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Microwave heating for accelerated aging of paddy and white rice

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Abstract

Microwave heating treatment (MWH) can be applied for accelerated rice aging. Two microwave powers (MWP) (1,000 and 2,000 W) and six exposure time (ET) (23, 26, 31, 41, 66, and 159 seconds) were applied to paddy (PD) and white rices (WR) of indica cultivar as potential accelerated rice aging agent. The newly harvested rice was sun dried to < 14% dry basis and then heated under MWH. The head rice yield (HRY), color and gel consistency were determined for microwave-treated and untreated sample (control). Furthermore, texture of cooked rice grains, pasting properties, and gel texture of rice paddy after optimum MWH (41 seconds) were further investigated. After 41 seconds of MWH (by two levels of MWP), the HRY of PD decreased (≈ 5 %) while other MWH conditions caused a larger decrease in HRY of PD, compared to the control sample, especially for higher MWP at 66 s (31.97%) and 159 s (74.78%). The cooking time of white rice (WR) was also decreased while that of PD increased, compared to the control sample. The gel consistency was increased and variously changed depends to the form of rice and ET. After MWH, the appearance of WR was whiter while the PD looked browner with increased on exposure time ET, compared to the control. The cooked rice from WR was more damaged and less uniformed compared to PD. Further investigation on optimum condition for PD (41s) indicated increase in hardness of cooked rice grains, pasting properties and soft gel when compared to the control sample. The effect of MWP and ET was dissimilar between PD and WR on different rice aging properties, in which the PD seemed more effective to be applied as accelerating rice aging agent.

Keywords: Accelerated rice aging; microwave heating; white rice; paddy.
Abbreviations: CI_Color intensity; ET_Exposure time; GC_Gel consistency; HRY_Head rice yield; PD_Paddy rice: MWH_Microwave heating treatment; MWP_Microwave power; WI_Whiteness index; WR_White rice.

Introduction

Rice plays an important role in economic development of many countries in Asia. The consumers who prefer the firmness of cooked rice normally require the rice be stored for a certain time. The firmness and fluffiness of cooked rice from freshly harvested paddy are generally increased by traditional paddy storage method, which is ~3-6 months or more. This phenomenon is called as aging of rice (Indudhara et al., 1978). However, under natural storage condition, the rice is stored for a quite long time, which is considered as non-economic aspects due to storage space requirement, insect damage, and high operating cost (Gujral and Kumar, 2003). For this reason, the accelerated rice aging techniques have been applying for a faster boost in rice cooking quality. Rice aging mechanism is a complicated process, which has been not completely understood so far (Zhou et al., 2002). Generally, physical and physicochemical changes are related to the alteration of different rice chemical components which may affect rice aging pathway (Champagne et al., 1999; Lim et al., 1999; Teo et al., 2000; Jaisut et al., 2009; Likitwattanasade and Hongsprabhas, 2010; Le and Songsermpong, 2013).
Conventional heating methods such as conduction and convection are normally used to accelerate rice aging. Rough, brown, or milled rice are heated by conventional intermediate and high temperatures (Bhattacharya et al., 1964; Limchan et al., 1999). The suitable wet heat treatment of freshly harvested paddy was studied by Gujaral and Kumar (2003). Fluidized bed with high temperature (Jaisut et al., 2009) or fluidized bed combined with tempering and ventilation (Soponronnarit et al., 2008) was also studied for accelerated rice aging. Recently, the optimum conditions for accelerated aging of paddy were conducted by controlling temperature of incubator and relative humidity for certain period of storage (Likitwattanasade and Hongsprabhas, 2010; Rayaguru et al., 2011). The heating treatment could generally be from dry heat to moist heat treatment. The process has to be carried out for a long period of time, which may vary from minutes to several hours, even more than ten days. Electromagnetic waves have been applied as short time treatment techniques in rice acceleration such as gamma irradiation and radio frequency. However, the knowledge of application of microwave heating treatment (MWH) on rice aging is limited. Meanwhile, the MWH has been shown a great effect on major rice components especially starch through re-associate branch chains of amylopectin and protein through inactivate enzyme activities (Delwiche et al., 1996; Lewandowicz et al., 2000; Anderson and Guraya, 2006; Palav and Seetharaman, 2007; Zhao et al., 2007; Emami et

al., 2011). During microwave heating, the vibrating motion of the polar molecules such as water, starch and proteins may result a rapid increase in temperature leading to a component modification (Sowbhagya and Bhattacharya, 2001; Ashraf et al., 2012). However, for starch sample, the supported effect from MWH is the rapid heating rate while the effect of microwave energy (vibration effect) is not completely understood yet or did not have a significant impact (Fan et al., 2013).

It is well-known that the MWH provides benefits for low moisture content grains in terms of being fast and effective drying in comparison with conventional methods. In conventional heating mechanism, the heat transfers at the surface of the grain and then proceeds inside. As results of this process, the heating treatment process takes a long time. Moreover, at the low initial moisture content, such heating mechanism may cause a lot of cracks inside the kernel leading to quality degradation. However, in microwave drying, heat generation takes place within and throughout the kernel, which creates a positive temperature gradient and outward moisture drying potential (Manickavasagan et al., 2006). Therefore, the heating results in microwave heating could be faster and the heating treatment process could be taken place in shorter time. Moreover, the rapid heat generation inside products increases the rate of water removal (Yongsawasdigul and Gunasekaran, 1996; Tang et al., 2000; Wang et al., 2001) which could provide some changes in rice chemical structure associated with rice aging. So far, the study with MWH on grains at low moisture content for accelerated rice aging has been limited.

Although the microwave heating treatment process on rice is faster than conventional heating method, major problem in MWH is about uneven heating at surface or inside grain kernel since the sinusoidal wave pattern of microwave develops hot and cold spots on the bulk grain sample (Manickavasagan et al., 2006). The location of hot and cold spots may vary in different dryers based on the position of magnetron and other components but almost a similar non-uniform heating pattern is expected in all microwave dryer (Manickavasagan et al., 2006). Moreover, because rice sample contains other chemical compositions such as starch, protein, and lipid containing polar groups beside the water, they certainly influence the process of heat generation under MWH (Fini and Breccia, 1999).

Since the major effect of uneven heating of MWH has effectively solved yet, the screening study of the effect of MWH and then the optimal heating conditions of MWH at different exposure time and microwave powers should be selected for specific dryer. This study was aimed to (1) investigate the effect of single stage heating at high microwave power on accelerated aging properties for two rice forms (paddy and white), and (2) further characterize physical and physicochemical properties of selected/optimum conditions.

