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Research Article

Effect of Mulberry Leaf Tea on Texture, Microstructure, Starch Retrogradation, and Antioxidant Capacity of Rice Noodles

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The effect of mulberry leaf tea (MT) on texture, microstructure, starch retrogradation, and antioxidant capacity of rice noodles was investigated. Addition of MT powder at 5 to 25% increased protein, fiber, and antioxidant capacity of rice noodles. The presence of phenolic compounds in MT enhanced firmness and elongation of rice noodles, while fiber disrupted the noodle microstructure, resulting in lower firmness and elongation at high concentration. MT noodles kept for 7 days at 4°C had total phenolic content and antioxidant capacity 7 times and 5 times higher than the control rice noodles at day 0, respectively. Addition of MT reduced the retrogradation enthalpy of rice flour and retarded increase in firmness and decrease in elongation of rice noodles during storage. Addition of MT improved the nutritional benefits and antioxidant capacity of rice noodles and also the textural properties during storage.

1. Introduction

Rice noodles are an important staple food, especially in Asia. Recently, the demand for gluten-free noodles with more nutrition such as high protein, fiber, and antioxidant nutrients has increased among worldwide consumers. From the nutrition viewpoint, rice noodles contain lower protein than wheat noodles. In addition, rice noodles have low fiber, phytonutrients, and antioxidant contents. Many ingredients are added to rice noodles to improve their nutrition such as buckwheat for fiber and protein [1], rice bran for fiber [2], and matcha for polyphenols [3].

Mulberry leaves contain high protein (18.41-24.63%), fiber (8.17-10,11%), and minerals (8.91-11.73%) but low fat (4.24-6.57%) [4]. Mulberry leaves also contain major phenolic compounds including 5-*O*-caffeoylquinic acid, 4-*O*-caffeoylquinic acid, and quercetin-3-*O*-rutinoside [5]. These phenolic compounds in mulberry leaves have many pharmacological activities such as anti-inflammatory [6], antiobesity [7], and antidiabetic properties [8]. Nevertheless, the use of mulberry leaves as human food is limited and occurs mostly as mulberry leaf tea (MT), which is popular in China, Thailand, Japan, Korea, and European countries due to its health benefits. Addition of MT in rice noodles improves the nutritional benefits. However, MT is high in phenolic compounds that may affect the quality of rice noodles, especially the texture.

Phenolic compounds interact with both protein and starch to alter the properties of wheat noodles and rice noodles. Han et al. [9] reported that green tea polyphenols improved dough stability, resistance, and chewiness of wheat noodles by promoting hydrogen bonding and hydrophobic interactions, SH/SS interchange reactions, and aggregation of molecular chains. The effect of tea polyphenols on noodle quality depended on addition levels, form, and type of noodles [10]. Using 2% green tea, black tea, or oolong tea reduced hardness, cohesiveness, chewiness, resilience, and tensile strength of white salted noodles but increased these properties in yellow alkaline noodles. Information about the effect of polyphenols on rice noodle properties is limited. Rice noodles added with immature persimmon juice had higher breaking strength and breaking strain due to interaction between the tannin in persimmon and the carbonyl group of proteins through hydrogen bonding [11], while interaction between soy protein isolate and polyphenol from ogaja increased tensile properties and decreased cooking loss of rice noodles [12]. Matcha polyphenols interacted with starch and protein in rice noodles resulting in low-ordered crystalline structure and dense microstructure, while matcha-fortified rice noodles (0.5-2% matcha powder) had higher chewiness and stretchability [3].

Previous studies also reported that green tea polyphenols retarded starch retrogradation in wheat starch [13] and rice starch [14, 15] because OH groups in the polyphenols associated with OH groups in the starch molecules and interfered with the starch polymer chain alignment.

Several high-fiber ingredients such as mushrooms [16], oat bran, whole barley flour, and resistant starch [17], and rice bran [2] have been added to improve noodle nutrition. However, adding inappropriate amounts of fiber caused poor cooking and eating quality of noodles because the excess fiber interrupted the formation of gluten networks in wheat noodles [16, 18] and the formation of amylose networks in rice noodles [2].

MT is rich in phenolic compounds and fiber. The high phenolic content may enhance the formation of strong rice noodle structure and retard the retrogradation of rice noodles during storage, while the high fiber of MT may interfere with the formation of amylose network, resulting in weak noodle structure and poor cooking quality. To the best of our knowledge, no reports have been published detailing the effects of MT polyphenols and fiber on rice noodle quality.

