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Effect of Heat-Moisture Treatment on Qualities of Gluten-Free Alkaline Rice Noodles from Various Rice Flour Varieties

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ABSTRACT

The effects of heat-moisture treatment (HMT) applied to various rice flour varieties on the quality of gluten-free alkaline rice noodles (gluten-free ARN) made from the rice flour varieties were investigated. Three rice varieties: Chai Nat 1 (CN 1), Khao Dawk Mali 105 (KDML 105) and Rice Division 6 (RD 6) containing 30.07, 17.35 and 3.92% amylose content, respectively, were modified by HMT. The HMT was applied to rice flour with 25 g/100 g moisture at 120 °C for 5 h. The changes in the physicochemical properties on the RVA paste viscosity, thermal properties and water-binding capacity of the HMT rice flours were determined. Applications of the HMT rice flour from the three varieties to blend with the native CN 1 rice flour (30.07% amylose) at 30, 40, 50, 60 and 70% affected the cooking quality, texture properties and sensory evaluation of the resultant gluten-free ARN. The cooking loss and firmness of the gluten-free ARN with 30% HMT-RD 6 rice flour were not significantly different from those of the gluten-free ARN with 30% HMT-KDML 105 rice flour. Sensory evaluation based on firmness, adhesiveness, flavor and overall liking of both rice noodles (from 30% HMT-RD 6 and 30% HMT-KDML 105 rice flour) also had higher scores than those of the gluten-free ARN made from other composite rice flours.

Keywords: heat-moisture treatment, rice flour, gluten-free alkaline rice noodle

INTRODUCTION

The food industry is being continually challenged to redesign local foods into healthy foods that contain nutrients and also have potential properties to reduce the risk of celiac disease where the food contains wheat but also maintains the desirable characteristics of appearance, taste and texture, while still using the same methods and processes. One way to achieve this is by using rice flour instead of wheat flour. Rice flour is popular as a food ingredient since it is low in fat content, neutral in flavor and highly hypoallergenic (Pongjanta *et al*., 2008). Rice flour can also be used to produce gluten-free rice bread for gluten-sensitive individuals (Yeh, 2004). Thus, gluten-free alkaline rice noodles (ARN) made from rice flour provide opportunities and choices for both producers and consumers. However, the native rice flour by itself cannot be used practically for gluten-free ARN preparation since rice protein lacks the functionality of wheat gluten in making a cohesive dough structure. Some partial starch gelatinization is required to render it more susceptible to water hydration and to form the amylose network that can act as a binder to form flexible dough (Lai, 2001). Moreover, the partial gelatinization can help to improve functional properties and give

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body and texture to products made from rice flour (Sozer, 2009). However, the functionality of the rice flour depends upon both the rice variety and the type of modification. The combinations of variety and modification method can produce rice flours suitable for different products (Yeh, 2004).

Heating starch with limited moisture content changes its physicochemical properties. Heat-moisture treatment (HMT) is a physical modification that involves treatment of starch granules at low moisture and high temperature conditions, such as for rice at less than 30% moisture w/w and 100–120 °C, respectively (Shih *et al.*, 2007). The effects of HMT on rice starch depend on the variety and type of the rice starch, the treatment conditions (particularly moisture content and temperature) and the duration of the treatment. All changes in the starch granules are associated with the unique physicochemical properties of HMT rice flour. The general effects reported in previous work (Hormdok and Noomhorm, 2007; Shih *et al.*, 2007; Khunae *et al.*, 2007) include a decrease in the peak viscosity, an increase in the gelatinization temperature and paste stability of starch, and the consequent changes in its functionality. Some of the reported results on HMT might also have been influenced by partial gelatinization (Eerlingen *et al.*, 1996). Similar results were reported by Lorlowhakarn and Naivikul (2006) who observed some fractures on the surface of the HMT rice starch granules. This might have been the result of the heat and moisture used in the modification method, which caused some swelling or partial gelatinization around the surface of the starch granules. Such a proposition was also supported by the finding that the swelling powers of HMT flours were higher than those of native flours at low temperature (below 70 °C). In addition, Hormdok and Noomhorm (2007) proposed that this was probably because the particularly high temperature and long duration of HMT caused some partially gelatinized granules which resulted in a less rigid starch gel structure.