Results and Discussion

Effect of microwave heating treatments on head rice yield

According to Fig 1, two levels of microwave power (MWP) resulted in sample with a decreased head rice yield (HRY), compared to untreated rice (control sample), in which the HRY of higher MWP decreased more than that of lower MWP. The extremely lower HRY was found at 159 s for two levels of MWP. However, the HRY of the sample treated at 41s for both levels of MWP seemed to be higher in comparison with other treatments and not much different from that of control sample. The control sample had 36.76% of HRY while the HRY of 1,000 W at 41 s gained 34.99% and that of 2,000 W at 41 s 35.04%. For the quality of dried paddy, the HRY is one of the most important characters concerned by rice millers. Commonly, the higher the HRY is, the better the heating condition. In this study, the percentage of HRY was found to be lower than previously reports (Bhonsle and Sellappan, 2010; Rayaguru et al., 2011) due to the difference in degree of milling and type of milling machine. Moreover, the different HRY between studies was also depended on rice varieties, cultivation practices, drying conditions (Dipti et al., 2003) and inherent fissures or cracks inside the kernels. Fissuring can occur in the field prior to harvest, or during harvesting and processing (Cnossen et al., 2003).

The extreme reduction in HRY for samples at 66 and 159 s may be the effect of higher heat generation by MWH for rice grains with low moisture content. Moreover, the fluctuation in HRY could be found between different exposure time of MWH. For example, the HRY of sample heated at 1,000 W at 26 s seemed to decrease when compared to that at 23 and 31 s; however, the samples at these microwave heating conditions were not much different. Similarly, the samples at 23, 26, and 31 s for 2,000 W were not significantly different for HRY although there seemed to decrease as decreased heating time. The fluctuation in HRY was due to the fluctuated heat generation by MWH. Since MWH is the selected heating technique, the suitable moisture content may cause change in rice starch properties, in terms of more agglomeration. Under MWH, there is an interaction between microwave and dielectric properties in rice sample (polar molecules which can be water or other molecules such as starch and protein). The water in rice is the most concern as a polar molecule when the rice is placed in the microwave field. Moreover, the protein may also be another component that interacting with microwave. These components with polar groups are considered to interact with microwave, which are converted into heat (Fini and Breccia, 1999). The relationship between the amount of heat generation as well as the changes in chemical components inside rice kernel and heating time under MWH may not be a linear relationship. The increase in temperature inside rice may not be linear with that in heating time since there were many factors influencing on temperature generation such as density, specific heat, and thermal conductivity of rice. The various increases in heat between samples could be achieved due to different heating time, which lead to various types of cracks and fissures. The results indicated that the crack or fissure generation is occurred from changes in rice chemical components, which are significantly happen due to duration of heating time. The decrease in HRY may be due to the imbalance loss of moisture during MWH that caused high moisture gradient and then weaken strength in kernel due to crack and results in more broken kernels (Juliano, 1985). Theories on fissure formation, as a result of drying, are based on the response of rice kernel to tensile and compressive stresses due to moisture content gradients within the kernel (Cnossen et al., 2003). Therefore, any non-uniformity of MWH could lead to the moisture gradients which caused differential stress inside the kernel, which, if sufficiently large, causes the kernel to fissure.

The inherent cracks or fissures existed in kernel occurred in the field prior to harvest, or during harvesting and processing prior to MWH, which may or may not extend during MWH due to the process of starch gelatinization. For 41 s, the starch may be at an appropriate condition taking place the process of gelatinization. Some fissures or cracks could be sealed or

Table 1. Effect of microwave heating condition on pasting, cooked rice and gel texture properties.

Conditions	Pasting properties			Texture of cooked rice grains		Texture of gel	
	Peak (cP)	Final vis. (cP)	Setback (cP)	Hardness (N)	Stickiness (N)	Hardesss (g)	Adhesiveness (g.sec)
1000W,41s	1188.5±0.70b	1653 ± 15.76ab	577 ± 18.48a	89.43±6.33b	20.45 ± 1.94b	56.91±5.13b	57.85 ± 5.35b
2000W,41s	1206 ± 9.89b	1698.5 ± 41.72b	606.5±60.17a	90.18±5.74b	15.74 ± 1.65ab	57.49±8.55b	45.33 ± 6.27ab
New PD	1155.5 ± 2.14a	1552.5 ± 0.74a	517.5±0.62a	77.65±7.14a	13.45±2.12a	72.86±9.89a	50.79 ± 8.04a

Different letter in column is significant difference at the significant level $p < 0.05$ (PD: Paddy)

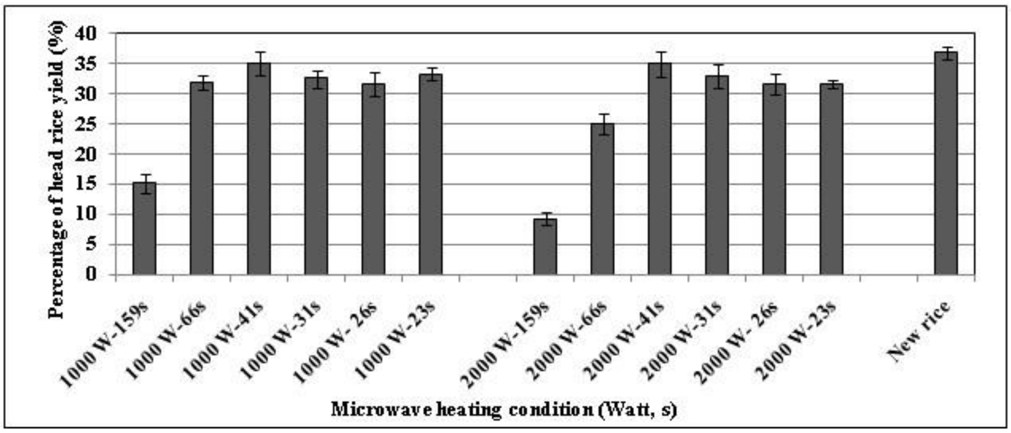

Fig 1. Effect of microwave heating conditions on head rice yield (The vertical bars present ± standard deviation, n = 3).

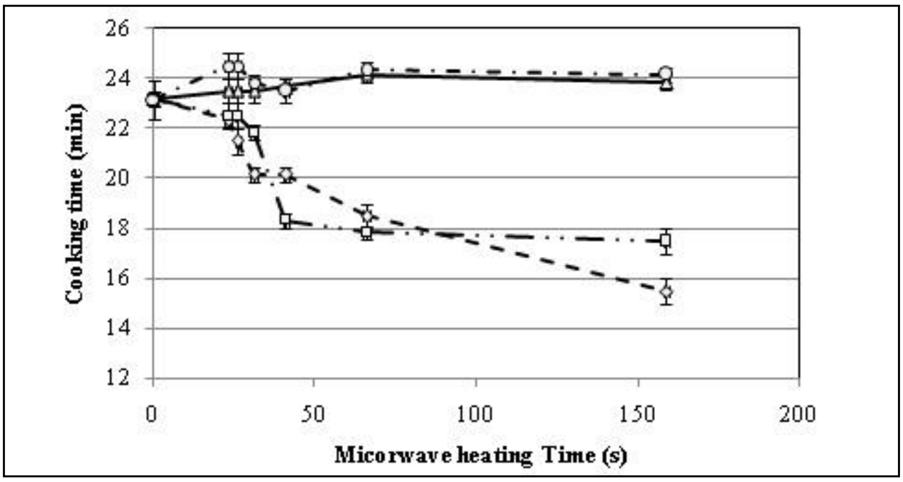

Fig 2. Effect of microwave heating conditions on cooking time (─ ─◊─ ─: 1,000 W, White rice; ─ · ·□─: 2,000 W, White rice; ──Δ──: 1,000 W, Paddy; ─ ·○─: 2,000 W, Paddy)