This study investigated the effect of MT addition on texture, starch retrogradation, antioxidant capacity, and microstructure of rice noodles. Effects of the phenolic compounds and fiber in MT on the texture and microstructure of rice noodles were also compared. The impact of MT on starch retrogradation inhibition was observed firstly using differential scanning calorimetry (DSC). The antioxidant capacity and texture of rice noodles during storage at 4°C were also examined. Our results will assist the production of fortified MT rice-based products by food manufacturers.

2. Materials and Methods

2.1. Materials. Rice flour was prepared from high-amylose rice grain (Chai Nat1 variety) using a wet-milling process, following Sangpring et al. [19]. Rice flour samples were packed in polyethylene bags, sealed, and kept at -20°C until use.

Commercial mulberry leaf tea from Buriram 60 cultivar was purchased from a local company (Nopparat Company, Kanchanaburi, Thailand). The mulberry leaf tea was ground using a pin mill (Bonny YPT-302S, Yor Yong Hah Heng Ltd., Bangkok, Thailand), sieved, packed in aluminum bags, vacuum sealed, and kept at -20°C until use.

2.2. Methods

2.2.1. Preparation of Fresh Mulberry Leaf Tea Noodles. The MT powder was mixed with rice flour at 5, 10, 15, 20, or 25 g/100 g rice flour. Then, the mixture was mixed with distilled water, and the moisture content was adjusted to 64% wet basis. The slurry was steamed to form a noodle sheet and cut into 1.7 mm width noodle strands following the method of Klinmalai et al. [20]. Total phenolic content, antioxidant capacity, and textural properties of the fresh noodles were immediately measured after preparation.

To study changes in texture and antioxidant activity during storage, fresh rice noodles with 10 g MT powder/100 g rice flour were prepared as mentioned above. The noodles were packed in aluminum foil pouches and stored at 4°C for 7 days. The chilled noodles were then measured for total phenolic content, antioxidant activities, and textural properties at 0, 1, 3, 5, and 7 days of storage.

To verify the effects of phenolic compounds and fiber in MT powder on the texture of rice noodles, MT rice flour noodles were prepared by adding the MT extract separately from the MT residue. The MT extract was prepared by soaking 6 g of MT powder in 60 g of distilled water for 2 h. Then, the mixture was centrifuged at 10,000 g, 4°C for 15 min. The supernatant was added to 40 g of rice flour to prepare fresh noodles as described above. The MT residue was prepared by soaking 6 g of MT powder in 60 g of 80% methanol for 2 h, before centrifuging and soaking in distilled water for 2 h, 2 times and dried at 105°C for 2 h. The dried residue was used to prepare 15 g of MT residue/100 g flour fresh noodles as described above.

2.2.2. Proximate Analysis. Moisture, crude protein, crude fat, crude ash, and crude fiber contents of the mulberry leaf tea noodles were determined by AACC methods 44-20, 46-12, 3025, 0801, and 32-10, respectively [21].

2.2.3. Total Phenolic Content and Antioxidant Capacity. The MT noodles were extracted following the method of Pothinuch and Tongchitpakdee [5] with some modifications. Five grams of MT noodles were mixed with 10 ml of 80% methanol using a homogenizer (Disperser T10 basic, IKA®-Werke GMBH & COKG, Staufen, Germany) for 2 min on ice, and then kept in an icebox for 1 h before extraction for 15 min using an ultrasonicator (Ultrasonicator Powersonic™ ultrasonic cleaner, Chest Ultrasonics, Penang, Malaysia). The suspension was centrifuged at 10,000 g for 15 min at 4°C, and the supernatant was collected. The residue was reextracted with another 10 ml of 80% methanol. The supernatants were combined, adjusted to a volume of 25 ml, and filtrated through no. 1 Whatman filter paper. The extract was kept at -20°C until measurement.

The total phenolic content of each extract was determined using the Folin-Ciocalteu method according to Wolfe and Liu [22], with results expressed in mg of gallic acid equivalent (GAE)/100 g dry sample.

The DPPH radical scavenging activity of rice noodles was determined according to Brand-Williams et al. [23], with results expressed in mg of Trolox equivalent/100 g dry sample.

The oxygen radical absorbance capacity-fluorescence assay (ORAC) was conducted according to the method of Prior et al. [24], with results expressed in μM Trolox equivalent (TE)/g dry sample.

2.2.4. Texture Measurement. Firmness of the MT noodles was measured following AACC method 66-50 [21] using a texture analyser TA.XTplus, Stable Micro Systems, Surrey, UK, using a light knife blade (A/LKB) probe at 70% strain and test speed of 0.2 mm/s.

