International Food Research Journal 21(2): 703-712 (2014)
Journal homepage: http://www.ifrj.upm.edu.my

Head rice yield, pasting property and correlations of accelerated paddy rice aging properties by microwave heating conditions

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Article history

Received: 5 July 2013
Received in revised form: 15 October 2013
Accepted: 16 October 2013

Keywords

Microwave heating
Accelerated rice aging
Heating round
Microwave power level
Paddy rice
Correlation

Abstract

Head rice yield (HRY) and eating qualities can be improved by accelerated newly harvest paddy rice aging. In this study, microwave heating of continuous microwave dryer was applied to heat the newly harvested paddy rice. The microwave power level (MWL), exposure times (ET), and heating rounds (HR) on accelerated rice aging properties such as head rice yield and pasting properties, water uptake, solid loss, texture of cooked rice and color changes were investigated. The newly harvested paddy rice without microwave treatment was used as a control sample. The results showed that three chosen factors were mainly affected the HRY and the hardness. One round and two rounds of microwave heating caused lower HRY; however, three rounds resulted in the sample with the noticeably improved HRY when compared to one round, two rounds, and newly harvested rice. The HRY had a positive correlation with the hardness ($P \leq 0.001$) and the color intensity ($P \leq 0.05$) but a negative correlation with the moisture content ($P \leq 0.001$), water uptake ($P \leq 0.01$), solid loss ($P \leq 0.05$), and lightness ($P \leq 0.001$). The stickiness and solid loss were diversely changed after microwave heating but insignificantly different by varied microwave heating conditions. The hardness and the stickiness of cooked rice did not have a significant correlation with microwave heating. The MWL and HR produced the changes in viscosity properties of flour of newly harvested rice especially in peak and final viscosity. The peak viscosity and the final viscosity were decreased while breakdown and setback viscosity were slightly increased with increased HR and MWL. These changes seem to demonstrate the aging characteristics. The effect of HR on aging properties was particularly noticeable in this study. Furthermore, the resulting higher order polynomial interaction among microwave heating conditions on respective aging properties suggests that microwave-accelerated rice aging is a complex process.

Introduction

Rice, one of most important cereals in the world, is a staple food source for more than a half of the world's population. Commonly, a large amount of the rice is consumed by cooking along with a small portion of processed foods. Cooking quality is one of the most important steps influencing the acceptability of rice. However, the rice from freshly harvested paddy generally leaves a thick gruel texture when being cooked. These cooking properties may not be accustomed to consumers who prefer the fluffiness or firmness. Those characteristics of rice could be improved when the freshly rice is traditionally stored at least 3-6 months; this phenomenon is called aging of rice (Indudhara Swamy *et al.*, 1978). By natural storage condition, the rice is stored quite long time, which is considered as a non-economic aspect such as storage space requirement, inset damages, and high opening cost. To avoid such drawbacks, the accelerated rice aging technique is normally used to shorten this process. On the other hand in comparison with parboiled rice technique that involves soaking, steaming, and drying, the process of the accelerated aging is taken place only partial of parboiling process so that the accelerated rice process is more economical than the traditional parboiling process (Gujral and Kumar, 2003).

So far, accelerated rice aging methods have been applied which generally used conventional heating methods. The heating treatment could be dry heat or moist heat treatment. The process at least takes minutes to several hours, even more than ten days. Rice aging mechanism is a complicated process involving changes in different rice chemical components leading to physical and physicochemical changes, which has been not completely understood so far (Zhou *et al.*, 2002) and dominantly explained by two main components, protein and starch (Teo *et al.*, 2000; Zhou *et al.*, 2003; Likitwattanasade and Hongsprabhas, 2010).

Electromagnetic waves have been detected and applied as short time treatment techniques in rice acceleration, for instance, gamma irradiation,

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radio frequency and microwave. The effects of electromagnetic waves on rice aging might be different from those appearing in ordinary rice (Sirisoontaralak and Noomhorm, 2007) and in conventional heating method of accelerated rice aging. Microwave heating (MWH) treatments have been shown a great effect on major rice components especially starch and protein through inactivation of enzyme activities. MWH resulted in changes in gelatinization mechanism (Palav and Seetharaman, 2007), increased or decreased starch digestibility or resistant starches (Emami *et al.*, 2011), structure of starch (Anderson and Guraya, 2006) or amylose content and protein properties (Delwiche *et al.*, 1996; Lewandowicz *et al.*, 1997; Palav and Seetharaman, 2007; Zhao *et al.*, 2007). Those component changes after MWH treatment related to hardness and adhesiveness of cooked rice (Zhao *et al.*, 2007).