changed the status when the starch partially gelatinized (Soponronnarit et al., 2008). This phenomenon may be an appropriate explanation in this study. Some results showed reduction or stagnation when heating time increased. Moreover, the changes in starch granules also affect HRY at low moisture content rice sample. More agglomerations of starch granules at low moisture content led to the fact that the rice was more tolerant to impact force during milling and subsequently increased in HRY (Juliano, 1985; Le and Songsermpong, 2013). The result suggested that the selected condition for HRY is necessarily chosen at suitable MWH conditions.

Effect of single stage heating at high microwave power on accelerated aging properties of rice

Effect of microwave heating treatment on cooking characteristics

The cooking time at different MWH are shown in Fig 2. The cooking time of untreated rice (control sample) was 23.17 min. For white rice (WR), the cooking time decreased by increased exposure time (ET), compared to control sample.

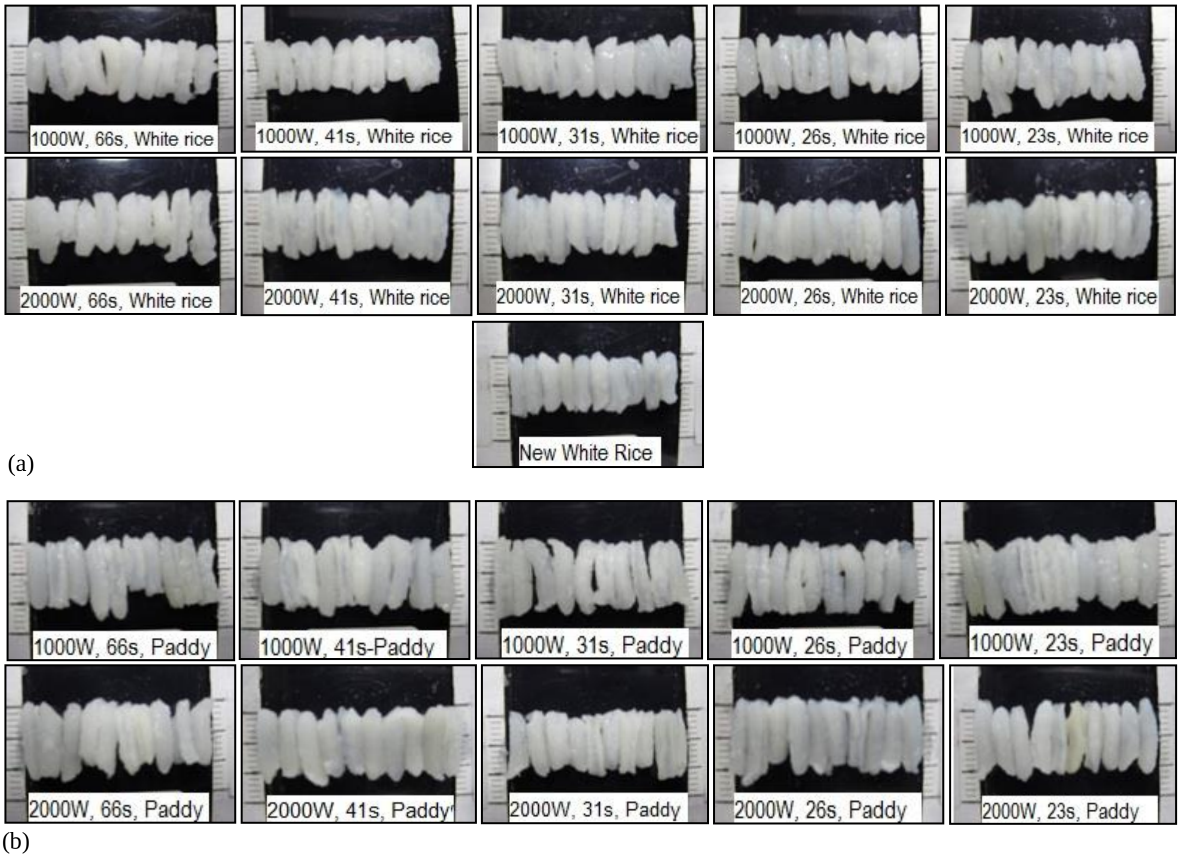

Fig 3. Effect of microwave heating conditions on appearance of cooked rice from white rice treated form (a) and paddy treated form (b).

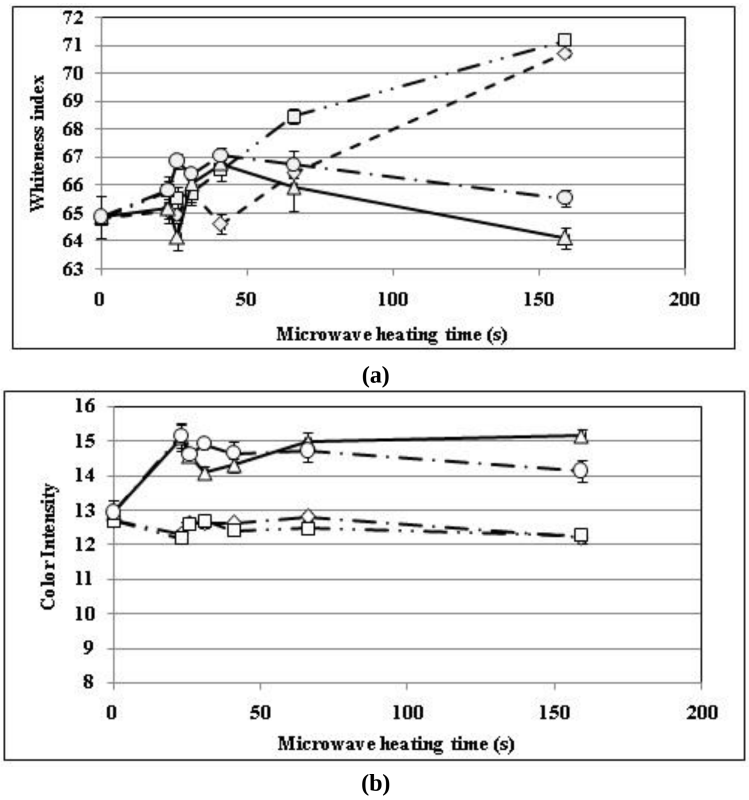

Fig 4. Effect of microwave heating conditions on whiteness index (a) and color intensity (b) (— —◇— —: 1,000 W, White rice; — · ·□—: 2,000 W, White rice; ——Δ——: 1,000 W, Paddy; — ·○—: 2,000 W, Paddy).