Tensile testing of the MT noodles was conducted according to Puhin et al. [25] using a texture analyser with a spaghetti tensile grip (A/SPR) probe at a test speed of 3 mm/s. Tensile strength (kPa)and elongation at break (%) were calculated according to equations (1) and (2).

$$\text{Tensile strength} = \frac{\text{Maximum force at break}}{\text{Cross-section area of noodle}}, \tag{1}$$

$$\%\text{Elongation} = \frac{\text{Extended distance at break(mm)}}{\text{Initial distance(mm)}} \times 100. \tag{2}$$

The chilled MT rice noodles were kept at room temperature for 30 min and then boiled in water at 100°C for 10 s before textural measurement, as described above.

2.2.5. Scanning Electron Microscopy (SEM). Fresh MT rice noodles were dried using a freeze dryer (GAMMA 2-16 LSC, Martin Christ, Osterode am Harz, Germany). The dried noodles were placed on a stub and coated with gold palladium at 10 nm thickness. The microstructure of the MT rice noodles was observed under a scanning electron microscope (Quanta 450, FEI, Oregon, USA) at 100x magnification with an accelerated voltage of 10 kV.

2.2.6. Retrogradation Properties. Retrogradation of rice flour with MT powder was analyzed using a differential scanning calorimeter (DSC1 STAR System, Mettler Toledo, Greifensee, Switzerland). The rice flour and MT powder were mixed at ratio 10 : 1 (based on flour weight). The mixture was accurately weighed into a stainless pan (120 μl). Distilled water was added to adjust the moisture content to 64%. The pan containing the sample was sealed and equilibrated at room temperature for 2 h before analysis. An empty stainless pan was used as a reference. Then, the sample was heated from 30°C to 130°C with heating rate of 5°C/min. After heating, the pan with the sample was stored at 4°C for 1 and 7 days, and then rescanned under the same conditions. The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c), and amylopectin retrogradation enthalpy (ΔH_R) of the first peak were determined. This experiment was conducted at least in duplicate.

To investigate the effects of phenolic compounds in the MT extract on the retrogradation properties of rice flour, three concentrations of MT extracts were prepared as follows. One, two, or four gram of MT powder was mixed with 60 g of distilled water in order to prepare 1.67%, 3.33%, and 6.67% w/w for 2 h. Then, the mixtures were centrifuged at 4°C, 10,000 g for 15 min. Each supernatant was separated and used instead of distilled water for the measurement of starch retrogradation, as mentioned above. Total phenolic contents in the MT extracts were 6.98 ± 0.31, 13.84 ± 0.23, and 22.01 ± 0.93 mg GAE/100 g water for the 1.67%, 3.33%, and 6.67% w/w samples, respectively. The amount of phenolic compounds in these systems was assumed to be equal to the amount of phenolic compounds in 2.5%, 5%, and 10% MT rice noodles, respectively.

2.2.7. Statistical Analysis. The means of all results were compared using analysis of variance (ANOVA). Duncan's multiple range test was used to determine significant differences among the treatments ($p \leq 0.05$) using SPSS version 27.0 for Windows software.

3. Results and Discussion

3.1. Composition and Antioxidant Activity of Mulberry Leaf Tea Noodles. Protein, fat, ash, and crude fiber of rice flour were 7.16 ± 0.09%, 0.20 ± 0.01%, 0.19 ± 0.01%, and 0.31 ± 0.01%, respectively. By contrast, protein, fat, ash, and crude fiber of MT were 30.81 ± 0.34%, 3.46 ± 0.17%, 10.62 ± 0.02 %, and 11.49 ± 0.29%, respectively. Protein and crude fiber contents of MT were several times higher than rice flour, and addition of MT dramatically increased protein and crude fiber in rice noodles (Table 1). Addition of MT increased crude fiber content by 5-8 times compared with the 0% rice noodles, with levels of mulberry leaf tea from 5 to 25%. Addition of MT increased the protein content of noodles 1.16-1.55 times from 0% rice noodles. The protein content of MT rice noodles increased to as high as wheat flour noodles (7-9% for Japanese white salted noodles and 11-11.5% for alkaline noodles) [26].

MT showed high total phenolic content at 478.23 ± 8.53 mg GAE/100 g dry sample due to abundant phenolic compounds [5] with high antioxidant capacity of 617.12 ± 33.76 mg TE/100 g dry sample in DPPH and 3,264.13 ± 128.77 μM TE/g dry sample in ORAC. Addition of mulberry leaf tea (5-25%) increased the total phenolic content (3.83-13.5 times), DPPH radical scavenging activity (3.06-11.82 times), and ORAC (5.84-6.38 times) of rice noodles (Table 1). Therefore, adding mulberry leaf tea to rice noodles improved both nutrition and antioxidant capacity.