In microwave processing, intermolecular friction mainly caused by bipolar rotation of polar molecules, generates heat internally in the material resulting in an instant temperature increase. Sample geometry, size, and volume altogether affect the distribution of microwave heating (Remmen *et al.*, 1996; Khraisheh *et al.*, 1997; Yang and Gunasekaran, 2004). Apart from the chemical compositions of heated sample, water is the most important component in MWH system while the water also joins in properties of other components. Thus, the moisture movement during MWH is one of the important processes that may be related to rice aging acceleration. Since the bound water (low initial moisture sample) is related to the structure of the solid, how water transportation is carried out from the interior to the surface of the solid that could explain for physical and physicochemical changes (Park, 2001). The aging process is a complex process involving interaction of different rice chemical components. A little moisture available might increase their interaction during MWH. Moreover, intermittent heating including tempering has been applied for dehydration process which obtains a number of advantages especially in head rice yield due to reduced moisture gradient created during drying (Steffe *et al.*, 1979). Moreover, the reheated samples by MWH possibly caused moisture loss which may facilitate for acceleration of rice aging since when the rice aging more than 3 months, the moisture of grain is normally decreased during long storage time (Juliano, 1985; Soponronarit *et al.*, 2008).

Apart from the initial moisture content that are very critical for chemical interactions and avoid the risk of burning (Sale, 1976), the suitable exposure time, the MW power and the heating round are also very crucial for MWH. The inappropriate MWH condition may cause an increase in temperature of heating grains higher than that allowed which results in disadvantages for head rice yield. For starch materials, some researchers found that the initial moisture content should be smaller than 23% wet basis and the use of microwave power level at the level that the temperature generated inside product not higher than 100^{o}C to avoid the damage of starch (Kaasová *et al.*, 2002; Pinkrová *et al.*, 2003). Thus, it is necessary to select the suitable MW powers, exposure times and heating rounds for a certain moisture content rice sample.

According to previous results, the microwave shows as a potential technique to accelerate rice aging. In addition, microwave becomes more popular nowadays as techniques of short time treatment while the information about accelerated rice aging is still limited. The purpose of this research was to investigate the effect of high microwave power heating conditions on head rice yield, pasting properties and accelerated aging properties of rice.

Materials and Methods

Sample preparation

The newly harvested paddy rice of Phitsanulok 2 variety was received from Phatumthanee Rice Research Center, Thailand. The seeds were sun dried at less than 40^{o}C to reduce moisture content less than 14% wet basis. Then, the seeds were divided into 2 parts corresponding with and without microwave treatment (control sample). After MWH treatments, the samples were stored in the closed container (sealed plastic bag) for further analysis.

Milling of paddy

The samples were de-husked to be brown rice by a laboratory de-husker machine (motor 0.5 HP/ 220 V/ 50 Hz, Ngek Seng Huat Part., Ltd., Bangkok, Thailand). The brown rice was then milled to be white rice. For milling process, each of batch equal to 100 g was put into miller and polished to white rice. The period of milling was 30 s for each batch. The head white milled rice was used for investigating aging properties.

Microwave heating treatment and experimental design

A continuous type of industrial microwave dryer (2,450MHz) operated at 220VAC, 50 Hz, 2,000 W, 2 magnetrons designed by Prof. Dr. Monai Krairiksh, King Mongkut's Institute of Technology Ladkrabang. The microwave dryer consisted of a controlled speed conveyer belt assembly, microwave applicator, fan, leakage prevention system, and a control panel. The speed of the conveyer belt and the power output of microwave generator could be adjusted (two levels in this study). The fan was on at all times during the experiments and the air inlet temperature was measured as 30 ± 1°C. For each run, the amount of 150g samples was put into container made by hard paper. The top surface was flattened before being run on the conveyer belt. Three containers were used for one experimental run.

The experimental design of 2 x 3 x 3 corresponding with two levels of microwave power output (1,000 and 2,000 W), three level of exposure time (23, 31, and 41s) and three rounds of heating (1, 2, and 3 rounds) was applied involving the tempering period of 90 min between each round. Samples were collected and stored in polyethylene bags at room temperature respectively for further analysis. The initial and final moisture contents after microwave treatment was measured.

Statistical analysis

The data were analyzed using Statgraphic Centurion version XV software (StatPoint Technologies, Inc., Warrenton, VA 20186, USA). Analysis of variance and the least significant difference multiple range test was applied to analyze the data. Pearson correlations between each pair of variables were used in the multiple-variable analysis at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$ respectively.

Moisture content determination

Moisture contents of samples were determined in replication (≈ 10 g for each sample) applying oven method at 105°C for 24 h (Swamy *et al*., 1971).

Physical and physicochemical property determination

Head rice yield

The head rice yield (HRY) was performed according the Rice Research Institute, Thailand. HRY is defined as the ratio of mass of head rice obtained from milling to mass of paddy at the beginning. This value was determined in triplicate.