The cooking time of 41, 66, and 159 s (at 2,000 W) was much lower than that of control sample while that of 23, 26, and 31 s for those MWP was insignificantly different, compared to control sample although they seemed to be slightly lower than control sample. There was significant difference in cooking time for WR between two levels of MWP. For paddy (PD), the cooking time increased after MWH. The cooking time of 1,000 W slightly increased when ET increased from 23 to 41 s, while that of 2,000 W highly increased. There was no significant difference in cooking time between two levels of MWP after 31 s for PD. The lower cooking time was due to more crack formation of rice grains since the cracks could allow water to infuse the kernels at the greater rate (Rosniyana et al., 2004). On the other hand, the cooking time was also depended on chemical components such as starch and protein (Zhou et al., 2002). For WR, the sample without husk and bran layer was directly exposed to the microwave heating, which was different from PD. The MWH is influenced by dimension, density, and dielectric properties (different rice components) of sample.

The differences in rice components including the water probably caused the difference in interactions between starch and protein under MWH, which led to different changes in physical (crack or fissure) and physicochemical properties (gelatinization or denaturation). The higher cracks or fissures led to the higher water penetration during cooking resulting in the sample with the lower cooking time. In this study, the samples at 23, 26 and 31 s at 1,000 and 2,000 W for WR seemed to be slightly decreased in cooking time. On the other hand, the samples at other ET had a huge decrease in cooking time, when compared to the control sample. Moreover, the cooking time of these samples for higher microwave power was lower than that for lower microwave power. Different heat generations may be accounted for such a difference. The effect of higher heat generation for higher microwave power might cause a higher water removal or high moisture diffusion, remarkably influencing chemical components and subsequently results in more cracks or fissures. On the other hand, the change in cooking time may be due to the increase in water insolubility of rice starch during MWH. The increase in water insolubility of rice starch was taken place during the aging process resulting in a slower rate of cooking (Rosniyana et al., 2004). Moreover, any changes that are not sufficiently breaking up the cell wall (crack or fissure) or cell membrane results in the sample with disordered cells. The disordered cell wall in rice kernel could slow down the hydration rate and result in the sample with the higher cooking time, in comparison with counterparts. However, such phenomenon just happened at the suitable time under MWH. The more extension in heating time from such change resulted in samples with huge cracks as observed by the largely decrease in cooking time. Similarly, for the PD, the increase in cooking time was explained by physical characteristics such as cell wall disorders and chemical aspects such as insoluble starch, starch gelatinization or denaturing of protein (mentioned earlier). Results showed that the form of treated rice influenced the cooking time and generally, the WR had a significant lower cooking time than the milled rice of treated paddy. These results indicated that PD was more resistant than WR under MWH at the different heating time, especially at the heating time greater than 31 s suggesting the accelerated aging properties of PD at these periods of ET.

Effect of microwave heating treatment on cooked rice appearance

The images of 159 s were not shown since the rice was almost broken after cooking as porridge. Generally, MWH caused changes in rice size and shape after cooking, which depended on the form of treated rice. According to Fig 3, the ET of longer 66 s resulted in the cooked samples for both PD and WR with extensive loss such as broken kernels or voids. This was due to the fact that such ET caused the rice more cracks or fissures that facilitated the water penetration during cooking process. The higher rate of water penetration may result in the cooked sample with voids when being cooked. The WR under MWH at shorter 41s seemed to variously change in size and shape when compared to control sample, while the PD had more uniformity especially at higher MWP. Moreover, the length and the width of cooked rice from PD seemed to be longer and larger than those of WR and control sample (Fig 3), which was an essential of rice aging according to Gujaral and Kumar (2003) and Jaisut et al. (2009). These researchers reported that the cooked rice kernels from accelerated rice aging increased in volume and elongation.

For WR, the length and width of cooked rice kernel were variously changed. There were various sizes and shapes between cooked rice kernels after MWH. The different changes in length and shape may be due to the non-uniform heating effect of MWH when cooked. Moreover, the moisture distribution in each kernel may not be similar prior to MWH. Therefore, the effect of MWH may be dissimilar for individual rice kernel and subsequently the different temperature may result in different kernels. Such heating effect of MWH also leads to various changes in protein and starch granules. The starch and protein were proved to influence swelling of cooked rice kernel since these two components are related to water absorption of the kernel (Zhou et al., 2002; Zhao et al., 2007). The various changes in size and shape for treated white rice suggests a non-uniform microwave heating effect on white rice , resulted in varied cell wall disorders. According to Rosniyana et al. (2004), the changes in volume expansion of cooked rice kernels are due to interaction between heat treatment with moisture content. For MWH, it might be explained with the interaction between microwave and rice components including the water inside the rice kernel. Due to the non-uniform heating characters of MWH, some parts of kernel may have the opened cell walls , resulted in the cooked rice with partially broken rice or voids on the surface of cooked rice due to the huge rate of water penetration. The other parts in the kernel may have closed cell walls that resist the high pressure inside the cell during cooking process, which resulted in the increased volume of kernel. Subsequently, the cooked rice kernels were not uniform in size and shape. In general, after MWH the size and shape of cooked rice kernels were changed variously in white rice (Fig 3a).

For paddy rice, excepting for the samples at 66 s, other conditions of MWH had a better uniform length which was also longer than treated white rice. The results may be the fact that for milled rice from treated paddy, the process of separating after milling process may remove a part of weak kernels (easily broken kernels) after MWH. The remained kernels was quite resistant during cooking process especially for samples at 23, 26, 31, and 41 s of 2,000 W (Fig 3b).

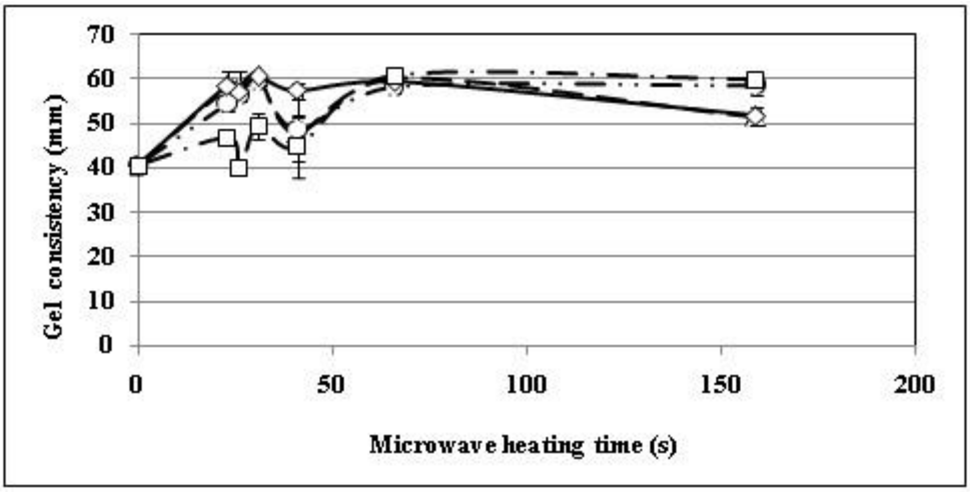

Fig 5. Effect of microwave heating conditions on gel consistency (— —◊— —: 1,000 W, White rice; — · ·□—: 2,000 W, White rice; ──Δ──: 1,000 W, Paddy; — ·○—: 2,000 W, Paddy).