A reasonable amount of research has been conducted on modifying rice starch functionalities by HMT, but studies on its applicability in food products are rather limited. Lorlowhakarn and Naivikul (2006) found that a mixture of native CN 1 rice flour and 10% HMT-CN 1 rice flour could be used to make rice noodles that had a tensile strength more acceptable to panelists than noodles made from the unmodified rice flour. However, to date there has been no study on utilizing HMT rice flour in gluten-free ARN. In the present study, HMT samples of three rice flour varieties were prepared using the optimum conditions and their physicochemical properties analyzed. The objective of the study was to examine the potential of mixing different ratios of the three different varieties of HMT rice flours to native CN 1 rice flour in order to produce gluten-free ARN.

MATERIALS AND METHODS

Materials

Three rice varieties: RD 6 (waxy rice), KDML 105 (low amylose) and CN 1 (high amylose) from the Bureau of Rice Research and Development, Thailand, were used in the study. Commercial wheat flour was used as a control. Analytical grades of chemicals were used and were purchased from the Sigma Chemical Company, Saint Louis, USA.

Rice flour preparation and chemical composition of raw materials

Three paddy rice varieties were milled after 4 months aging. The milled rice grains were steeped in water for 4 h to soften the kernels and then ground by a double-disk stone mill (Super Masscolloider, MKPB6-2, Masuko Sangyo Co., Ltd., Japan) with water at a ratio of water to rice of 2:1 (w/w). The rice slurry was poured into a thick cloth bag and centrifuged using a basket centrifuge (locally made in Thailand) for 10 min to remove the excess water. The rice cake was then dried in a tray dryer at 45 ± 5 °C to uniform moisture content (less than 12%). The rice flour samples were ground by hammer mill (Ultra-Centrifugal Mill, Type ZM 1, Retsch GmbH, Haan, Germany) and passed through a 100-mesh sieve and packed in polyethylene bags, sealed and stored at 4 °C for further modification and determinations. The rice flour samples were analyzed for moisture, protein, fat and ash content by the AACC (2000) methods. The amylose content (%) was determined colorimetrically after iodine binding (Juliano, 1971).

HMT of rice flour

The HMT of rice flour samples was carried out using the method of Lorlowhakarn and Naivikul (2006) with slight modification. The moisture content (10%) of the native rice flour was adjusted to 25% by mixing thoroughly with distilled water (15%) and equilibrated at 4 °C for 24 h. The native rice flours (50 g dry basis) were weighed in aluminum pouches, sealed and then placed in a tray dryer at 120 °C for 5 h. Afterwards, HMT rice flour samples taken out of the pouches were spread on aluminum trays and then dried in a hot-air drying oven at 45 ± 5 °C to uniform moisture content (less than 12%). The HMT rice flour samples were then milled, sieved through a 100-mesh screen and kept in sealed polyethylene bags and stored at 4 °C.

Physicochemical properties analysis

The granule morphology of the native and HMT rice flour samples was examined using a scanning electron microscope (SEM; JEOL, JSM 6310F, Japan) at 10 kV accelerating voltage using the secondary electron technique (Lorlowhakarn and Naivikul, 2006). The pasting properties of the native and HMT rice flour samples were determined by a Rapid Visco Analyser (RVA3D, Newport Scientific, Warriewood, NSW, Australia) according to the method of AACC Standard No.61-02.01 (AACC, 2000). The thermal properties of the native and HMT rice flour samples were measured by a differential scanning calorimeter (DSC; Mettler Toledo AG, Greifensee, Switzerland). The water-binding capacity of the native and HMT rice flour samples was analyzed following the method of Singh *et al*. (2005).