Color changes

Color of samples was measured after microwave treatments by Hunter-Lab colorimeter XE-scan (Chromameter model CR-300, Japan). Measurement was based on the CIELAB system with color values of L^*, a^* and b^* display. Each treatment was measured in eight replicates and two samples were conducted. The lightness (L^*), the color intensity (C^*) and hue angle (h) were calculated according to Mohammadi *et al.* (2008) and Saricoban and Yilmaz (2010). The higher color intensity was corresponding with browner appearance.

$$C^* = \sqrt{a^* + b^*} \qquad (1)$$

$$h = arctan\frac{b^*}{a^*} \qquad (2)$$

Cooking process

The amount of 2 g of head milled white rice was put in an aluminum can containing 10 g of distilled water. The container was covered by aluminum foil, and then placed in small electric cooker at temperature of boiling water of 97 ± 2°C. The small hole was made on aluminum foil during cooking to avoid the cover pushed out and also to control cooking temperature during cooking process. Each of experimental run was corresponding with three containers. The process was conducted at optimum cooking time (12 min). Temperature during cooking was controlled by small electric cooker and a sensor of digital thermocouple that was set up hermetically on the container with aluminum foil.

Water uptake

$$\text{Water uptake (\%)} = \frac{W_c - W_{uc}}{W_c} x100 \qquad (3)$$

where W_c and W_{uc} is the weight of cooked and uncooked kernels respectively.

Texture analysis

Ten-cooked kernels were placed on the platform of the texture analyzer machine (TA-XT2, Texture Technologies Corp., UK). A cylindrical probe of 36 mm diameter attached to a 50kg load cell was used to compress the kernel to 85% of its original height at a crosshead speed of 10 mm/min. The values were reported by the mean of ten replications (modified from Rewthong *et al*., 2011). Hardness and stickiness was determined from the maximum and the negative force value.

Solid loss

Solid loss was referred to the method of Gujral and Kumar (2003) with modification. The head white rice (2 g, milled rice) was put in an aluminum can containing 20 ml of distilled water. The rice was cooked for 12 min in an electric cooker (electric cooker was used to boil water during cooking). The cooking water was collected and transferred into a reweighed aluminum can and dried at 105°C in hot air oven for 24 h to remove moisture. The aluminum can was cooled in a desiccator and weighed to determine the increase in weight of the can. The average of three replications was reported.

$$\text{Solid loss (\%)} = \frac{\text{Increase in weight of can}}{\text{Weight of rice sample}} \times 100 \quad (4)$$

Pasting properties

The pasting properties of rice flour (180-micron size) with and without MWH treatment were analyzed using a Rapid Visco Analyzer (RVA-4, Newport Scientific Pty. Ltd., Australia). The pattern of RVA analysis was referred to Yu *et al*. (2012). The pasting properties were measured for selected conditions. In this study, the rice of two levels of microwave power (1,000 and 2,000 W), one level of exposure time (41 seconds) and three rounds of heating was measured for the pasting properties. The peak viscosity, breakdown, trough, final viscosity, and setback were recorded for samples with replications.

Results and Discussion

Effect of microwave heating condition on head rice yield

According to Figure 1, for one and two rounds, two levels of MWH resulted in sample with a decreased HRY in comparison with that of new rice in which the HRY of 2 rounds was higher than that of 1 round for two levels of MWH. The improved HRY was found at 3 rounds for both two levels of MWH. Moreover, there was a significant difference in HRY between two levels of MWH at the 3 rounds while the HRY was insignificant difference at 1 and 2 rounds. In this study, it was found that the paddy rice treated at 2,000 W for three rounds at 41 s obtained the highest HRY in comparison with counterparts. The increase in HRY is possibly due to more agglomeration of starch granules especially at low moisture content. Thus, the rice was more tolerant to impact force during milling (Juliano, 1985) while the decrease in HRY may be due to the imbalance loss of moisture during heating that caused high moisture gradient during MWH and then weaken strength in kernel due to crack and resulting in more broken rice (Juliano, 1985). This practice was also related to other aging properties in this study. This explanation can be seen again when discussing the result of correlation of aging properties.

Effect of microwave heating condition on physical and physicochemical properties

The physical and physicochemical properties of accelerated rice aging are shown in Table 1 at different heating conditions as compared to newly harvested rice.

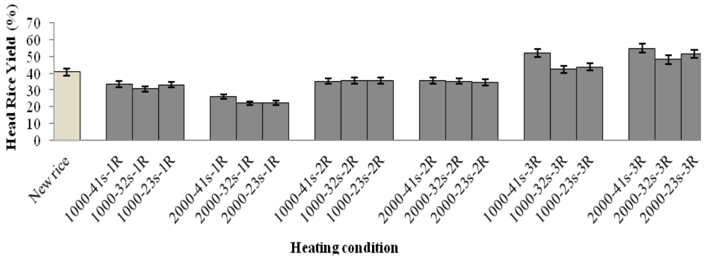

Figure 1. Head rice yield at different microwave heating conditions

The vertical bar represents ± SD (n = 3); 1000 and 2000 =1,000W and 2,000W; R = round; e.g., 1000-41s-1R= 1000W, 41s and 1round.