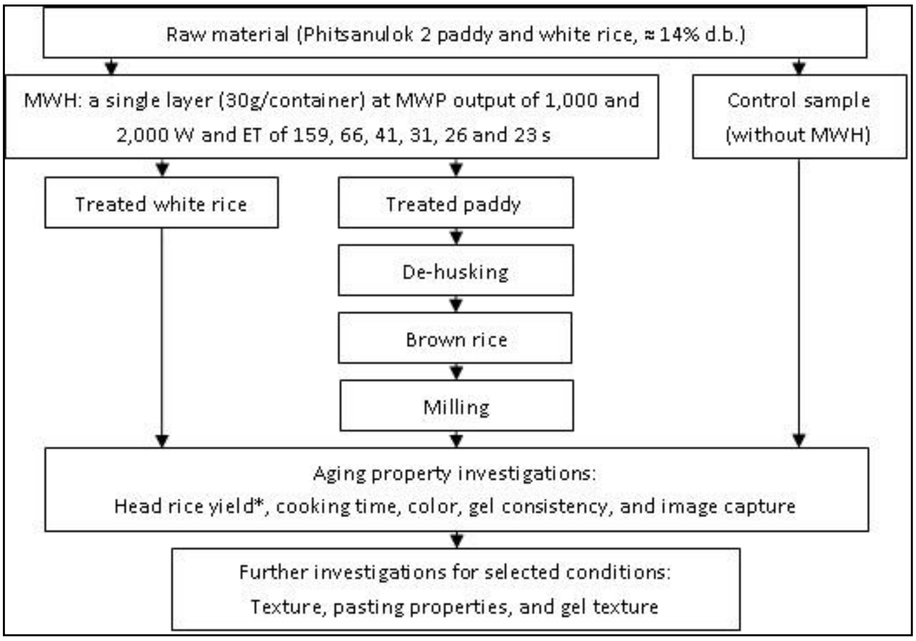

Fig 6. Experimental plan of microwave heating treatment (*determined for paddy).

The appearance of cooked rice at these conditions was more opaque. Meanwhile, for the white rice, such weak kernels were still kept same, before and after MWH. Therefore, different kernel characters created from MWH resulted in various sizes and shapes after cooking (Fig 3a).

Effect of microwave heating treatment on color changes

It was interesting that in WR, the higher MWP and longer ET cause the whiter and more opaque rice kernel, leading to increase in whiteness index (WI) and decrease in color intensity (CI) (Fig 4). The remarkable changes in those values were found for 66 and 159 s of two levels of MWP. The color of WR at these conditions was sharply changed, which was observed as waxy rice appearance. Meanwhile, the WI of PD variously changed after MWH depending on ET, while the CI increased remarkably, compared to control sample. This may be due to the higher moisture gradients corresponding with high temperature generated inside the rice kernel that facilitate the pigment of color moving from bran layer to endosperm (Rao and Juliano, 1970; Islam et al., 2004). In addition, the condensation of water during MWH might lead to an increase in the amount of free amino acid (Iyota et al., 2002). With rapid increase in paddy temperature, Maillard reaction and the infusion of color substances from rice husk and rice bran into endosperm may be accelerated (Inprarsit and Noomhorm, 2001). However, in WR, the outer layer is removed before heating and the water loss and change in chalky area of rice grains might be correlated to the increased whiteness of rice. This phenomenon is well-known and consistent with report of Rordprapat et al. (2005). It was noted that when the surface becomes whiter, it also creates a lot of cracks and fissures in kernel that results in broken grains during cooking (Rao et al., 2007). These results found to be well-agreed with the results of cooking time: the increased CI seemed to have a higher cooking time. For non-waxy rice, the rice becomes whiter (opaque) that is undesired for rice industry. The kernel with free of chalk and very translucent was desired by most segment of rice industry according to Champagne (2007). According to the results, the milled rice from treated paddy form was more desired than that from treated white rice form under MWH.

Effect of microwave heating treatment on gel consistency

The cooled tube was laid horizontally, and the length of the gel was measured after 30 min, as distance from the bottom of the tube to the gel front by digital veneer caliper (Cagampang et al., 1973). The GC of the rice samples is 26─40 and 41─60 mm which are categorized as hard and medium gel in general. The GC of 61 to 100 mm is classified as soft gel. The tendency of cooked rice that has a hard gel after being cooked seems to be harder on cooling. The GC was measured as medium hard to medium in this study (Fig 5), according to Cagampang et al. (1973). The rice without MWH was in a margin of hard gel while among the MWH conditions, the length of blue gel was variously changed by MWH conditions. The freshly harvested rice had a harder gel than the microwave treated rice (Rosniyana et al., 2004) who reported that fresh paddy had a hard gel and the gel consistency did not significantly change during storage. However, the changes in gel consistency proved the changes in properties of rice chemical components after MWH.

For PD, there was a slight difference in gel consistency while there was a larger difference for WR with two levels of MWP, depending on ET. For WR, the higher MWP seemed to be harder GC at 26 and 41 s. In higher yielding rice, the GC ranged from 40─48 mm, corresponding with control sample and 41 s. The GC was variously changed with increased microwave heating time. The various changes may be due to the different changes in chemical components under MWH. The various gel consistencies may relate to various changes in cooking time and color changes. In this part, the GC of WR was largely different between two levels of MWP, especially at the heating time from 23 to 41 s. This may be due to the fact that at these ET, two levels of MWP differently interacted with rice components (including water) which result in remarkable changes in chemical properties between samples of two levels of MWP. The difference of gel in this study in comparison with previous researches of high amylose content may be due to the different degree of milling and grinding. The degree of milling was related to the presence of lipid while the degree of grinding was related to the complete dispersion of starch or ease of gelatinization. The incomplete dispersion led to formation of opaque clumps and consequently resulted in a more dilute gel that is softer than it should really be, if fully dispersed (Perez, 1979). Moreover, the fraction of soluble protein could show the effect on gel consistency values. The high values of gel consistency are associated with high protein content (Juliano, 1985). Although there was a fluctuation in gel consistency after MWH between two forms of rice and different MWH conditions, MWH resulted in samples with higher gel consistency or soft gel when compared to control sample. Although it is unclear to find a link between gel consistency and aging of rice, the soft gel resulted from MWH suggested that the microwave heating could improve the quality of rice, according to Perez (1979), the soft gel was preferred to the hard gel.

