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Microwave- and Oven-Heat Moisture Treatment of Broken Rice Flour and the Improvement in Flat Rice Noodle Quality

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ABSTRACT

The characteristics of starch used in the production of rice noodles greatly influenced the product quality. Some rice noodle varieties are made from rice flour, which is typically derived from broken rice grains. Broken rice flour has been associated with a higher level of starch damage that could adversely affect the cooking, textural, and eating qualities of noodles. Hydrothermal treatments have been proposed as a technique for improving starch functionality. This study aims to investigate the effect of different techniques employed in heat moisture treatment (HMT) applied to broken rice (MR263) and their impact on flat rice noodle quality. Rice flour adjusted to 20% moisture content was subjected to two HMT techniques; oven-heat moisture treatment (O-HMT) at 110°C for 3 h and microwave-heat moisture treatment (M-HMT) at 119 W for 5 min. HMT reduced the swelling capacity and solubility of the flour. M-HMT flour had the lowest swelling capacity, whereas O-HMT flour exhibited the lowest solubility. The oven-HMT reduced the L* and whiteness index values of both rice flour and noodles, whereas the microwave-HMT recorded comparable color parameters as the non-treated samples. HMT improved the cooking quality of flat rice noodles, resulting in lower water absorption and cooking loss. Noodles made with oven-treated flour had the lowest cooking loss, whereas the microwave-treated flour resulted in noodles with the lowest water absorption. O-HMT produces noodles with greater improvement in gel texture. Despite the reduced whiteness of the O-HMT noodle, it received higher consumer acceptance in terms of appearance, color, flavor, and hardness. Heat moisture treatment can be used as an economical viable technique for enhancing the quality of flat rice noodles. The varying noodle quality resulting from both oven- and microwave-HMT is attributed to a distinct degree of molecular changes in the starch components, which eventually impact the overall product quality.

1. Introduction

Rice noodles are one of the most popular foods widely consumed in Southeast Asia. The characteristics of the noodles are influenced by the flour composition and the properties of the starch

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granules. Long grain rice with intermediate to high amylose (>22%) is the most suitable candidate for rice noodle manufacturing [1]. Flours with low gelatinization temperature, hard gel consistency, low swelling power, and low solubility tend to produce good quality rice noodles [2,3]. The noodles are typically made from rice flour or by grinding rice grains into a slurry.

Broken rice, a by-product of the rice milling process, is a common source of rice flour. Milling of rice grains normally results in 20% of broken rice [4]. The broken rice grains have a length dimension that is less than 8/10 to not less than 2/10 of the average length of the grain. The grains are further divided into large and small broken pieces [5]. In the food industry, broken rice is normally mixed with head rice at retail, converted into flours, and used in the brewing industry [6]. The compositional differences and degree of starch damage compared with head rice limit the applicability of the flour. Studies have shown that broken rice contains a higher level of starch damage and lower amylose content [7,8], which are factors that affect the final product quality. A higher level of starch damage has been correlated with poor noodle quality, such as excessive water absorption, undesirable high cooking loss, and lower hardness and chewiness [9,10]. Grains with lower amylose result in higher cooking loss and inferior textural properties [11]. Therefore, modification of the properties of broken rice is required to overcome these limitations.

Hydrothermal treatments such as heat-moisture treatment (HMT) are physical modification techniques that have been used to improve the functional and physical properties of starch without changing its molecular composition [12]. HMT involves subjecting starch, which has been adjusted to a low moisture content that is insufficient to cause starch to gelatinize, to temperatures higher than both the glass transition and gelatinization temperatures for a predetermined duration. Typically, the starch is adjusted to a moisture content ranging from 10% to 35% and treated at a temperature spanning 84 to 130°C with exposure time varying from 15 min to 16 h [13,14]. Previous authors [15] demonstrated that rice noodles made with the incorporation of 10% flour that was heat-moisture treated at 120°C for 5 h had higher tensile strength than noodles made of unmodified rice flour. In a separate study by Hormdok and Noomhorm [16], the incorporation of 50% of rice starch subjected to HMT at 110°C for 1.5 h in noodle processing resulted in noodle with higher hardness along with a reduction in cooking loss and adhesiveness, indicative of less surface stickiness of cooked noodles.