Moisture loss: During MWH, there was a loss of moisture content corresponding with an increased microwave power level, exposure time, and heating round. After 3 rounds of MWH, the range of moisture content was from 11.38 to 12.68% wet basis. Moreover, there was a significant difference at different exposure time at 3 rounds of MWH. Moreover, it is well- known that the water removal in mw heating system is quite fast in comparison with that of conventional heating. The instant removal of water from inside may be resulted in more cell membranes and cell walls disorganized especially when increased the heating round. Since the moisture loss from the grains was supported to lead disorganization of cell membranes (Jain *et al.*, 2006). This process possibly affected starch agglomeration of starch granule and subsequently tolerant to impact force during milling (Juliano, 1985). The cell wall structure of aged rice was found to be important for water penetration (Zhou *et al*., 2003).

Water uptake: After MWH, the water uptake increased in comparison with that of new rice for all treatments. After three rounds of MWH, the water uptake became similarly to that of new rice while it was alternatively different for 1 and 2 rounds. Among three rounds of MWH, one round and two rounds had a similar trend in water uptake; the water uptake was increased as increased MWH power. The trends of 3 rounds were different from counterparts; at 2,000 W for 3 rounds, the sample showed nearly lower water uptake when compared to 1,000 W. Indudhara Swamy Swamy *et al.* (1978) found that the water absorption increased slightly and remained flat at storage times of one year. Moreover, Ranilli *et al.* (2003) found that the water absorption increased over the first two months of storage before returning to near-original values. According to the result of this study, three rounds at higher MWH power caused rice more aging when compared to counterparts.

Color: The colors also changed variously after mw heating time which alternatively increased or decreased in compassion with those of new rice. However, the results indicated that mw heating condition did not influence the color of rice too much.

Table 1. Changes of physical and physicochemical properties at different microwave heating conditions

Attribute	Exposure time (s)	Heating round/Microwave power level (W)					
		1		2		3	
		1000 W	2000 W	1000 W	2000 W	1000 W	2000 W
Moisture content (% wet basis)	0	13.68±0.03c	13.68±0.03c	13.68±0.03b	13.68±0.03d	13.68±0.03d	13.68±0.03a
	41	13.37±0.03a	13.05±0.05a	12.98±0.07ab	12.39±0.06a	11.80±0.10a	11.38±0.02b
	31	13.44±0.09ab	13.39±0.05b	12.91±0.13a	12.78±0.08b	12.27±0.10b	12.14±0.04c
	23	13.59±0.11bc	13.59±0.18bc	13.15±0.60ab	13.02±0.12c	12.68±0.09c	12.53±0.16d
WU (%)	0	61.23±1.89a	61.23±1.89a	61.23±1.89a	61.23±1.89a	61.23±1.89a	61.23±1.89a
	41	63.08±1.60ab	65.44±0.84b	62.91±0.44a	65.19±1.24c	64.30±0.54a	62.55±0.30a
	31	68.15±1.08c	64.89±1.44b	62.94±0.39a	63.24±0.95ab	63.63±0.29a	62.16±0.59a
	23	64.92±0.74b	64.00±0.78b	68.80±0.51b	64.18±0.45bc	63.98±2.52a	63.05±0.04a
L*	0	74.20±0.04a	74.20±0.04a	74.20±0.04a	74.20±0.04a	74.20±0.04a	74.20±0.04a
	41	75.15±0.17b	76.01±0.35b	76.14±0.18b	76.37±0.19c	74.65±0.22b	75.14±0.13b
	31	75.53±0.11c	75.55±0.19b	76.11±0.05b	75.42±0.02b	74.13±0.12a	76.46±0.11a
	23	76.00±0.21d	76.54±0.32c	76.55±0.06c	75.63±0.22b	75.74±0.37c	74.19±0.24a
C	0	14.77±0.08b	14.77±0.08b	14.77±0.08a	14.77±0.08c	14.77±0.08b	14.77±0.08ab
	41	14.65±0.12b	14.25±0.08a	14.46±0.29a	14.23±0.17a	14.39±0.05a	14.80±0.20b
	31	14.49±0.04a	14.21±0.07a	14.59±0.16a	14.34±0.26ab	15.19±0.11c	14.50±0.17a
	23	14.73±0.05b	14.46±0.28a	14.49±0.11a	14.58±0.16bc	14.75±0.28b	14.58±0.12ab
h	0	89.38±0.06a	89.38±0.06a	89.38±0.06a	89.38±0.06a	89.38±0.06b	89.38±0.06a
	41	89.57±0.06b	90.23±0.06c	90.00±0.28b	90.27±0.12c	89.70±0.08c	89.86±0.20b
	31	89.99±0.08c	89.77±0.20b	90.15±0.10b	89.91±0.07b	88.83±0.06a	90.13±0.17b
	23	89.64±0.07b	90.04±0.07c	90.29±0.09b	89.92±0.33b	89.60±0.38bc	89.93±0.12b
Hardness (N)	0	151.78±1.15c	151.78±1.15b	151.78±1.15d	151.78±1.15b	151.78±1.15b	151.78±1.15b
	41	134.99±1.78a	122.30±4.06a	123.28±2.89a	137.74±1.83a	150.79±1.11b	157.62±3.09c
	31	140.35±4.87b	121.79±5.12a	135.10±1.89b	157.47±2.71c	140.37±5.25a	144.51±2.21a
	23	149.69±1.30c	119.02±1.17a	144.62±3.83c	136.70±0.66a	163.23±2.84c	143.16±3.41a
Stickiness (-N)	0	21.14±1.59a	21.14±1.59a	21.14±1.59ab	21.14±1.59a	21.14±1.59a	21.14±1.59a
	41	19.38±2.40ab	19.03±1.49a	25.50±1.89a	18.95±5.72a	20.46±3.04a	21.23±3.42a
	31	20.21±1.43a	21.90±1.54a	18.10±2.35b	17.58±0.33a	23.58±3.08a	22.07±1.24a
	23	16.29±2.26b	21.83±1.89a	20.55±4.60ab	18.19±2.49a	23.77±2.63a	16.34±1.07b
Solid loss (%)	0	3.61±0.16a	3.61±0.16a	3.61±0.16a	3.61±0.16a	3.61±0.16a	3.61±0.16a
	41	4.33±0.27a	3.83±0.39a	3.70±0.32a	4.03±0.25a	4.01±0.62a	3.41±0.01a
	31	4.58±1.21a	4.48±1.38a	4.02±0.62a	4.41±0.61a	3.93±0.54a	3.69±0.66a
	23	4.37±0.82a	3.94±0.55a	3.77±0.47a	4.22±0.88a	4.34±0.07a	3.27±0.11a