Preparation of gluten-free ARN

HMT rice flour from three varieties (CN 1, KDML 105 and RD 6) was used alone or in composite with CN 1 rice flour in various dry basis proportions of 0, 30, 40, 50, 60, 70 and 100% to produce gluten-free ARN. Wheat flour was used as a control. Gluten-free ARN was prepared using a modified method of Ito *et al*., (2007). Some 0.5% Na_2CO_3 solution was added to 30 g of the blended rice flour sample using a kitchen aid (Thaimixer, KV-05, Thailand) for 10 min to form a dough at 42–45% moisture content. The dough was stored in a plastic bag, kept at room temperature (27 °C) for 20 min and then sheeted and passed through a laboratory noodle-making machine (Marcato, OIIIpia 150, Italy) to achieve a final noodle sheet thickness of 1.5 mm. The dough sheet was then cut into 2.0 mm widths for further quality analysis.

Evaluation of gluten-free ARN

Cooking qualities

The cooking procedure for gluten-free ARN was a modification of the AACC standard method No. 66-50.01 (AACC, 1999). Gluten-free ARN samples (5 g) were boiled in 150 mL distilled water for 5 min, drained for 5 min and then weighed. The cooking loss was determined by evaporating the cooking water and rinse water in a pre-weighed beaker in a hot-air oven at 105 °C to get a constant weight. The cooking loss was calculated based on the dry weight of the noodles. The cooking yield was the percentage of weight increase in the cooked rice noodles compared to the gluten-free ARN before cooking.

Texture evaluation

Instrumental texture measurements were performed using a TA-XT (Texture Analyzer; TA–XT Plus, Stable Micro System). Cooked noodle firmness was determined by a modification of the AACC standard method No. 16-50 (AACC, 1999). Gluten-free ARN samples were cooked in water at 100 °C for 5 min and immediately transferred to tap water for 1 min. Cooked gluten-free ARN samples were drained over a wire sieve and cut into 5 cm lengths and measured immediately. Three strands of cooked gluten-free ARN were placed side by side on the platform perpendicular to and centered under a perspex knife blade. Texture profile analysis was carried out to a distance of 0.25 mm at a pretest speed 0.50 mm/s and a post-test speed of 10.00 mm/s using compression mode. The maximum force (*g*) to compress the cooked gluten-free ARN samples was noted as the firmness.

Sensory evaluation

Gluten-free ARN samples were presented to the panelists after having been boiled with soup and mixed with garlic oil. Gluten-free ARN samples and the control wheat were placed in wire mesh baskets and boiled for 5 min, drained and then immediately transferred to tap water for 1 min. After that, gluten-free ARN samples were mixed with fried garlic in vegetable oil before being served with soup to panelists within 15 min. The cooked noodle samples were evaluated by 15 panelists based on firmness (the force required to press on the cooked noodles during the first mastication), adhesiveness (the force required to separate the cooked noodles that adhere on the oral mucosa and teeth during mastication), flavor and overall liking using the 9-point hedonic scale where 9 indicates ‘most liked’ and 1 represents ‘most disliked’ (Lawless and Heymann, 1998).

Experimental design and statistical analysis

A completely randomized design (Smith *et al*., 2003) was used to evaluate the means of the physicochemical analysis of the native and HMT rice flour samples. The data obtained for the physicochemical properties were subjected to analysis of variance (ANOVA), followed by the Duncan’s multiple range test (DMRT) procedure for the difference between treatments at the 0.05 confidence level.

A completely randomized block design (Smith *et al*., 2003) was used for the sensory scores of gluten-free ARN. The means for treatments were calculated and ANOVA and DMRT were used to compare the differences in the mean values at the 0.05 confidence level.

RESULTS AND DISCUSSION

Chemical composition of native rice flour

The chemical compositions of the three varieties of native rice flour (RD 6, KDML 105 and CN 1) and wheat flour are shown in Table 1. The rice flour samples contained moisture, protein,

Table 1 Chemical composition of wheat flour and native rice flour obtained from RD 6, KDML 105 and CN 1[1].