HMT treatments influence the color of the treated flour or starch and the resulting products. The application of conventional HMT such as using an oven has been associated with a reduction in L* values and an increase in b* values of the treated broken rice flour and product derived from the treated flour [17,18]. The undesirable color changes could result in unfavorable acceptance by consumers. Several authors have compared HMT performed on various flours and starches using other techniques such as autoclaving and microwave [19,20]. In general, the microwave-HMT process requires a shorter treatment time than other HMT techniques. This is attributed to uniform heating facilitated by microwave non-ionizing electromagnetic radiation, which can induce alterations in the material properties due to rapid alternations of the electromagnetic field at high frequency [21]. Although the modification of rice using both oven and microwave has been previously reported, there are no reports on the comparison of both techniques on the physicochemical properties of the flour and product derived from it. Therefore, this study aimed to investigate the effect of conventional HMT using an oven compared with that using microwave on the properties of broken rice and flat rice noodles made from the treated flour.

2. Methodology
2.1 Material

Broken rice grains (MR263) harvested in May 2018 were obtained from BERNAS Rice Milling Plant at Seri Tiram Jaya, Tanjung Karang, Selangor, Malaysia. The amylose content of the rice is 21.7%. The rice grains were vacuumed packed and stored at 4°C until further use.

2.2 Preparation of Rice Flour

Broken rice flour was prepared using the semi-dry milling technique [22]. The grains were softened by soaking in distilled water at a ratio of 1:2 (w/w) for 1 h at ambient temperature. The grains were spread out on trays after draining, and the surface was dried for 30 min at room temperature. The grains were then ground using a food processor (MK-5087M, Panasonic). The flour was dried in a hot air dryer at 40°C to a moisture content of 10 ± 2%. The dried sample was ground and sieved through a 425 µm mesh sieve. The samples were packed in polyethylene (PE) bags and stored at room temperature until further use.

2.3 Heat Moisture Treatments of Rice Flour

The rice flour was heat -moisture-treated (HMT) using two techniques; conventional (with oven) and microwave. The non-treated flour served as the Control sample. Before HMT, the moisture content of the flour was adjusted to 20% (w/w). The flour was spread on a rectangular tray for moisture adjustment, and the necessary volume of distilled water was sprayed on the flour, while it was continuously stirred with a spatula to prevent lumps. The moisture-adjusted flour was then packed in a PE bag and stored overnight at 4°C to equilibrate the moisture content. The chilled flour was brought to room temperature prior to the HMT process.

For oven-HMT (O-HMT), 500 g of flour packed in an airtight glass jar was placed in an oven set at 110°C for 3 h. In the microwave-HMT technique (M-HMT), 500 g of flour was placed in a microwaveable PP container. The container's lid was poked with a needle to create several holes to avoid pressure build-up. The sample was treated at 119 W for 5 min in a microwave oven (EMO-A2071, Elba, Kuala Lumpur). At the end of the hydrothermal treatments, the flour was dried in a hot air dryer at 40°C to a moisture content of 10%. The dried flour was subsequently sieved through a 425 µm sieve. Two batches of samples were prepared for each treatment.