Data shown as mean ± standard deviation (n = 3 for moisture content, water uptake, and solid loss; n = 8 for color and texture)
Means with different superscript letters with the same column for each attribute differ significantly ($P < 0.05$).

Jaroenkit *et al.* (2013) also supported that MWH did not much affect on color during heating cooked brown rice. However, in consideration as a detail, there were changes in color of heating rice when compared to the new rice especially the lightness and hue value. The changes in color may be due to color pigment and moisture removal associated Maillard reaction during mw heating. The various Maillard reactions could be happened between reducing sugar from the heated starch, and the amino group in the protein during MWH due to various effects of MWH on rice depending on moisture and compositions inside. Warchalewski and Gralik (2010) verified that MWH of wheat grains within the temperature range of 28-98°C statistically significant increased in reducing sugars content but was noted in grain samples heated only to 48°C; a decrease was noted above this temperature. Since the unique interaction between microwave and rice component including water, the temperature during MWH did not show linear relationship among MWH conditions. Therefore, the different results of Maillard reaction may result in different colors of treated samples. This indicates that accelerated rice aging by microwave, no single criteria of color are sufficient to be used as an index of accelerated rice aging. The study of Kapoor *et al.* (2011) on deterioration of seed due to accelerated rice aging also confirmed similarly.

Texture: The hardness of three rounds at 41s was significantly increased in comparison with that of new rice while it decreased for 1 and 2 rounds. The stickiness alternatively decreased and increased after MWH as compared to that of new rice and varied among heating times. It was obvious that after MWH, the hardness and stickiness were variously changed when compared to new rice. The increase in hardness was found corresponding with three rounds of MWH. This could be explained by the fact that the optimal cooking time is modified with microwave treatment due to physical and physicochemical changes. The increase in hardness of cooked rice was explained by increasing disulfide linkages in protein (Chrastil, 1990). After three rounds, the starch granule in rice kernel might become stronger plus the cell membrane disorganization which led to the fact that the water might be less contacted to the granules and subsequently reduced hydration process when the rice was cooked in certain cooking time. The cooked rice grain had a lower water uptake and subsequently became harder. The interaction of microwave and rice components including water might be varied between 1,000 and 2,000 W. The MWH treatment of cereals was able to increase the water holding capacity. However, due to various effects of microwave interacting with water and other components in rice, this led to varied values of water uptake after cooking. Since the quality and quantity of various types of proteins, starches, and dietary fibers in any raw material could predict the texture of product (Ashraf *et al*., 2012).