Rice variety[2]		Chemical composition (% dry basis)			Amylose
	Moisture	Protein	Fat	Ash	(%)
Wheat	12.59^a	10.63^a	0.86^b	0.25^c	26.32^b
RD 6	10.69^b	6.15^d	0.47^d	0.21^d	3.92^d
KDML 105	9.33^c	6.39^c	0.95^a	0.49^a	17.35^c
CN 1	10.43^b	7.59^b	0.81^c	0.40^b	30.07^a

1 Mean values in the same column with different superscript letters are significantly different ($P < 0.05$).

2 CN 1= Chai Nat 1; KDML 105 = Khao Dawk Mali 105; and RD 6 = Rice Division 6.

fat and ash contents between 9.33 and 10.69%, 6.15 and 7.59%, 0.47 and 0.95% and 0.21 and 0.49%, respectively, whereas the wheat flour contained contents of 12.59% moisture, 10.63% protein, 0.86% fat and 0.25% ash. The RD 6 (waxy rice) samples had the lowest amylose content (3.92%) followed by KDML 105 (17.35%), while CN 1 had the highest amylose content (30.07%), whereas the wheat flour contained 26.32% amylose.

Physicochemical properties of native and HMT rice flour samples

SEM micrographs of native and HMT rice flour samples

SEM micrographs of the native and three HMT rice flour samples are shown in Figure 1 and indicate that all the native rice starch granules in the rice flour samples had polygonal shapes with diameters between 3 and 5 μm (Figures 1a1, 1b1 and 1c1). The HMT-CN 1 starch granules had the same shape, but the single starch granule distribution was reduced (Figure 1c2), while the HMT-RD 6 and HMT-KDML 105 rice starch granules were aggregated and the surface of the starch granules was melted connecting with other starch granules surface (Figure 1a2 and 1b2). In addition, some starch granules had lost their polygonal shape into a flat surface. These were probably the result of partial gelatinization during modification (Lorlowhakarn and Naivikul, 2006; Hormdok and Noomhorm, 2007).

Pasting properties of native and HMT rice flour

The pasting profiles of the native and three HMT rice flour samples are presented in Figure 2. After modification, different varieties of rice flours showed the same trend in pasting characteristics. The peak viscosities (101.71–242.00 Rapid Visco Units; RVU) and breakdown (21.83–50.50 RVU) of the HMT rice flours were lower than those of the natives. When the HMT flour samples with different varieties were compared, the peak viscosity of HMT-RD 6 (242.00 RVU) was higher than those of HMT-KDML 105 (131.32 RVU) and HMT-CN 1 (101.71 VU). The peak viscosity (indicating the amount