2.4 Analysis of Broken Rice Flour
2.4.1 Swelling power and solubility

Rice flour suspension (1.0%, w/w) was prepared by mixing 0.3 g of flour with 30 mL of distilled water in a 50 mL centrifuge tube. The suspension was gently vortexed until the bottom of the tube was free of lumps. The suspension was heated in a water bath at 90 ± 1°C for 30 min with intermittent swirling at 5-min intervals. The sample was then immediately cooled in an ice bath. It was then centrifuged at 3000 rpm for 15 min. The supernatant was carefully decanted and dried at 105°C to a constant weight. The weight of the wet sediment was recorded. The swelling power and solubility were calculated according to Yang *et al.,* [23]. Solubility was expressed as the percentage of the dried supernatant weight based on the weight of the dry sample. The swelling power was expressed as the ratio between the weight of the wet sediment and the weight of the initial dry sample (deducting the amount of soluble starch).

$$\text{Solubility, S (\%)} = \frac{\text{Weight of the dried supernatant (g)}}{\text{Weight of dry rice flour (g)}} \times 100 \quad (1)$$

$$\text{Swelling power (g/g)} = \frac{\text{Weight of wet sediment x 100}}{\text{Weight of dry rice flour } (100-\text{S})} \quad (2)$$

2.4.2 Color

The color of the rice flour was determined using a Chromameter (Model CR-410, Konica Minolta Incorporation, Japan). Measurement was based on the Hunter system with L* as the lightness (0 = black, 100 = white), a* (-a* = greenness, +a* = redness) and b* (-b* = blueness, +b* = yellowness). The whiteness index (WI) was calculated using the following equation [24]:

$$\text{Whiteness index (WI)} = 100 - [(100 - L)^2 + a^2 + b^2]^{0.5} \quad (3)$$

2.5 Preparation of Flat Rice Noodles

Rice noodles were prepared according to the method of Cham and Suwannaporn [25] with some modifications. Broken rice flour (100 g) was mixed with 150 mL of distilled water to obtain a concentration of 40% (w/w). The slurry was equilibrated at room temperature for 1 h. Vegetable oil was applied onto a square baking pan (175 mm length x 175 mm width) to prevent the noodles from sticking to the pan. The rice slurry (50 mL) was spread evenly into the pan and then steamed at 100°C to complete the gelling process. The noodles were cooled to room temperature. The noodle sheet (1.0 – 2.0 mm thickness) was cut into thin strips of 10 mm width 50 mm length.

2.6 Physico-chemical Properties of Flat Rice Noodles
2.6.1 Color

The colour of rice noodles were determined using the Chromameter and Whiteness Index was calculated as described in section 2.4.2.

2.6.2 Water absorption and cooking loss of flat rice noodles

The water absorption method and cooking loss method of flat rice noodles were determined according to AACC standard methods No. 54-50.01 and No. 66-50.01 [26,27], respectively, with some modifications. The noodles (5 g) were cooked in 150 mL of boiled distilled water for 1 min. The cooked noodles were drained for 5 min and weighed. The cooking water was dried in a drying oven at 105°C until it reached a constant weight. Water absorption was defined as the percentage of weight increase in boiled rice noodles compared with that in steamed noodles prior to boiling (unboiled). Cooking loss was calculated as the percentage of dry matter lost during boiling relative to the weight of the unboiled noodle.

$$\text{Water Absorption (\%)} = \frac{\text{Weight of boiled rice noodles (g) - Weight of unboiled rice noodles}}{\text{Weight of unboiled rice noodles (g)}} \text{ x } 100 \quad (4)$$

$$\text{Cooking Loss (\%)} = \frac{\text{Weight of dry matter in supernatant (g)}}{\text{Weight of unboiled rice noodles (g)}} \text{ x } 100 \quad (5)$$

2.6.3 Sensory evaluation

The sensory characteristics of the flat rice noodles were evaluated by 40 untrained panelists aged 20–50 years. The noodles were boiled, and the samples were stored not more than 1.5 h in a plastic container before testing. Samples evaluated using a nine-point hedonic scale with '1' indicates 'dislike extremely' and '9' indicates 'like extremely'. The attributes evaluated were appearance, color, hardness, stickiness, chewiness and overall acceptability.

