Food Eng. 2008;87(3):357–62.
36. Huang S, Martinez MM, Bohrer BM. The compositional and functional attributes of commercial flours from tropical fruits (Breadfruit and Banana). Foods. 2019;8(11):586. https://doi.org/10.3390/foods8110586
37. Rao MV, Akhil K, Sunil C, Venkatachalapathy N, Jaganmohan R. Effect of microwave treatment on physical and functional properties of foxtail millet flour. Int J Chem Stud. 2021;9(1):2762–7.

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