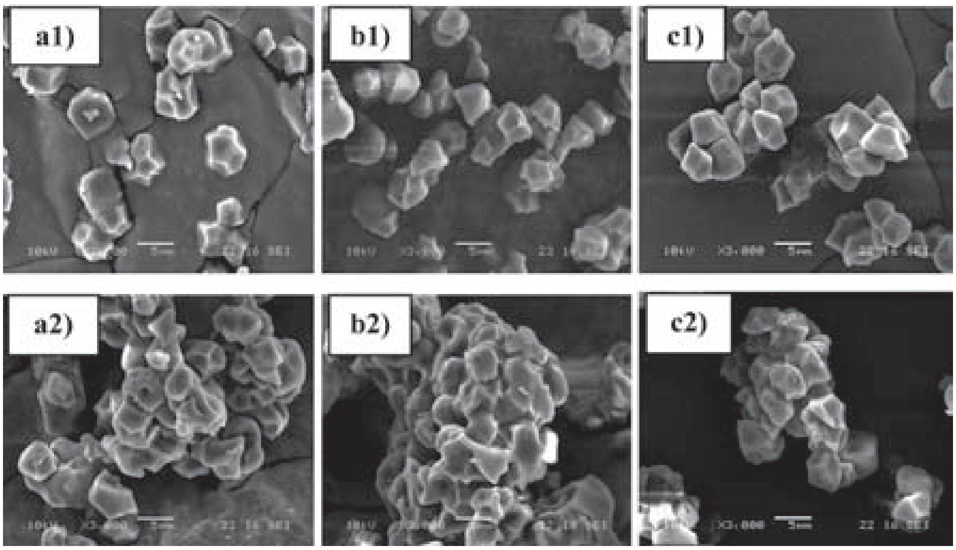

Figure 1 Scanning electron micrographs (magnification at ×3,000) of: a1) native RD 6; b1) KDML 105; c1) CN 1; a2) HMT-RD 6; b2) HMT-KDML 105; and c2) HMT-CN 1 rice starch granules in the flour samples.

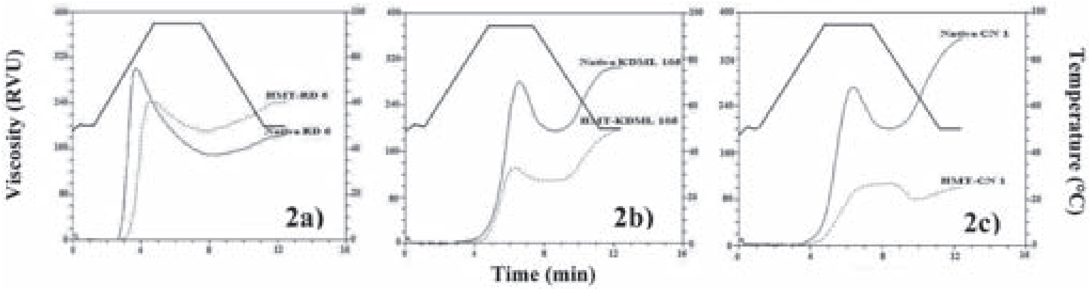

Figure 2 RVA pasting profile curves of native and HMT rice flours from: 2a) RD 6; 2b) KDML 105; and 2c) CN 1. The temperature profile is represented by the straight line graph in each figure. Viscosity is measure in Rapid Visco Units (RVU).

of swelling of starch granules) was apparently lower in the HMT samples compared with the natives. A similar observation was noted by Lorlowhakarn and Naivikul (2006) for CN 1 rice flour. Hormdok and Noomhorm (2007) also reported a similar finding with a decrease in the peak viscosity of HMT rice flour. The low breakdown value indicated that the starch granules in the HMT rice flour were more durable to heating and shearing.

Thermal properties and water-binding capacity

The thermal properties of the HMT rice flours were significantly different ($P < 0.05$) from those of their natives (Table 2). The onset (*To*; 64.69–74.24 °C), the peak (*Tp;* 70.31–85.27 °C), and the conclusion (*Tc;* 81.80–88.80 °C) temperatures of gelatinization, and the temperature range (*Tc*-*To;* 14.36–18.40 °C) of the three HMT rice flours were higher than those of their natives. The higher values of *To*, *Tp*, *Tc* and *Tc*-*To* observed for the HMT rice flours indicated that some of the double helices in the crystalline regions of the starch granules of the HMT rice flour had undergone rearrangement or transition during HMT resulting in strong interactions between the starch chains within the granules. Therefore, high temperature was required to disrupt the formation of new molecular structures within the starch granule (Khunae *et al*., 2007). The enthalpies of gelatinization (ΔH) (4.72–6.61 J/g) of the HMT rice flours were lower than those of their natives (8.48–9.44 J/g). This suggested that some partially

Table 2 Thermal properties and water binding capacity of native and three HMT rice flours[1].