2.7 Statistical Analysis

Data were analyzed using Minitab version 16.0 (Penn State, USA) and one-way analysis of variance (ANOVA). Tukey's test was used for the analysis of significant differences ($p< 0.05$). All measurements were performed in triplicate.

3. Results and Discussion

3.1 Swelling Power and Solubility of Broken Rice Flour

Table 1 shows the swelling power and solubility of the hydrothermally treated broken rice flour. In general, the heat moisture treatments of broken rice flour at 110°C for 3 h (O-HMT) and 116W for 5 min (M-HMT) did not significantly change the swelling power of the starch granules. The swelling power ranged from 10.22 ± 0.42 to 10.92 ± 0.42 g/g, with a slight decrease observed in the hydrothermally treated samples. The microwave-treated flour (M-HMT) recorded a higher reduction (6.41%) than the oven-treated flour (1.28%). The solubility of the broken rice flour ranged from 7.24 ± 0.71 to 8.80 ± 1.75 %, with the highest solubility recorded in the non-treated flour (Control). HMT of the flour reduced starch solubility regardless of the technique used, with reductions ranging from 1.59 to 17.72%. The oven-heat moisture treated (O-HMT) sample exhibited the lowest solubility, indicating that less leaching of starch components occurred during the heating process.

Table 1
Swelling power and solubility of hydrothermally treated broken rice flour

Samples[1]	Swelling power (g/g)	Solubility (%)
Non-treated	10.92 ± 0.42^{a}	8.80 ± 1.75^{a}
O-HMT	10.78 ± 0.36^{a}	7.24 ± 0.71^{b}
M-HMT	10.22 ± 0.42^{a}	8.66 ± 1.5^{ab}

Similar findings have been reported by previous authors [18,28], who demonstrated a reduction in both starch granule swelling and leaching of water-soluble components in heat-moisture-treated rice. A greater reduction (28.2%) in swelling power was reported in rice flour treated at 110°C for 3 h [15], which could be due to the differences in amylose content and the nature of the rice grain used. The lower swelling and solubility of the heat-moisture-treated flours could be due to changes in the starch components. It has been reported that HMT leads to the degradation of the outer linear chains of amylopectin [29], resulting in the formation of linear amylose molecules. Amylopectin is known to be associated with the control of swelling of starch granules [30]. Therefore, an increase in amylose caused a decrease in the swelling capacity of starch granules.

The slightly higher granule swelling of O-HMT flour compared with that of M-HMT flour could be due to the milder nature of the oven heat treatment compared with the exposure to microwave radiation. This resulted in less degradation of the outer linear amylopectin chains in the O-HMT sample. In contrast, the rice flour may have absorbed more energy during microwave treatment, thus promoting a greater disruption of glycosidic bonds and consequent breakage of the amylopectin chains, thereby causing a higher decrease in the swelling power of the M-HMT flour.

Solubility is associated with the leaching of amylose molecules that diffuse from starch granules during swelling [30]. The reduction in the solubility of HMT flours perhaps attributed to the stronger bonding forces within the starch granules. Previous authors reported that HMT enhanced the interactions between amylose-amylose and/or amylose-amylopectin molecules and promoted the formation of amylose-lipid complexes [31,32], which hindered the leaching of starch components. The higher solubility observed in M-HMT compared with O-HMT flour could be due to the higher level of short chain amylose in the former, because more outer linear chains of amylopectin are degraded. In addition, a loss in the physical integrity of microwave-treated starch granules have been reported [33], which could result in higher solubility than the O-HMT sample.