Solid loss: The solid loss did not change much when compared to new rice although it seemed to

Table 2. Multiple range tests for aging properties by microwave power level, exposure time, and heating round

Contrast	HRY		WU		L*		C		h		Hard.		Stick.	
	Sig.	Diff	Sig.	Diff	Sig.	Diff	Sig.	Diff	Sig.	Diff	Sig.	Diff	Sig.	Diff
MW (W)														
1000 - 2000	*	1.29	ns	0.06	ns	0.04	*	0.20	*	-0.25	*	4.68	ns	-1.19
Exposure time (s)														
23 - 32	ns	1.06	ns	-0.04	*	0.53	ns	0.05	ns	0.11	*	2.81	ns	1.08
23 - 41	*	-2.75	ns	-0.02	ns	0.15	ns	0.14	ns	-0.04	*	4.95	ns	1.26
32 - 41	*	-3.81	ns	0.02	*	-0.38	ns	0.09	ns	-0.14	ns	2.15	ns	0.19
Round														
1 - 2	*	-7.36	*	0.28	*	-0.24	ns	0.02	*	-0.22	*	-7.80	ns	0.04
1 - 3	*	-20.80	*	0.29	*	1.12	*	-0.24	*	0.20	*	-18.59	ns	1.47
2 - 3	*	-13.44	ns	0.01	*	1.36	*	-0.25	*	0.41	*	-10.79	ns	1.43

* denotes a statistically significant difference at $P < 0.05$. (Method: LSD).
ns: non-significant

Table 3. F values and significant level from ANOVA for effect of process conditions on head rice yield and aging properties

Source	HRY	WU	L*	C	h	Hardness	Stickiness	Solid loss
MAIN EFFECTS								
A:MW	4.75*	1.64^{ns}	0.30^{ns}	11.89**	12.25**	23.41***	2.13^{ns}	1.38^{ns}
B:Exposure time	14.78***	0.22^{ns}	15.50***	1.96^{ns}	1.38^{ns}	8.80***	0.93^{ns}	1.11^{ns}
C:Round	424.23***	15.51***	111.12***	8.29***	10.73***	124.35***	1.40^{ns}	2.66^{ns}
INTERACTIONS								
AB	0.03^{ns}	7.62**	15.35***	3.43*	0.95^{ns}	59.19***	0.49^{ns}	0.42^{ns}
AC	47.03***	4.83*	11.74***	1.08^{ns}	8.11**	82.49***	4.56*	3.22^{ns}
BC	5.47**	5.96***	4.12**	1.85^{ns}	0.67^{ns}	22.87***	2.27^{ns}	0.17^{ns}

*$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$; ns: non-significant

be increased after MWH except for three rounds of higher power level of MWH. Among three rounds, the rice after 3 rounds at higher mw power level seemed to be stronger during boiling process which was explained by less water uptake and solid loss when compared to counterparts.

A summary of effect of individual factor's level on rice aging properties is shown in Table 2. There was a significant difference between two levels of mw power in HRY, color intensity, h value, and hardness. Among three exposure times, the HRY was insignificantly different between 23 s and 31 s; the lightness was similar between 23 s and 41 s while the similar hardness was found for 31 s and 41 s. The HRY, lightness, h value and hardness were significantly changed at every round while the water uptake was not significant between two and three rounds. The color intensity was insignificantly different between one and two rounds which meant the appearance of treated rice noticeably changed after two rounds of MWH.

Table 3 shows the effect of three factors as the main and interaction effects on accelerated rice aging properties. Three factors showed a great effect on HRY especially exposure time and heating round ($P \leq 0.001$). The heating round influenced most of attributes except for stickiness and solid loss. The stickiness and solid loss were insignificantly affected by three factors' level in this study although the interaction effect of microwave power and heating round was revealed on stickiness. The water uptake, color intensity, and h value also were not influenced by different exposure times. The water uptake was not significantly different by two levels of MWH power and three levels of exposure time. The hardness was hugely affected by three factors' level as the main and interaction effects.

The interrelation between three factors was remarkably revealed among aging attributes especially for hardness, lightness, and water uptake. The significant effects of the interaction and the required higher order terms for those attributes suggest that the other factors might be involved. In other words, the factors influencing those attribute are not only three chosen factors in this study but there might be other factors involved. On the other hand, the effect of microwave power level, exposure time, and heating round were respectively shown at different accelerated aging properties. However, different levels of three chosen factors did not vary the stickiness and the solid loss in general. Moreover, three levels of exposure time did not result in different browning appearances of heated sample. The browning reaction was not significantly enhanced when increased the exposure time.