3.2. Texture of Mulberry Leaf Tea Noodles. Textural properties of noodle added with 5-25% MT are shown in Table 1. Firmness of rice noodles decreased with increase in MT (Table 1). Moreover, tensile strength and %elongation of rice noodles increased with addition of MT up to 5% and then decreased with mulberry leaf tea higher than 10%. These results showed that the noodle structure became stronger with addition of MT. The results agreed with Li et al. [3] who reported that hardness, tensile strength, and extensibility of rice noodles increased with addition of matcha (tea powder) due to tea polyphenols-protein-starch interaction supporting the formation of a more stable noodle structure.

Table 1: Proximate analysis, total phenolic content, antioxidant activity, and textural properties of fresh mulberry leaf tea noodles.

Amount of mulberry leaf tea (%)	Protein (% dry basis)	Fat (% dry basis)	Ash (% dry basis)	Fiber (% dry basis)	Total phenolic content (mg GAE/100 g dry sample)	DPPH (mg TE/100 g dry sample)	ORAC (μM TE/g dry sample)	Firmness (kPa)	Tensile strength (kPa)	Elongation (%)
0	7.31 ± 0.22^{f}	0.0191 ± 0.0126^{f}	0.23 ± 0.02^{f}	0.30 ± 0.01^{f}	7.02 ± 0.70^{f}	13.85 ± 2.00^{f}	194.45 ± 25.01^{b}	289.17 ± 18.98^{a}	79.90 ± 0.78^{bc}	73.60 ± 0.37^{c}
5	8.49 ± 0.01^{e}	0.0339 ± 0.0007^{e}	0.82 ± 0.01^{e}	1.69 ± 0.02^{e}	26.90 ± 0.69^{e}	42.51 ± 2.90^{e}	1135.86 ± 137.46^{a}	264.67 ± 10.91^{cb}	88.82 ± 1.17^{a}	83.43 ± 1.21^{b}
10	9.42 ± 0.03^{d}	0.0454 ± 0.0020^{d}	1.23 ± 0.01^{d}	1.85 ± 0.02^{d}	51.94 ± 1.48^{d}	83.59 ± 3.07^{d}	1176.37 ± 53.30^{a}	243.49 ± 17.86^{bc}	81.50 ± 1.54^{b}	73.46 ± 0.08^{c}
15	10.08 ± 0.01^{c}	0.0832 ± 0.0017^{c}	1.63 ± 0.02^{c}	2.01 ± 0.01^{c}	68.80 ± 1.09^{c}	103.92 ± 1.92^{c}	1202.94 ± 129.69^{a}	236.28 ± 11.40^{c}	78.41 ± 1.27^{c}	63.37 ± 1.49^{d}
20	10.63 ± 0.05^{b}	0.1179 ± 0.0098^{b}	1.92 ± 0.01^{b}	2.20 ± 0.01^{b}	80.68 ± 1.31^{b}	124.68 ± 3.72^{b}	1221.77 ± 65.24^{a}	213.36 ± 2.82^{d}	71.73 ± 0.85^{d}	50.01 ± 0.89^{e}
25	11.34 ± 0.07^{a}	0.1508 ± 0.0062^{a}	2.36 ± 0.03^{a}	2.46 ± 0.07^{a}	95.40 ± 0.95^{a}	163.78 ± 3.22^{a}	1241.14 ± 50.77^{a}	191.74 ± 8.58^{e}	66.01 ± 0.69^{e}	39.65 ± 0.59^{f}

Values are mean ± S.D. of three independent determinations. $^{a, b, \text{and } c}$: mean values followed by the same letter in the same column are significantly different ($p \leq 0.05$).

Table 2: Texture and total phenolic content of fresh rice noodles added with mulberry leaf tea extract and mulberry leaf tea residue.

Sample	Firmness (kPa)	Tensile strength (kPa)	Elongation (%)	Total phenolic content (mg GAE/100 g dry sample)
0% MT noodles	289.17 ± 18.98^{b}	79.90 ± 0.78^{b}	73.60 ± 0.43^{b}	7.02 ± 0.70^{c}
15% MT noodles	236.28 ± 11.40^{c}	78.41 ± 1.27^{b}	65.37 ± 1.49^{c}	58.26 ± 0.50^{b}
MT extract noodles	394.66 ± 14.29^{a}	83.52 ± 0.07^{a}	81.22 ± 1.07^{a}	60.31 ± 0.85^{a}
MT residue noodles	201.94 ± 2.96^{d}	76.83 ± 2.8^{c}	63.44 ± 0.29^{d}	7.88 ± 0.12^{c}

$^{a, b, \text{and } c}$: mean values followed by the same letter in the same column are significantly different ($p \leq 0.05$).