3.2 Colour of Rice Flour and Flat Noodles

The comparison of the color of broken rice flour and flat rice noodles is shown in Table 2. In general, oven-heat moisture-treated flour (O-HMT) recorded a decrease in whiteness, as evidenced by lower lightness (L* value) and higher a* and b* values. In contrast, microwave treatment did not cause significant color changes in the flour (Figure 1). The color parameters of M-HMT were comparable to those of non-treated flour (Control), except for a minimal increase in the b* value. A similar finding was observed in microwave-treated taro starch [33]. The whiteness index of the broken rice flour ranged from 87.34 to 94.4, indicating that O-HMT had a significantly ($p<0.05$) lower whiteness, whereas M-HMT had a whiteness index comparable to that of non-treated flour. A similar trend was observed for the color of the flat rice noodles, with the noodles made with O-HMT having a darker color than the other samples. These results are consistent with those reported for rice noodles [15] and dumplings [18] prepared with heat moisture-treated rice flour.

Table 2
Colour characteristics of broken rice flour and flat rice noodles[1]

Samples	L*	a*	b*	Whiteness index
		Broken rice flour		
Non-treated	96.19 ± 0.09^a	0.10 ± 0.02^b	4.05 ± 0.04^c	94.44 ± 0.08^a
O-HMT	92.60 ± 0.08^b	1.60 ± 0.02^a	10.14 ± 0.08^a	87.34 ± 0.11^c
M-HMT	95.92 ± 0.19^a	0.09 ± 0.02^b	4.32 ± 0.05^b	94.05 ± 0.13^b
		Flat rice noodles		
Non-treated	68.53 ± 1.53^a	1.16 ± 0.04^c	13.61 ± 0.49^c	65.62 ± 1.23^a
O-HMT	62.88 ± 0.78^b	8.26 ± 0.08^a	25.94 ± 0.16^b	53.96 ± 0.64^b
M-HMT	68.11 ± 1.50^a	1.69 ± 0.10^b	14.65 ± 0.26^b	64.82 ± 1.28^a

In general, lower L* and whiteness index, higher a* and b* values were observed in the noodles compared with the flour. The whiteness index of the flat rice noodles was comparable to that reported by Weng *et al.*, [34], with values ranging from 66.0 to 68.0 for cooked rice noodles. The darkening of the O-HMT flour could be due to the Maillard reaction that occurs during the thermal process. However, the minimal changes in M-HMT could be due to the shorter treatment time during microwave radiation, which prevents the Maillard reaction from occurring. Therefore, it can be concluded that the microwave-heat moisture treatment process is capable of preserving the color of both rice flour and noodles.

Fig. 1. Broken rice flour obtained from non-treated, oven- and microwave-heat moisture treatments

3.3 Colour of Rice Flour and Flat Noodles

Figure 2 shows the flat rice noodles made with broken rice flour. In general, noodles made with heat-moisture-treated flour had a better appearance than those made from non-treated flour. The O-HMT and M-HMT noodles had a smoother surface with a harder gel texture, and the oven-treated flour had a better appearance and gel with a smooth cut surface. The noodle gel made from the non-treated flour exhibited a non-smooth surface. The gel is weak with a stickier texture, resulting in an uneven surface when cut. However, the noodles made with O-HMT flour had a darker color than the whitish color of non-treated and M-HMT noodles.

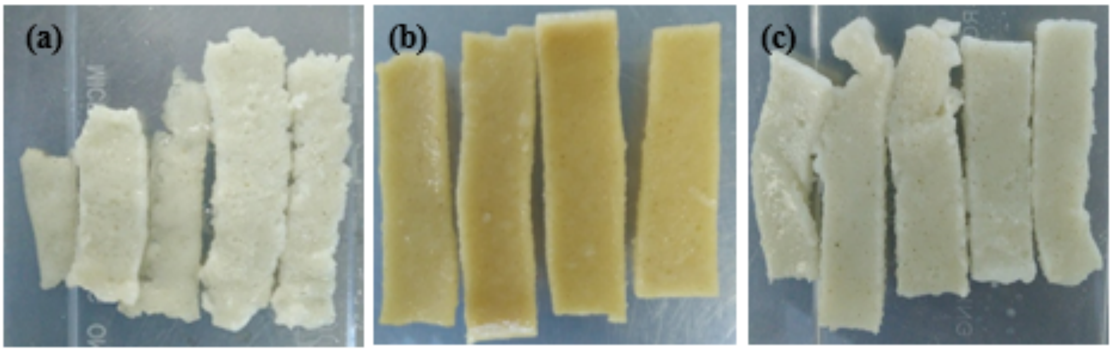

Fig. 2. Flat rice noodles made using (a) non-treated, (b) oven-heat moisture treated (O-HMT), and (c) microwave-heat moisture treated broken rice flours