Samples[2]	Thermal properties					Water binding capacity(%)
	To (°C)	*Tp* (°C)	*Tc* (°C)	*Tc*-*To*(°C)	Δ*H* (J/g)	
Native RD 6	59.77[h]	67.34[f]	74.36[g]	14.60[b]	9.44[a]	201.83[d]
HMT-RD 6	64.69[f]	77.07[cd]	83.04[c]	18.40[a]	6.61[c]	240.33[b]
Native KDML 105	62.13[g]	67.05[f]	72.79[h]	10.66[c]	8.48[b]	208.33[c]
HMT-KDML 105	67.24[e]	70.31[e]	81.80[e]	14.56[b]	4.72[e]	273.50[a]
Native CN 1	72.74[c]	76.87[d]	81.16[f]	8.42[d]	8.86[b]	189.67[e]
HMT-CN 1	74.24[b]	85.27[b]	88.60[b]	14.36[b]	5.52[d]	237.33[b]

1 Mean values in the same column with different superscript letters are significantly different ($P < 0.05$).

2 Native RD 6= Native Rice Division 6 rice flour; HMT-RD 6 = Heat-Moisture Treated Rice Division 6 rice flour; Native KDML 105 = Native Khao Dawk Mali 105 rice flour; HMT-KDML 105 = Heat-Moisture Treated Khao Dawk Mali 105 rice flour; Native CN 1= Native Chai Nat 1 rice flour; HMT-CN 1 = Heat-Moisture Treated Chai Nat 1 rice flour.

gelatinized starch granules were less heat stable with fewer double helices in the amorphous and crystalline regions which might have been unwound and melted during HMT gelatinization (Hormdok and Noomhorm, 2007).

The values for water-binding capacity (WBC) of the HMT rice flours were significantly different from those of the native rice flours (Table 2). The HMT rice flours (RD 6, KDML 105 and CN 1 rice varieties) were higher in water-binding capacity (237.33–240.33%) than their natives (189.67–208.33%). The results indicated that the heating treatment provided the rupture or weakening of the forces that maintained the granules, thus facilitating water binding of the granules.

Quality of gluten-free ARN from HMT and composite rice flours

Cooking quality

The cooking quality of the gluten-free ARN samples was significantly different from that of the control wheat noodles (Table 3). The cooking yields of gluten-free ARN samples varied among treatments. Almost all the gluten-free ARN samples had a cooking yield (41.95–106.83%)

Table 3 Effect of various HMT rice flours and ratio replacement of native CN 1 rice flour on cooking quality and firmness of gluten-free ARN[1].

Treatment[2]	Cooking yield(%)	Cooking loss(%)	Firmness force (*g*)
Wheat noodle (Control)	163.36^{a}	9.59^{g}	35.33^{a}
Native CN 1 (100)	-[3]	-	-
HMT-RD 6 (100)	-	-	-
HMT-KDML 105 (100)	-	-	-
HMT-CN 1(100)	-	-	-
CN 1: HMT- RD 6 (70:30)	106.83^{c}	11.62^{ef}	13.42^{b}
CN 1: HMT- RD 6 (60:40)	71.35^{e}	11.61^{ef}	8.83^{e}
CN 1: HMT- RD 6 (50:50)	58.25^{f}	9.64^{g}	9.79^{d}
CN 1: HMT- RD 6 (40:60)	98.72^{d}	11.51^{f}	7.78^{f}
CN 1: HMT- RD 6 (30:70)	108.81^{c}	11.55^{ef}	7.43^{f}
CN 1: HMT-KDML 105 (70:30)	165.50^{a}	12.47^{e}	13.37^{b}
CN 1: HMT-KDML 105 (60:40)	115.52^{b}	19.62^{d}	10.50^{c}
CN 1: HMT-KDML 105 (50:50)	44.62^{g}	26.46^{c}	10.43^{cd}
CN 1: HMT-KDML 105 (40:60)	41.95^{g}	29.10^{b}	10.53^{c}
CN 1: HMT-KDML 105 (30:70)	37.00^{h}	34.42^{a}	10.36^{cd}
CN 1: HMT- CN 1 (70:30)	-	-	-
CN 1: HMT- CN 1 (60:40)	-	-	-
CN 1: HMT- CN 1 (50:50)	-	-	-
CN 1: HMT- CN 1 (40:60)	-	-	-
CN 1: HMT- CN 1 (30:70)	-	-	-