Effect of microwave power and heating round on pasting properties

In this study, there were changes in viscosity properties after MWH treatment for all treatments relatively compared to non-treated sample (Table 4). Peak viscosity, final viscosity and trough were decreased with increased heating rounds. After 1 round of MWH, those attributes increased when compared to the new rice. According to natural rice aging, the peak viscosity decreased while the final,

Table 4. Pasting properties of rice flour with and without microwave heating treatment at different microwave heating powers and heating rounds

Sample	Peak vis.	Trough	Breakdown	Final vis.	Setback
1000-41s-1R	1189.5±0.71c	1072±2.83cd	117.5±3.54ab	1651±15.56ab	579±18.38a
1000-41s-2R	1159.5±13.44b	1049.5±19.09bc	110±5.65a	1647.5±6.36ab	598±12.73a
1000-41s-3R	1157±1.41b	1040±0.00bc	117±1.41ab	1589.5±4.95ab	549.5±4.95a
2000-41s-1R	1209±9.90c	1088±18.38d	121±8.49ab	1696.5±41.71b	608.5±60.10a
2000-41s-2R	1152±18.38b	1030±25.46b	122±7.07ab	1637±63.64ab	607±89.10a
2000-41s-3R	1113±16.97a	980±4.24a	133±12.73b	1594±84.85ab	614±80.61a
New rice	1154.5±2.12b	1037±0.00bc	117.5±2.12ab	1551.5±0.71a	514.5±0.71a

Subscription at the same column for each attribute are not significantly different at $P < 0.05$.
(1000 and 2000 = 1,000W and 2,000W; R = round)

Table 5. Correlation coefficients of aging attributes

	Moisture content	Water uptake	Solid loss	Hardness	Stickiness	L	C	H
HRY	-0.7904***	-0.3714**	-0.2743*	0.6774***	-0.0367^{ns}	-0.6400***	0.3213*	-0.1683^{ns}
Water uptake	0.2148^{ns}		0.2171^{ns}	-0.1723^{ns}	0.1646^{ns}	0.2022^{ns}	-0.2524^{ns}	0.0569^{ns}
Solid loss				-0.0518^{ns}	0.0914^{ns}	0.080^{ns}	-0.0849^{ns}	-0.1110^{ns}
Hardness					0.0941^{ns}	-0.3592**	0.2917*	-0.2185^{ns}
Stickiness						0.0503^{ns}	-0.2007^{ns}	0.2206^{ns}
L							-0.3889**	0.5538***
C								-0.6969***
h						0.5538***		
Moisture content								

Pearson Correlation (n = 54)
$^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$; ns: non-significant

the setback and the pasting temperature increased (Indhudhara Swamy *et al.*, 1978; Perdon *et al.*, 1997). Those attributes were similarly found in this study although other attributes were variously changed corresponding with heating rounds and MWH powers. The peak and final viscosity noticeably affected by MWH conditions in this study.

The breakdown and the setback were fluctuated for lower MWH power while for higher MWH power it was increased in breakdown and setback viscosity as increased heating round. Noomhorm *et al.* (1997) reported that after aging, the ability of starch granules to rupture after cooking reduced which means decrease in breakdown viscosity. However, in this study, it was mostly increased in breakdown. This is similar to the research of Anderson and Guraya (2006) for MW-heated starch. For microwave heating, researchers also found that the breakdown of non-waxy starch heated in microwave oven increased from 29.8 RVU (non-treated starch) to 35.8 RVU (MWH). The increased breakdown could be explained by cell wall structure of starch granule that might be destroyed during microwave repeated heating. This allowed water absorption and enhanced water penetration during the RVA run (Zhou *et al.*, 2003). Moreover, the rupture of starch released the soluble amylose which meant the breakdown of starch related to the solubility of starch. The more soluble of starch the more it will be thin on shearing (Hoseney, 1998). In addition, the setback viscosity was supported by Jaisut *et al.* (2009) and Soponronnarit *et al.* (2008) as an index of accelerated rice aging; increase in setback value associated with rice aging. The result of increased setback when compared to new rice was found in this study although there was no significant difference. On the other hand, it might be included other interactions apart from starch (Sowbhagya and Bhattacharya, 2001) such as protein solubility (Ashraf *et al.*, 2012). Microwave interaction with those components including water might change the starch granule towards decreased hydrophobicity that could affect granule hydration and swelling during early heating period. This limited swelling of starch granules and resulted in lower peak viscosity (Zhou *et al.*, 2003). On the other hand, at the limited water content, the effect of MWH on starch can be as a process of modification. The interaction between starch and microwave at low moisture content could result in different oxidized starches, i.e. different yield of carboxyl and carbonyl groups and depolymerization (Wing and Willett, 1997). This led to various interactions with other components in rice and resulted in alternative changes of viscosity. However, in general there was insignificant difference in breakdown and setback when compared to new rice in this study.