Cooked rice grain texture, pasting properties and gel texture of microwave-treated paddy at selected conditions

After comparison between WR and PD for several physical and physicochemical properties, we found that exposure time should be shorter or equal to 41 s since the greater heating time resulted in more losses. For WR, the appearance of treated white rice was whiter, which may not be preferred by industry. For PD as subjected to heating treatment, the most important aspect, which should be concerned, is about the head rice yield. The large reduction in the head rice yield may be not preferred by rice miller. According to this study, the heating time more than 41 s resulted in the samples with huge reduction in head rice yield, while less than 41 s exposure, can reduce the head rice yield. Moreover, regarding to heating effect from MWH for the lower heating times of 41 s, the heat generation and distribution inside kernel may not be well distributed. The hypothesis was that among 4 levels of heating time (23, 26, 31, and 41 s), the longer time of microwave heating could be better for heat generation and distribution through rice kernels. Therefore, by compromising between the accelerated rice aging and head rice yield purpose, the selected conditions of 1,000 and 2,000 W at 41 s were further studied for PD to compare with new PD.

According to Table 1, the hardness and stickiness of samples under MWH were higher than those of untreated rice in this study. There was no significant difference of hardness but a difference of stickiness between two levels of MWP. Apart from depended physical characteristics, the texture of cooked rice was also depended on chemical characteristics of raw kernels such as amylose content and temperature of gelatinization (Mestres et al., 2011). The hardness and stickiness were affected by amylose and short chain of amylopectin leached out during cooking process (Rewthong et al., 2011). Higher MWP might result in samples with internal cracks and fissures leading to more leached out components during cooking and then resulting in lower stickiness.

The viscosity properties after MWH increased when compared to non-treated sample (Table 1). The peak viscosity, final viscosity and setback increased with increased MWP, especially for the peak and final viscosity. These were essential changes of rice aging (Indudhara et al., 1978; Perdon et al., 1997; Noomhorm et al., 1997). Increased setback was as an index of accelerated rice aging (Jaisut et al., 2009 and Soponronnarit et al., 2008). In this study, although the setback of samples treated by MWH was not significantly different from new rice, there was an increase in setback after MWH and more extension with higher MWP. Increase in setback indicated a higher degree of retrogradation that led to increase in firmness of cooked rice (Soponronnarit et al., 2008).

The microwave electromagnetic energy absorption capacity influences the gelatinization of starch (Palav and Seetharaman, 2007). The extension of capacity was directly related to the water content in rice samples during MWH. As samples heated under MWH, the water molecules in the rice kernel mainly absorbed the microwave electromagnetic energy and continuously converted the electromagnetic energy into kinetic and thermal energy. The rapid movement of the water molecules caused constant collisions between the water molecules with rice components such as starch granules and protein, which may accelerate the movement of these components in rice matrix. As the water reached boiling point, the water diffusion may pass through starch granules and other components to transfer thermal energy, resulting in a rapid increase in the temperature. The temperature of samples rose quickly, which may lead to the loss of ordered structure of the starch such as double helices (Fan et al., 2013). As temperature rose up, the structure of protein was changed due to denaturation. Moreover, the water molecules in the starch granules absorb a large amount of microwave energy and create continuous movement and vibration, which may lead to an increased interaction inside (between two components of starch) and outside the starch granules (starch components with protein).

The absorption capacity of the microwave electromagnetic energy in starch granules is different between two levels of MWP. Higher MWP resulted in the samples with higher kinetic energy and then highly promoted the transformation from ordered to disordered structures (Fan et al., 2014). The internal structure of starch and the content of changed structures were different between two levels of MWP. Different MWP caused different moisture removals and altered starch granules in terms of transformation of the ordered structures. Subsequently, together with changes in structure of protein, alteration of starch gelatinization process may be resulted in rice kernel during cooking process.

It was obvious that after MWH, the gel strength decreased, when compared to the new PD (Table 1), while the adhesiveness could increase or decrease depending on MWP. It seemed that the hardness of gel at 1,000 W was lower than that at 2,000 W, while the adhesiveness was higher. The result indicated that the sample with low initial moisture content could modify starch components, which may affect the gelatinization process of starch. A different mechanism of gelatinization was suggested from the researches (Goebel et al., 1984; Zylema et al., 1985; Palav and Seetharaman 2007). Those researchers found that the lacks of granule swelling and soft gel are two key observations that are different from conventional heating. Fan et al. (2013) reorted that the rate of heating determined the differences in the proportions of amorphous starch and double helices, while the electromagnetic effects of microwave heating did not have any significant impact on the ordered structures in starch granules. The effect of electromagnetic on starch and other rice components are not well-understood yet; therefore, more researches should be conducted.

The results found in this study were in agreement with the recent review study (Brasoveanu and Nemtanu, 2014), reporting that microwave irradiation induces generally rearrangements of starch molecules, leading to changes in properties like solubility, swelling power, rheological behavior, gelatinization temperatures and enthalpy as well as granule morphology and crystallinity. The researchers reviewed that those properties were depended on starch type and its moisture content, exposure time to microwave, processing temperature and absorbed microwave energy. According to results from selected conditions, the aging of PD was accelerated by MWH. Between two levels of MWP, the higher MWP resulted in sample with more extension of rice aging properties.

Materials and Methods

Sample preparation

The new paddy (PD) of Phitsanulok 2 variety (indica type) (≈ 14% d.b.) was obtained from Phatumthanee Rice Research Center, Thailand and then divided into 2 parts corresponding with and without MWH (as control sample).

Experimental design and microwave heating treatment

A continuous type of industrial microwave dryer (2,450 MHz) operated at 220 VAC, 60 Hz, 23 A (Industrial Microwave Systems, King Mongkut's Institute of Technology, Ladkrabang) consisted of a conveyer-belt assembly, microwave applicator, fan, and a control panel was used in this study. Two levels of output microwave heating (MWP) (1,000 and 2,000 W) and six levels of exposure time (ET) (23, 26, 31, 41, 66, and 159 seconds) were applied for both white rice (WR) and paddy rice (PD). Different ETs were achieved by changing the speed of the conveyor. For each run, 30 g sample were thinly spread on a ceramic container. Fifteen containers were applied for each experimental run. The top surface was flattened before being run on the conveyer belt. The experiment plan was depicted in Fig 6.

Milling and grinding

After MWH, all 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 separated into the head rice grains and broken grains by separator. For milling process, each of batches, equal to 100 gram was put into the miller and polished to white rice. The period of milling was 30 seconds for each batch. The head white rice was ground with a laboratory mill (motor 0.25 HP/220V/50Hz, Muninmax Ngow Huat Yoo Co., Ltd, Thailand) to obtain flour.

Statistical analysis

The data was analyzed by analysis of variance (ANOVA) and Duncan's multiple range test at the significant level $p \leq 0.05$ by STATGRAPHICS Centurion Version XVI (StatPoint Technologies, Inc. Warrenton, VA 20186, USA).