However, at higher amounts of MT, decrease in firmness, tensile strength, and %elongation occurred, indicating weaker noodle structure. The presence of fiber in MT may interrupt the noodle structure formation. The results concurred with Makhlouf et al. [17] who reported that fiber from barley, oat bran, and resistant starch reduced the firmness of pasta.

To prove whether the structure of rice noodles became weaker due to the presence of fiber, three kinds of sample that were noodles with MT powder, noodles with MT extract, and noodles with MT residue were prepared for a comparison in their texture and microstructure (SEM). The noodles with MT powder were a representative for noodle contained both of phenolic compounds and fiber. On the other hand, noodles with MT residue and noodles with MT extract were representatives for noodle contained only fiber or only phenolic compounds, respectively. The concentration of MT powder was chosen at 15% because the elongation of noodles started to decrease at this concentration as shown in Table 1. The MT extract was prepared by extracting MT powder with water by using the same ratio between water and MT powder (6 g MT powder/60 g water) and soaking time for preparing rice slurry for 15% MT noodles. Therefore, MT extract was rich in water soluble phenolic compounds without any fiber. Then, MT extract was used to prepared rice noodles at concentration which MT extract-rice noodles contained the same amount of phenolic compound with 15% MT noodles as shown in Table 2. The MT residue was prepared by washing MT powder with 80% ethanol following by washing with distilled water 2 times, so only fiber was assumed to left in this MT residue. The MT residue was used to prepared rice noodles at 15 g MT residue/100 g flour which contained the same amount of fiber with 15% MT powder noodles. The phenolic compounds in MT residue were similar to 0% MT noodles (Table 2), so it proved that there were no phenolic compounds from MT in MT residue noodles, and there was only fiber from MT.

The MT extract noodles had higher firmness, tensile strength, and %elongation than 0% MT noodles (Table 2). Moreover, the MT extract noodles had a smooth surface and fine internal structure (Figures 1(c) and 1(g)), possibly attributed to interaction between MT phenolic compounds and the protein in rice flour. Li et al. [3] reported that addition of matcha (tea powder) enhanced the formation of tea polyphenols-protein-starch networks, resulting in higher stretchability and dense microstructure of rice noodles. Han et al. [9] also reported that tea polyphenols induced the formation of hydrogen bonds and hydrophobic interactions of gluten networks in wheat noodles, which reflected the continuously developed noodle structure. The tea polyphenols also increased the hardness, chewiness and springiness of wheat noodles. In this study, the presence of MT phenolic compounds enhanced the firmness and elasticity of rice noodles. By contrast, fiber residues (arrows in Figures 1(d) and 1(h)) interrupted the noodle structure, resulting in disintegration and weakness. This result concurred with lower firmness, tensile strength, and elongation of MT residue noodles than 0% MT noodles (Table 2).

The microstructure of 15% MT noodles (Figures 1(b) and 1(f)) was rougher than MT extract noodles, and some fiber residues were visible, while firmness, tensile strength, and %elongation of 15% MT noodles were similar to MT residue noodles. Thus, the inferior texture of 15% MT rice noodles was attributed to the presence of excess fiber.

The presence of phenolic compounds in MT enhanced the formation of a strong noodle structure, while the presence of fiber interrupted the formation of the noodle structure. Hence, the amount of fiber was a limiting factor when adding MT to rice noodles.

3.3. Effect of Mulberry Leaf Tea on Starch Retrogradation. The noodles with 10% MT powder were chosen for studying the effect of MT powder on starch retrogradation inhibition in rice noodles because it was the most acceptable concentration form sensory test (data not shown). At day 1, onset temperature (T_o), peak temperature (T_p), and conclusion temperature (T_c) of 0% MT powder and 10% MT powder were not significantly different (Table 3). This result indicated that the presence of MT powder had no effect on the homogeneity of recrystallized amylopectin in samples. However, the retrogradation enthalpies of amylopectin (ΔH_R) of 10% MT powder were significantly lower than 0% MT powder. On day 7, the ΔH_R of 10% MT powder was still lower than 0% MT powder, and the amount of ΔH_R was similar of day 1.This indicated that the MT powder retarded starch retrogradation of rice flour during storage. This may be attributed to the phenolic compounds in MT powder. This result concurred with Wu et al. [14] and Xiao et al. [15] for retrogradation inhibition of green tea polyphenol. Wu et al. [14] explained that the OH groups of the phenolic compounds interacted with the OH groups of starch and interfered with the alignment of starch polymer chains.