The MWH condition affected on viscosity of new rice flour in this study; however, there were alternative changes at different rounds and MW powers. The changes of these properties indicate that the progressive arrangement of rice structure corresponding to MWH condition. This kind of structural arrangement seems to catch essence of the rice aging process. This kind of change related to all rice paddy properties. Increase in setback indicated a higher degree of retrogradation and this led to increase in firmness of cooked rice (Soponronnarit *et al.*, 2008).

Correlation of aging properties undergoing microwave-heating condition

After MWH operations, when heat and airflow were removed, the moisture continued to migrate from the center to the surface of the kernels and caused compressive stresses on the surface. When such compressive stresses of the surface exceed the internal tensile strength, cracking occurs within the kernel (Nguyen and Kunze, 1984). Moreover, in MWH system, due to the instant water removal and then moisture gradient in subsequence, the cracks or fissures could be formed during MWH. Thus, the reduced HRY was related to the higher internal cracking formation or fissure development during and after MWH. According to Table 5, for one and two rounds, those cracks might be extended during milling, which were more than three rounds. On the other hand, the HRY showed negative correlation ($P \leq 0.001$) with moisture content. In MWH, the moisture after one round was partially removed from the high initial moisture content (13.68% wet basis) when compared to two and three rounds. The moisture that partially removed from cell tissue might be not distributed homogeneously after one round. Thus, the higher imbalance of moisture distribution inside kernel might be presented in one round comparing to two and three rounds (lower moisture content). The higher imbalance of moisture inside kernel could result in high compressive stress on the surface.

In parallel, after one round of MWH, the initial strength of husk was still strong to cover the endosperm. The loosing husk was more extended as increased in heating rounds. From this result, it indicated that the increase in heating rounds for MWH of paddy rice was useful in terms of tenderizing and loosing the husk, which facilitated for de-husking process. The lower moisture content led to the husk easily removed out resulting in sample with decreased numbers of broken rice ($P \leq 0.001$).

MW power level did not affect lightness but affected browning appearance. The color intensity of heating rice was alternatively affected by MW power level and heating round. The temperature during MWH did not show a linear relationship with MW power level and heating round (significant interaction effect, Table 3). Therefore, various Maillard reactions between reducing sugar and the amino group in the proteins were obtained during microwave heating. Moreover, the HRY had a negative correlation with lightness and positive with color intensity. In other word, when the rice looked browner, the head rice yield was also improved. That was similar to natural rice aging and parboiled rice. However, there were alternative changes of color in this study.

The hardness was positively correlated with the HRY. The effect of 1,000 and 2,000 W was also different in this study (Table 2). The MWH treatment modified texture values especially hardness. This could be explained by the fact that the optimal cooking time was modified with microwave treatment (mentioned earlier part). Moreover, a respective interaction between MWH conditions suggest that aging properties were varied for MHW treatment, which explains for variation of hardness and stickiness of cooked rice (insignificant correlation, Table 5).

The water uptake was insignificantly correlated with the texture and the solid loss but significantly correlated to the HRY (negative correlation, $P \leq 0.001$). During boiling, the water penetrated inside kernel and the gelatinization process was taken place. The increase in water uptake might be related to internal crack generated after milling process. The crack plays an important role in water penetration during cooking. The internal cracks could be more existed in the sample with higher HRY.

Conclusion

MWH condition in this study produced noticeable effects on rice properties of newly harvested paddy rice in terms of accelerated rice aging. Three chosen factors remarkably influenced HRY especially heating round. The rice with three rounds of MWH was noticeably improved in HRY when compared to one round, two rounds, and new rice. After one and two rounds of MWH, the HRY significantly reduced in comparison with that of new rice. The HRY had positive correlation with hardness and color intensity but negative correlation with moisture content, water uptake, solid loss, and lightness. The stickiness and the solid loss were insignificantly affected by MWH conditions. The hardness and the stickiness of cooked rice did not have a significant correlation under MWH. MWH treatment produced the changes in viscosity properties of flour especially in peak and final viscosity. The peak viscosity and the final viscosity decreased while the breakdown viscosity slightly increased with increased heating round and microwave power level which caught essential aging characteristics. Furthermore, the statistical analyses showed significant interactions among conditions on respective aging properties. The resulting higher order polynomial interaction suggests that microwave-accelerated rice aging is a complex process that might still be influenced by other factors. The further analysis of each rice component influenced by MWH treatment through dielectric properties would be useful in managing microwave-accelerated rice aging conditions that will produce rice with specific and consistent functional properties.

Acknowledgements

This research was funded by The Commission of Higher Education and Thailand Research Fund with contract number MRG5080447. The authors would like to thank Department of Food Science and Technology, Faculty of Agro-Industry and Kasetsart University for supporting the scholarship.

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