Head rice yield

The head white milled rice was used for investigating aging properties. The head rice yield (HRY) was performed according to the Rice Research Institute, Thailand. The HRY is defined as the ratio of mass of head rice obtained from milling to mass of paddy at the beginning. The HRY was determined in 3 replications.

Color measurement

Measurement was based on the CIE-LAB system with color values of L^*, a^* and b^* display. Color of samples was measured after MWH by Hunter-Lab colorimeter XE-scan (Chromameter model CR-300, Japan). The whiteness index (WI) and the color intensity (CI) were determined according to Saricoban and Yilmaz (2010). The higher color intensity was corresponding with browner appearance. Eight replications and two samples were measured for color.

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (1)$$

$$CI = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

Determination of cooking time

The head white rice was washed by tap water prior to cooking process. The cooking process was performed in the aluminum cans covered by aluminum foils at 97 ± 2 °C on hot plate (modified Gujral and Kumar, 2003). Each sample contained 20 g of boiled distilled water and 5 g of washed rice. After 12 min, several kernels with chalky core were observed under two microscope glass slides. The period when the chalky core was disappeared was used as a cooking time.

Image investigation

The optimal cooking time was applied and then images captured. Ten cooked rice kernels randomly picked up from 3 aluminum cans which were conducted for cooking process. They were placed on a black background with the scale paper. The image of each sample was captured by 14.1 mega pixels Canon camera (Canon Ixus 130, Canon Inc, Japan).

Gel consistency

Gel consistency is an index of cooked rice texture, which is defined as the length of gelatinized rice flour paste in a test tube after cooling to the room temperature. The study was adopted the method of Cagampang et al. (1973) with minor modifications. The cooled tube was laid horizontally, and the length of gel was measured after 30 min, as the distance from the bottom of the tube to the gel front by digital veneer caliper.

Physicochemical and chemical properties of selected heating condition for paddy

In this study, the PD treated at two levels of MWP (1,000 and 2,000 W), and one level of ET (41 s) was applied for further investigation.

Texture of cooked rice grains

The optimal cooking time of 22 min was applied to cook for all treatments to determine textural properties. The method was modified from Rewthong et al. (2011). Six cooked kernels were placed on the platform of texture analyzer machine (TA-XT2, Stable Micro Systems., UK). A cylindrical probe of 36 mm diameter attached to a 50-kg 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. Hardness and stickiness were determined as maximum and negative force value, respectively.

Pasting properties

The pasting properties of rice flours (180-micron size) were analyzed using a Rapid Visco Analyzer (RVA-4, Newport Scientific Pty. Ltd., Warriewood, Australia). The pattern of RVA analysis was a standard method for rice flour. The peak viscosity, final viscosity, and setback were recorded for samples with duplication.

Gel texture

A texture analyzer (TA-XT2, Stable Micro Systems., UK) with a 50-kg load cell was used to determine the textural properties of rice gel using a two-cycle compression. A two-cycle compression of 85% of the original gel thickness was carried out according to a method modified from Yu et al. (2012). The flour gel after testing with RVA was poured into plastic box (diameter × high: 20.0 mm × 20.0 mm) and kept in a refrigerator for 36 h. The gel samples were then compressed with a 6 mm diameter ebonite probe at pre-test speed of 1.0 mm/s, test speed and post-test speed of 5.0 mm/s. The texture analyses were repeated 4 times per sample.

Conclusion

The white rice (WR) was more sensitive to microwave heating treatment (MWH) especially at higher MWP and ET than PD. The surface of treated white rice looked whiter than treated paddy which was browner. For WR, the length and width of cooked rice kernels were variously changed. The different changes in length and shape may be due to the non-uniform heating effect of MWH when cooked. There was a larger different effect of MWH between two levels of MWP for WR, rather than PD. For PD, MWH resulted in samples with a reduction of head rice yield (HRY). However, at the suitable heating time, the HRY was not changed too much when compared to the control sample. The investigated results of accelerated rice aging indicated that PD was more extended in aging than WR at low initial moisture content. The WR exposed directly to high MWH resulted in more damages during cooking such as more broken cooked rice and voids especially at longer ETs (41s). Two levels of MWP at 41s were used to treat the PD which caused increases in hardness, pasting properties and soft gel of flour. The effect of MWP and ET was dissimilar between PD and WR on different rice aging properties. The gel consistency and gel texture may not be correlated with rice aging while firmness of cooked rice kernels and setback could be more correlated to rice aging. The intermittent MWH with cycle heating including the tempering may be useful in enhancing HRY and other aging properties.

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References

Anderson AK, Guraya HS (2006) Effects of microwave heat-moisture treatment on properties of waxy and non-waxy rice starches. Food Chem. 97: 318–323.

Ashraf S, Saeed SMG, Sayeed SA, Ali R (2012) Impact of Microwave Treatment on the Functionality of Cereals and Legumes. Int J Agr Biol. 14: 1560–8530.

Bhattacharya KR, Desikachar HSR, Subrahmanyan V (1964) Curing of freshly harvested rice by heat treatment. Indian J Technol. 2: 378–380.

Bhonsle SJ, Sellappan K (2010) Grain quality evaluation of traditionally cultivated rice varieties of Goa, India. Recent Res Sci Tech. 2: 88–97.

Brasoveanu N, Nemtanu MR (2014) Behaviour of starch exposed to microwave radiation treatment: review article. Starch/Stärke. 66: 3–14.

Cagampang GB, Perez CM, Juliano BO (1973) A gel consistency test for eating quality of rice. J Sci Food Agr. 24(12): 1589─1594.

Champagne ET (2007) Assessing sensory quality of rice to meet industry needs. International Rice Research Meeting Proceedings. 11. United States Department of Agriculture, USA, 17 April 2007.

Champagne ET, Bett KL, Vinyard BT, McClung AM, Barton FE, Moldenhauer K, Linscombe S, McKenzie K (1999) Correlation between cooked rice texture and rapid visco analyser measurements. Cereal Chem. 76(5): 764─771.

Cnossen AG, Jeménez MJ, Siebenmorgen TJ (2003) Rice fissuring response to high drying and tempering temperature. J Food Eng. 59: 61–69.

Delwiche SR, McKenzie KS, Webb BD (1996) Quality characteristics in rice by near-infrared reflectance analysis of whole-grain milled samples. Cereal Chem. 73: 257–263.

Dipti SS, Bari MN, Kabir KA (2003) Grain quality characteristics of some Beruin rice varieties of Bangladesh. Pakistan J Nutr. 2: 242–245.

Emami S, Perera A, Meda V, Robert T, Tyler T (2011) Effect of microwave treatment on starch digestibility and physico-chemical properties of three barley types. Food Bioprocess Technol. 1─9.

Fan D, Ma W, Wang L, Huang J, Zhang F, Zhao J, Zhang H, Chen W (2013) Determining the effects of microwave heating on the ordered structures of rice starch by NMR. Carbohydr Polym. 92: 1395– 1401.