In order to prove that the phenolic compounds in MT was attributed to the inhibition of starch retrogradation in rice noodles, three concentrations of MT extract (1.67%,

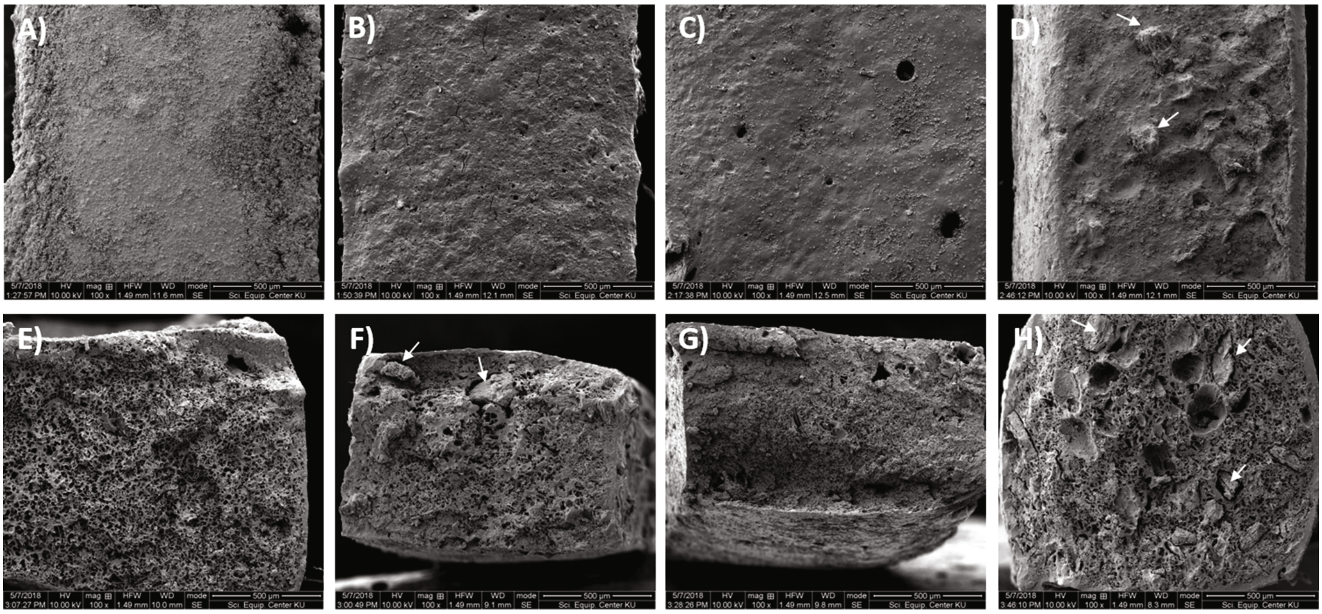

Figure 1: Microstructure of mulberry leaf tea rice noodles observed under a scanning electron microscope (SEM) at 100x. (a) surface of 0% MT rice noodles; (b) surface of 15% MT rice noodles; (c) surface of rice noodles with MT extract; (d) surface of rice noodles with MT residue; (e) cross-section of 0% MT rice noodles; (f) cross-section of 15% MT rice noodles; (g) cross-section of rice noodles with MT extract; (h) cross-section of rice noodles with MT residue. Arrows indicate fiber residues.

Table 3: Thermal properties of amylopectin retrogradation in rice flour with MT powder or MT extract.

Samples	Storage time (day)	T_o (°C)	T_p (°C)^{ns}	T_c (°C)	ΔH_R (J/g flour)
0% MT powder	1	50.75 ± 0.04^b	59.18 ± 1.07	65.63 ± 0.49^a	0.3100 ± 0.07^a
10% MT powder	1	51.95 ± 2.81^b	60.35 ± 0.31	65.58 ± 0.50^a	0.0935 ± 0.02^b
0% MT powder	7	50.84 ± 0.81^b	59.62 ± 0.27	63.05 ± 0.74^b	0.2750 ± 0.02^a
10% MT powder	7	52.36 ± 0.01^b	58.97 ± 0.46	63.30 ± 0.35^b	$0.0720 \pm 0.01b^c$
1.67% MT extract	7	57.32 ± 0.18^a	60.05 ± 0.45	61.60 ± 1.91^b	$0.0243 \pm 0.01b^c$
3.33% MT extract	7	56.81 ± 0.79^a	59.91 ± 0.13	62.15 ± 0.01^b	0.0167 ± 0.01^c
6.67% MT extract	7	57.11 ± 0.05^a	60.19 ± 1.45	61.99 ± 0.04^b	0.0095 ± 0.00^c

^{a,b,c}: mean values followed by the same letter in the same column are significantly different ($p \leq 0.05$). ns: means no significant difference among samples ($p > 0.05$).