The gelling time, which represents the time required to complete gelation during the steaming process, was observed for all samples. The completion of gelation was defined as the time at which all parts of the rice slurry in the baking tray turned to gel. This was measured by inserting a thin metal rod into the slurry at every one-minute intervals, and when the rod came out clean, this indicated that the gelation was complete. In general, the O-HMT sample required a shorter time to complete the gelation process (7 minutes), compared to the non-treated and M-HMT samples, which required 15 min to complete the gelation process. The shorter gelling time is an important characteristic of good quality noodles [35].

The poor texture of the noodles made from non-treated broken rice flour could be attributed to the presence of damage starch, which contributes to a higher water absorption capacity [36], resulting in a softer texture. On the other hand, the increase in amylose content in the hydrothermally treated starch, which is due to the degradation of the exterior linear chains of amylopectin molecules [37], could be the reason for the improved noodle texture produced with the HMT broken rice flours. Amylose regulates the gelling behavior of starch, with higher amylose associated with stronger gel. Previous authors reported an increase in gel hardness of heat-moisture-treated rice and sorghum starches [16,38], which was attributed to increased cross-linking between starch chains particularly the amylose fraction [16].

3.4 Water Absorption and Cooking Loss

The cooking properties of the flat rice noodles are shown in Table 3. The noodles from the non-treated sample had the highest water absorption and cooking loss. When comparing the HMT samples, the microwave-treated (M-HMT) noodles had the lowest water absorption, whereas the oven-treated sample (O-HMT) showed the lowest cooking loss. The noodles exhibited 10.74 to 39.11% and 8.31 to 30.23% reductions in water absorption and cooking loss, respectively, compared with the noodle made with non-treated flour. Both water absorption and cooking loss are highly correlated with the swelling power (r = 0.997) and solubility (r = 0.982) of the broken rice flour.

Table 3
Cooking properties of flat rice noodles prepared from non-treated and het-moisture treated broken rice flours

Samples	Water absorption (%)	Cooking loss (%)
Non-treated	16.11 ± 2.56^a	3.01 ± 0.32^a
O-HMT	14.38 ± 1.54^a	2.10 ± 0.17^b
M-HMT	9.81 ± 0.10^b	2.76 ± 0.10^a

Water absorption reflects the amount of water absorbed into the noodle matrix during cooking or boiling, whereas cooking loss reflects the amount of starch components leached out from the noodle matrix during cooking. High water absorption can lead to undesirable swelling of the noodle matrix, which negatively affects gel hardness. In contrast, lower cooking loss prevents a reduction in the gel texture of the noodle because more amylose is retained in the matrix. Cooking loss reflects the cooking quality of flat rice noodles by demonstrating their ability to resist structural breakdown during cooking [35]. High cooking loss has been associated with the sticky mouthfeel of rice noodles [3]. The current findings suggest that modification of the broken rice flour by heat-moisture treatment can prevent the absorption of too much water into the noodle matrix while simultaneously preventing the extreme loss of starch components into the cooking water. The improvement in the cooking quality of the noodle is attributed to the molecular rearrangement and greater interactions between the starch chains, forming stronger internal bonds, which eventually alters the degree of water binding and leaching of starch molecules in the heat-moisture-treated flours.