1 Mean values in the same column with different superscript letters are significantly different ($P < 0.05$).

2 Native RD 6= Native Rice Division 6 rice flour; HMT-RD 6 = Heat-Moisture Treated Rice Division 6 rice flour; Native KDML 105 = Native Khao Dawk Mali 105 rice flour; HMT-KDML 105 = Heat-Moisture Treated Khao Dawk Mali 105 rice flour; Native CN 1= Native Chai Nat 1 rice flour; HMT-CN 1 = Heat-Moisture Treated Chai Nat 1 rice flour; CN 1:HMT-RD 6 = composite CN 1 and Heat-Moisture Treated Rice Division 6 rice flour; CN 1:HMT-KDML 105 = composite CN 1 and Heat-Moisture Treated Khao Dawk Mali 105 rice flour; CN 1:HMT-CN 1 = composite CN 1 and Heat-Moisture Treated Chai Nat 1 rice flour.

3 Values in the table represented by a hyphen (-) indicate it was not possible to make gluten-free ARN with that treatment.

lower than that of the wheat noodles (163.36%), except for the composite gluten-free ARN made from CN 1and HMT-KDML 105 (70:30) rice flour (165.50%) that showed no difference ($P > 0.05$) from the control. In addition, the cooking yields of gluten-free ARN made from CN 1and HMT-RD 6 (70:30) and CN 1and HMT-RD 6 (30:70) were not significantly different. In contrast, the results showed that the cooking yield decreased significantly when the amount of HMT-KDML 105 rice flour was above 30%. The gluten-free ARN samples with 70% HMT-KDML 105 rice flour showed significantly higher cooking loss (34.42%) than the other treatments. In comparison with the wheat noodles, the cooking loss of the gluten-free ARN made from CN 1and HMT-RD 6 (50:50) was not significantly different from the wheat noodles. In addition, all gluten-free ARN samples had a higher cooking loss. However, the gluten-free ARN samples formulated with 30, 40, 60, 70% of HMT-RD 6 and 30% of HMT-KDML 105 rice flour substituted for CN 1 rice flour showed no significant differences in cooking loss (11.51–12.47%). The results indicated that the substitution of suitable HMT rice flour could improve the cooking quality, making CN 1 rice flour more appropriate for gluten-free ARN production.

The effects of HMT rice flour on the firmness of cooked gluten-free ARN are shown in Table 3. The entire cooked gluten-free ARN samples were significantly lower in firmness (7.43–13.42 g) than the wheat noodles (35.33 g). Replacement with 30% HMT-KDML 105 and HMT-RD 6 rice flour showed no significantly different effect on the firmness. However, the firmness of the cooked gluten-free ARN decreased with an increase in the proportion of the HMT rice flour. This might have resulted from the partially gelatinized starch granules around the surface, particularly at the high temperature and duration of HMT that caused some of the starch structure to collapse and resulted in a less firm starch gel (Hormdok and Noomhorm, 2007).

Sensory evaluation

The results of the sensory evaluation of the cooked gluten-free ARN and wheat noodles

Table 4 Effect of HMT replacement for CN 1 rice flour at 30, 40, 50, 60 and 70% on sensory quality of cooked gluten-free ARN[1].