3.33%, and 6.67%) which contained phenolic compounds from MT powder were prepared and added into rice flour for starch retrogradation measurement. The amount of phenolic compounds in rice flour-MT extract slurry was measured as shown in Table 4. The amount of phenolic compounds in MT extract sample increased with the increase of MT extract concentration, and they were close to the amount of phenolic compounds in 10% MT powder sample. The starch retrogradation inhibition of MT extract in rice flour is shown in Table 3. At 7 days of storage, onset temperatures (T_o) of samples with MT extract were higher than 0% MT powder, and $T_c - T_o$ of samples with MT extracts were narrower than 0% MT powder. This result indicated that recrystallized amylopectin in samples with MT extract was more homogenized and stable than 0% MT powder. Onset temperatures (T_o) of samples with MT powder were lower than samples with MT extract, while $T_c - T_o$ of samples with MT powder was broader than samples with MT extract. This result indicated that the recrystallized amylopectin in samples with MT powder was less homogeneous, attributed to the presence of fiber in MT powder that altered the homogeneity of the system.

Table 4: Total phenolic content in 10% MT powder rice flour slurry and MT extract-rice flour slurry for DSC measurement.

Samples	Total phenolic content (mg GAE/100 g dry sample)
0% MT rice flour slurry	ND
10% MT powder rice flour slurry	39.21 ± 1.67^b
1.67% MT rice flour slurry	31.15 ± 1.05^c
3.33% MT rice flour slurry	38.94 ± 0.88^b
6.67% MT rice flour slurry	44.31 ± 1.09^a

^{a,b,c}: mean values followed by the same letter in the same column are significantly different ($p \leq 0.05$). ND: means are not detectable.

Table 5: Textural properties, total phenolic content, and antioxidant of mulberry leaf tea rice noodles during storage at 4°C for 7 days.

Storage time (day)	Firmness of uncooked noodles (kPa)		Firmness of cooked noodles (kPa)		Tensile strength of cooked noodles (kPa)		Elongation of cooked noodles (%)		Total phenolic content (mg GAE/100 g dry sample)		DPPH (mg TE/100 g dry sample)		ORAC (μM TE/g dry sample)	
	0% MT powder	10% MT powder	0% MT powder	10% MT powder	0% MT powder	10% MT powder	0% MT powder	10% MT powder	0% MT powder	10% MT powder	0% MT powder	10% MT powder	0% MT powder	10% MT powder
0	291.17 ± 4.06^{eA}	265.00 ± 5.567^{eB}	101.76 ± 3.23^{eA}	48.85 ± 2.13^{dB}	62.48 ± 0.75^{aA}	52.49 ± 1.51^{aB}	52.92 ± 0.03^{aA}	45.90 ± 0.90^{aB}	5.01 ± 0.69^{a}	51.77 ± 0.46^{a}	10.75 ± 1.27	90.87 ± 1.12^{a}	194.45 ± 25.01^{a}	1176.37 ± 53.30^{a}
1	770.10 ± 2.07^{dA}	712.56 ± 7.18^{dB}	151.51 ± 1.33^{dA}	127.91 ± 2.71^{cB}	48.96 ± 0.51^{bA}	43.09 ± 2.16^{bcB}	37.13 ± 1.03^{cA}	32.01 ± 1.36^{dB}	2.18 ± 0.96^{b}	46.50 ± 0.95^{b}	ND	89.42 ± 1.09^{b}	84.55 ± 10.49^{b}	748.09 ± 37.78^{b}
3	946.57 ± 4.44^{cA}	876.49 ± 7.67^{cB}	154.36 ± 1.32^{cA}	145.11 ± 1.30^{bB}	42.40 ± 0.46^{dA}	42.38 ± 1.39^{bcA}	28.30 ± 0.03^{dB}	32.77 ± 0.57^{dA}	ND	44.88 ± 0.95^{c}	ND	76.75 ± 1.66^{c}	81.94 ± 19.40^{b}	744.66 ± 46.26^{b}
5	1038.52 ± 1.13^{bA}	960.68 ± 6.58^{bB}	158.72 ± 1.11^{bA}	150.00 ± 1.94^{aB}	43.20 ± 0.47^{dA}	40.73 ± 0.41^{cA}	35.48 ± 0.62^{cB}	37.69 ± 1.21^{cA}	ND	43.91 ± 0.59^{c}	ND	68.78 ± 1.45^{d}	73.55 ± 9.20^{b}	679.12 ± 60.98^{c}
7	1222.76 ± 4.02^{aA}	1064.48 ± 3.73^{aB}	163.18 ± 1.00^{aA}	152.75 ± 2.01^{aB}	47.21 ± 0.64^{cA}	44.99 ± 0.45^{bA}	39.50 ± 0.15^{bA}	40.70 ± 0.35^{bA}	ND	36.41 ± 0.84^{d}	ND	54.98 ± 1.68^{e}	73.57 ± 11.71^{b}	562.56 ± 44.58^{d}