It could be suggested that the differences in the cooking quality of the noodles made with oven- and microwave-treated flours are possibly due to differences in the molecular structure of the starch of the flours. The fewer breakage of the outer liner chains of amylopectin in the oven-treated flour caused the molecules to have a greater degree of branching and thus greater water absorption during boiling of the noodles. In contrast, the higher amylose content in the microwave-treated flour resulted in greater cooking loss than that in the O-HMT flour.

3.5 Sensory Evaluation of Flat Rice Noodles

Figure 3 depicts the sensory attributes of the flat rice noodles as evaluated by untrained panelists. In general, the O-HMT sample scored the highest among the tested attributes. The sample showed higher acceptability in terms of textural quality, namely hardness, chewiness, and stickiness. The harder gel of O-HMT reduced the stickiness of the rice noodles. The smooth appearance of O-HMT noodles leads to higher acceptance by panelists. Color is an important quality index for determining consumer preference. Traditional rice noodles usually have a whitish appearance. Interestingly, the brownish color of the O-HMT noodles has a higher score among the panelists. The flavor of the O-HMT noodles was higher than that of the other samples. In general, rice noodles have a plain taste. Some panelists described O-HMT as having a slightly burnt flavor, which could be attributed to the compounds formed via the Maillard reaction during the HMT process.

Although the M-HMT noodles had a smoother appearance than the non-treated sample, there was generally no significant difference in terms of all sensory attributes between the M-HTM and non-treated samples. The panelists concluded that both samples had a very soft texture, resulting in an unacceptable texture. The overall acceptability of O-HMT was 6.28, which was higher than that of the non-treated and M-HMT with values of 4.10 and 4.20, respectively. Therefore, it can be concluded that the oven-heat–moisture treatment of the flour can produce rice noodles with improved sensory acceptability.

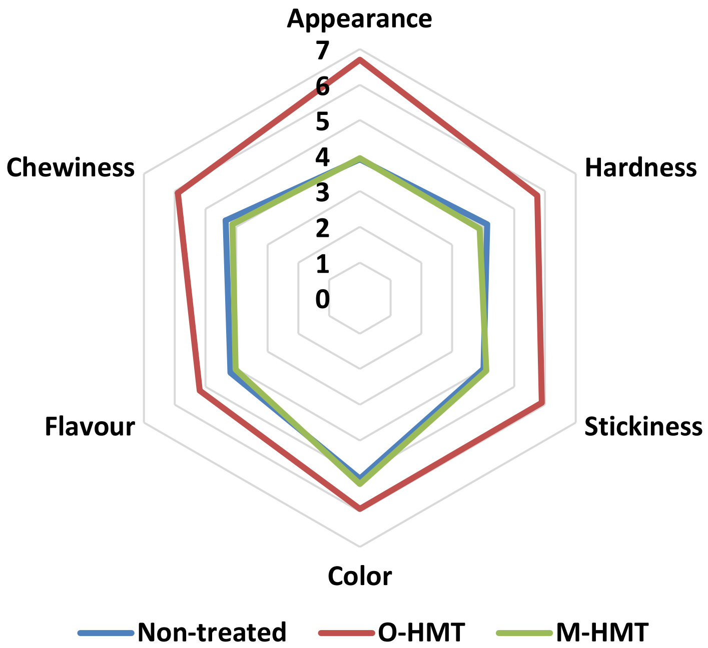

Fig. 3. Sensory quality of flat rice noodles

4. Conclusions

The heat-moisture treatment improved the quality of both broken rice flour and flat rice noodles. The water absorption capacity and cooking loss are highly regulated by the swelling power and solubility of the flour. The oven-HMT flour can be a good candidate for minimizing cooking loss, while the application of HMT via microwave reduces the extreme swelling of the noodle strands during the boiling process. The application of both oven and microwave as a means of heat application during the hydrothermal process resulted in different flour and noodle characteristics, which can be largely attributed to the different degrees of molecular changes, arrangement, and interactions between starch components that occurred in the samples. Nevertheless, the effect of dual modification could be further explored.

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