Fini A, Breccia A (1999) Chemistry by microwave. Pure Appl Chem. 71(4): 573–579.

Goebel NK, Grider J, Davis EA, Gordon J (1984) The effects of microwave energy and convection heating on wheat starch granule transformations. Food Microstruct. 3: 73–82.

Gujral HS, Kumar V (2003) Effect of accelerated aging on the physicochemical and textural properties of brown and milled rice. J Food Eng. 59: 117─121.

Indudhara SYM, Sowbhagya CM, Bhattacharya KR (1978) Changes in physicochemical properties of rice with aging. J Sci Food Agric. 29: 627─639.

Inprarsit C, Noomhorm A (2001) Effect of drying air temperature and grain temperature of different type of dryer and operation on rice quality. Dry Technol. 19(2): 389–404.

Islam MR, Shimizu N, Kimura T (2004) Energy requirement in parboiled and its relationship to some important quality indicators. J Food Eng. 63(4): 433─439.

Iyota H, Nishimura N, Onuma T, Nomura T (2002) Drying of sliced raw potatoes in superheated steam and hot air. Dry Technol. 19: 1411–1424.

Jaisut D, Prachayawarakorn S, Varanyanond W, Tungtrakul P, Soponronnarit S (2009) Accelerated aging of jasmine brown rice by high-temperature fluidization technique. Food Res Int. 42: 674–681.

Juliano BO (1985) Criteria and tests for rice grain qualities. In: Juliano BO (ed) Rice: chemistry and technology, 2nd edn. American Association of Cereal Chemists, St. Paul, Minnesota.

Le TQ, Songsermpong S (2013) Head rice yields, pasting properties and correlations of accelerated paddy rice aging properties by microwave heating conditions. Int Food Res J. 21(2): 703–712.

Lewandowicz G, Janowski T, Fornal J (2000) Effect of microwave radiation on physico-chemical properties and structure of cereal starches. Carbohydr Polym. 42: 193–199.

Likitwattanasade T, Hongsprabhas P (2010) Effect of storage proteins on pasting properties and microstructure of Thai rice. Food Res Int. 43: 1402–1409.

Lim HS, Lee J-H, Shin D-H, Lim HS (1999) Comparison of protein extraction solutions for rice starch isolation and effects of residual protein content on starch pasting properties. Starch/Stärke. 51: 120─125.

Limchan S, Chancharoensuk N, Thamakorn P (1999) Feasibility study on accelerated aging of rough rice. Paper was presented at the 30th anniversary agricultural exhibition of King's Mongkut Institute of Technology Ladkrabang, Bangkok, Thailand, 24-25 June 1999.

Manickavasagan A, Jayas DS, White NDG (2006) Non-uniformity of surface temperature of grain after microwave treatment in an industrial microwave dryer. Dry Technol. 24: 1559–1567.

Mestres C, Ribeyre F, Pons B, Fallet V, Matencio F (2011) Sensory texture of cooked rice is rather linked to chemical than to physical characteristics of raw grain. J Cereal Sci. 53: 81─89.

Noomhorm A, Kongseree N, Apintanapong N (1997) Effect of aging on quality of glutinous rice crackers. Cereal Chem. 74: 864─867.

Palav T, Seetharaman K (2007) Impact of microwave heating on the physico-chemical properties of a starch–water model system. Carbohydr Polym. 67: 596–604.

Perdon AA, Marks BP, Siebenmorgen TJ, Reid NB (1997) Effect of rough rice storage condions on the amyloghaph and cooking properties of medium-grain rice cv. Bengal. Cereal Chem. 74: 861─867.

Perez CM (1979) Gel consistency and viscosity of rice. In: Proceedings of a Workshop on Chemical Aspects of Rice Grain Quality, IRRI, 1978. Los Baños, Laguna, Philippines: International Rice Research Institute. p 293–302.

Rao PS, Bal S, Goswami TK (2007) Modeling and optimization of drying variables in thin layer drying of parboiled paddy. J Food Eng. 78: 480─487.

Rao RSN, Juliano SO (1970) Effect of parboiling on some physicochemical properties of rice. J Agric Food Chem. 11: 289–294.

Rayaguru K, Pandey JP, Poutray W (2011) Optimization of process variables for accelerated aging of basmati rice. J Food Quality. 34: 56–63.

Rewthong O, Soponronnarit S, Taechapairoj C, Tungtrakul P, Prachayawarakorn S (2011) Effects of cooking, drying, and pretreatment methods on texture and starch digestibility of instant rice. J Food Eng. 103: 258–264.

Rordprapat W, Nathakaranakule A, Tia W, Soponronnarit S (2005) Comparative study of fluidized bed paddy drying using hot air and superheated steam. J Food Eng. 71: 28–36.

Rosniyana A, Hashifah MA, Norin SAS (2004) Effect of heat treatment (accelerated ageing) on the physicochemical and cooking properties of rice at different moisture contents. J Trop Agric Food Sci. 32(2): 155–162.

Saricoban C, Yilmaz MT (2010) Modeling the effects of processing factors on the changes in colour parameters of cooked meatballs using response surface methodology. World Appl Sci. 9(1): 14─22.

Soponronnarit S, Chiawwet M, Prachayawarakorn S, Tungtrakul P, Taechapairoj C (2008) Comparative of physicochemical properties of accelerated and naturally aged rice. J Food Eng. 8: 268─276.

Sowbhagya CM, Bhattacharya KR (2001) Changes in pasting behavior of rice during aging. J Cereal Sci. 34: 115─124.

Tang J, Ikediala JN, Wang S, Hansen JD, Cavalieri RP (2000) High-temperature-short-time thermal quarantine methods. Postharvest Biol Tec. 21(1): 129–145.

Teo CH, Abd A, Cheah PB, Norziah MH, Seow CC (2000) On the roles of protein and starch in the aging of non-waxy rice flour. Food Chem. 69: 229–236.

Wang S, Tang J, Cavalieri R.P (2001) Modeling fruit internal heating rates for hot air and hot water treatments. Postharvest Biol Tec. 22(3): 257–270.

Yongsawatdikul J, Gunasekaran S (1996) Microwave-vacuum drying of cranberries: Part I. Energy use and efficiency. J Food Process Pres. 20: 121─143.

Yu S, Ma Y, Menager L, Sun D-W (2012) Physicochemical Properties of Starch and Flour from Different Rice Cultivars. Food Bioprocess Technol. 5: 626–637.

Zhao S, Xiong S, Qiu C, Xu Y (2007) Effect of microwaves on rice quality. J Stored Prod Res. 43(4): 496–502.

Zhou Z, Robards KT, Helliwelt S, Blanchard C (2002) Ageing of stored rice: Changes in chemical and physical attributes. J Food Sci. 35: 65─78.

Zylema BJ, Grider JA, Gordon J, Davis EA (1985) Model wheat starch systems heated by microwave irradiation and conduction with equalized heating times. Cereal Chem. 62: 447–453.