^{a,b,c}: means in the same column followed by different letters are significantly different ($p \leq 0.05$). ^{A,B,C}: means in the same row followed by different letters are significantly different ($p \leq 0.05$).

The ΔH_R of all samples with MT extracts was lower than 0% MT powder. Nevertheless, the range of MT extract concentration had no influence on the amount of enthalpy of ΔH_R. This indicated that the MT extracts retarded starch retrogradation of rice flour. This may be attributed to the phenolic compounds in MT extracts. This result was similar to sample with 10% MT powder (Table 3). Therefore, this result supported that the presence of phenolic compounds in MT powder retarded the starch retrogradation in rice flour.

3.4. Changes in Texture, Total Phenolic Content, and Antioxidant Activity of Mulberry Leaf Tea Noodles during Storage. Firmness and tensile strength of all samples increased, while %elongation decreased with increasing storage (Table 5). This indicated that starch retrogradation occurred during storage. However, the rate of increase in firmness and tensile strength and decrease in elongation of 10% MT noodles were slower than the control, attributed to the presence of phenolic compounds in MT powder that retarded amylopectin retrogradation. Therefore, MT noodles were softer and more elastic, with superior texture to the control after storage.

Total phenolic content and antioxidant capacity of MT noodles were enhanced by 5-*O*-caffeoylquinic acid, 4-*O*-caffeoylquinic acid, and quercetin-3-*O*-rutinoside, which are major phenolic compounds in mulberry leaves [5]. The stability of these phenolic compounds depends on many factors including oxygen value, pH, UV light, and temperature [27, 28]. Results showed that total phenolic content and antioxidant capacity of MT noodles decreased during storage. After 7 days of storage at 4°C, MT noodles retained 70% of the total phenolic content, 60% of DPPH scavenging activity, and 50% of ORAC compared to the initial sample at day 0. On day 7, the MT noodles had approximately 5 and 7 times higher total phenolic content and antioxidant capacity, respectively, compared to the control noodle (0% MT) at day 0.

Decrease in total phenolic content and antioxidant capacity in MT noodles during storage in an aluminum foil pouch at low temperature (4°C) was attributed to the oxidative degradation of phenolic compounds such as quercetin in the presence of oxygen [27]. Similar results in the degradation of quercetin, which is a major phenolic compound in MT, during storage at low temperature (4-20°C) in darkness were reported in many products such as onion, strawberry juice, and raspberry jam [28].

4. Conclusions

Addition of MT improved the nutrition of rice noodles, especially protein, fiber, and antioxidant capacity. The abundant of phenolic compounds in MT enhanced firmness and elongation of rice noodles, while fiber disrupted the noodle microstructure, resulting in lower firmness and elongation at high MT concentration. Therefore, a balance between the amount of phenolic compounds and fiber should be considered to achieve good quality rice noodles. Adding higher amounts of MT powder may also require the incorporation of other additives such as hydrocolloids, gum, and proteins. Further studies on how these additives impact the quality of MT noodles are needed. Addition of MT reduced the retrogradation enthalpy of rice flour, while the rate of increase in firmness and decrease in elongation of MT noodles were retarded during storage at 4°C due to the retrogradation inhibitory effect of phenolic compounds in MT. The MT rice noodles kept for 7 days had total phenolic content and antioxidant capacity 7 times and 5 times higher than the control at day 0, respectively. Therefore, the presence of MT improved the nutrition of rice noodles and also improved textural properties during storage.

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflict of interest in this work.

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