Treatments[2]	Sensory scores			
	Firmness	Adhesiveness	Flavor	Overall liking
Control (Wheat noodle)	7.47^{a}	7.60^{a}	7.67^{a}	8.07^{a}
CN 1:HMT-RD 6 (70:30)	5.13^{bc}	3.67^{def}	3.60^{f}	4.40^{cd}
CN 1:HMT-RD 6 (60:40)	3.27^{de}	2.80^{fg}	3.80^{ef}	3.20^{ef}
CN 1:HMT-RD 6 (50:50)	3.13^{de}	3.00^{efg}	4.60^{cdef}	3.00^{ef}
CN 1:HMT-RD 6 (40:60)	2.27^{f}	2.07^{g}	4.00^{def}	2.27^{g}
CN 1:HMT-RD 6 (30:70)	1.87^{f}	1.67^{g}	3.40^{f}	1.87^{g}
CN 1:HMT-KDML (70:30)	6.20^{b}	6.00^{b}	6.13^{b}	6.13^{b}
CN 1:HMT-KDML (60:40)	5.87^{b}	5.13^{bc}	5.73^{bc}	5.13^{bc}
CN 1:HMT-KDML (50:50)	5.87^{b}	4.73^{bcd}	5.20^{bcd}	4.40^{cd}
CN 1:HMT-KDML (40:60)	4.07^{cd}	4.27^{cde}	4.93^{bcde}	4.73^{cd}
CN 1:HMT-KDML (30:70)	3.60^{d}	3.87^{cdef}	4.60^{cdef}	4.00^{de}

Hedonic scale of 1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely.

[1] Mean values in the same column with different superscript letters are significantly different ($P < 0.05$).

[2] CN 1:HMT- RD 6 = composite CN 1 and Heat-Moisture Treated Rice Division 6 rice flour; CN 1:HMT- KDML 105 = composite CN 1 and Heat-Moisture Treated Khao Dawk Mali 105 rice flour.

in soup are presented in Table 4. The scores for flavor, firmness, adhesiveness and overall acceptance of the cooked gluten-free ARN from 30, 40, 50, 60, and 70% HMT-RD 6 and HMT-KDML 105 replacement for CN 1 rice flour were significantly different from those of the wheat flour (control). Firmness and adhesiveness scores decreased as the level of HMT-RD 6 and HMT-KDML 105 substitution increased up to 70%. No significant differences in firmness were found among the gluten-free ARN with 30% HMT-RD 6 (5.13) and 30 to 50% HMT-KDML 105 (5.87–6.20) replacement for CN 1 rice flour. The adhesiveness scores of the gluten-free ARN with 30 to 50% HMT-KDML 105 replacement for CN 1 rice flour (4.73–6.00) were also not significantly different. However, the gluten-free ARN samples made from CN 1:HMT-KDML 105 (70:30) were found to have the highest scores for firmness (6.20) and adhesiveness (6.00) compared with the other treated gluten-free ARN samples. No differences in flavor scores were found among the gluten-free ARN with 30 to 70% HMT-RD 6 and HMT-KDML 105 replacement for CN 1 rice flour. The gluten-free ARN sample with the highest (6.13) overall acceptance score was the gluten-free ARN with 30% HMT-KDML 105 replacement which was not significantly different from that with 40% HMT-KDML 105 replacement for CN 1 rice flour.

CONCLUSION

The results obtained from the study showed that the HMT modification applied to three rice flours (RD 6, KDML 105 and CN 1) with 25 g/100 g moisture at 120 °C for 5 hr led to changes in the physicochemical properties of the rice flour. The surface of some starch granules melted connecting with the surface of other starch granules which indicated that starch granules had been partially gelatinized with consequent changes in physicochemical properties. The *Tc* - *To* of the HMT rice flour shifted to a higher temperature while ΔH decreased. In addition, the peak viscosity and breakdown values of the HMT rice flours were lower than those of the native rice flours. The treatment conditions of HMT increased the water-binding capacity of the rice flour resulting in heat-moisture treated rice flour being partially gelatinized and more susceptible to water hydration, thus making the amylose network act as a binder. The cooking quality, firmness and sensory evaluation of gluten-free ARN from the three HMT rice flours blended at 30, 40, 50, 60 and 70% with the native CN 1 rice flour were compared. The results showed that both the cooking loss and firmness of gluten-free ARN with 30% HMT-RD 6 rice flour were not significantly different from those of the gluten-free ARN with 30% HMT-KDML 105 rice flour. The composite 70% native CN 1 and 30% HMT-KDML 105 rice flour had higher scores for the sensory evaluation (flavor, firmness, adhesiveness and total acceptance) than the gluten-free ARN made from other composite rice flours.

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