CHAPTER 4

EFFECTS OF MILLED RICE GRAIN MOISTURE CONTENT DURING ACCELERATED AGING ON PHYSICO-CHEMICAL, PASTING AND TEXTURAL PROPERTIES, AND AROMA INTENSITY OF FRESHLY HARVESTED RICE CV. KDML 105

4.1 Introduction

As already known, change in cooking and eating properties of cooked rice from stored paddy is associated with time of storage (aging levels). Aging can improve some of eating properties of rice that is preferred by Asian consumer, but aging at the same time, reduced amount of 2-acetyl-1-pyrroline which is the most important quality indicator for aromatic rice. To derive rice of having aged characteristics shortly after the mature paddy had just been harvested, a technique called accelerated aging has been employed (Gujral and Kumar, 2003; Soponronnarit *et al*., 2008). The technique was reported to be a success in improving cooking and eating properties of the freshly harvested rice. Gujral and Kumar (2003) reported that freshly harvested paddy could be successfully aged by steaming and effects of the accelerated aging treatment increased with increasing grain moisture content. Accelerated aging of paddy with dry heat treatments had also been reported to improve some rice quality attributes that could be comparable to those of naturally-aged rice and aging with higher grain moisture content had been recommended (Soponronnarit *et al*., 2008). These research results suggested the importance of grain moisture content in aging treatment. The present study was thus conducted to include grain moisture content as an additional accelerated aging factor.

The objective of this study was to evaluate the effects of milled rice grain moisture content during accelerated aging with different exposure temperatures and durations. Effects of the treatment were evaluated based on physico-chemical property changes in terms of pasting properties, textural properties, color parameters, solid loss, amylose content and kernel elongation. Aroma quality of the aged rice samples was also determined in terms of the amount of 2-acetyl-1-pyrroline and relative amount of *n*-hexanal.

4.2 Materials and Methods

In this Chapter, exposure durations from each of the temperature treatment (100, 110 and 120°C) in Chapter 3 that indicated good aging effects were selected to study further. These aging treatments were studied in combination with two different milled rice grain moisture contents (13.3 and 16.6% MC wet basis). Effects of the combined accelerated aging treatments were determined and compared, based on changes in the physico-chemical properties as studied in Chapter 3. In this experiment, loss of solid during cooking, change in amylose content, cooked rice kernel elongation and aroma quality as measured by the amount of 2-acetyl-1-pyrroline and relative amount of *n*-hexanal of the accelerated aged rice samples were also determined.

4.2.1 Rice Samples and Preparations

Rice cv. KDML 105 was grown in 2005 season at Lampang Agricultural Research and Training Center, Rajamangala University of Technology Lanna, Lampang, on the same experimental plots of rice sample used in the previous year experiment. Preparation of rice samples was done as mentioned in Chapter 3. The rice was harvested at maturity by hand, left to dry 2 to 3 days in the field and then threshed to paddy of approximately 14% MC. The freshly harvested paddy sample was dehulled by a McGill sample sheller and the resulting brown rice was milled for 30 sec in a friction-type miller operating with a 1.0 kg weight positioned at the end of a 25-cm mill lever arm. Head rice was separated from the broken kernel by a cylinder grader and stored at room temperature for subsequent treatments. A portion of the rice sample was separated and determined for its physico-chemical properties. Protein (N×5.95) and lipid contents of the head rice as determined by AOAC (1999) standard methods were 7.64 and 0.88%, respectively. Apparent amylose content was 17.59% (w/w) as determined according to the method of Juliano *et al.* (1981).

4.2.2 Accelerated Aging Treatments

Prior to accelerated aging treatment, the head rice sample was divided into 2 portions by a Boerner divider (Seedburo Equipment Co., Chicago, IL). One portion was allowed to equilibrate with room atmosphere and another portion was adjusted to be high in MC by placing the samples in sealed plastic boxes containing distilled water for 7 days at room temperature. The MC of both sample portions was determined in triplicates at day 7 by drying in an oven setting at 103°C for 17 hrs and the MC was 13.4 and 16.6% (wet basis, wb) for ordinary and high MC grain, respectively. Processing of accelerated aging rice was done by placing 370 g of rice sample into aluminum containers and sealed. The containers were then exposed to three different temperatures and the selected duration treatments, namely, 100°C (60, 90 and 120 min), 110°C (30 and 45 min) and 120°C (15 and 30 min) in an automatic autoclave (SS-320, Tomy Seico Co. Ltd., Wako, Saitama, Japan). Temperature at the center of the rice containers was recorded using a data logger and the mean reported was an average of three replications. Temperature profiles of the three extreme (100°C-120 min, 110°C-45 min, and 120°C-30 min) accelerated aging treatments are shown in Figure 4.1 and for the rest are presented in Appendix 1 and 2. After exposure, the samples were cooled down for about 2 hr at 21°C and kept in zip-locked plastic bags at 4°C for physico-chemical properties analyses. For 2-acetyl-1-pyrroline and *n*-hexanal determination, the samples were kept at -20°C.

4.2.3 Determination of Pasting Property, Textural Property and Color Parameters

Sample preparation and analyses for pasting property, textural property and color parameters were conducted by similar procedure as described in Chapter 3.

4.2.4 Determination of Solid Loss, Amylose Content and Kernel Elongation

Solid loss during cooking was determined by boiling 5.00 g milled rice in a test tube containing 30 ml distilled water for 15 min in a hot water bath set at 99±1°C. The drained cooking water was oven-dried and weighed to determine the percent of solid loss. Apparent amylose content was determined using an iodine colorimetric method as described by Juliano *et al.* (1981). Kernel elongation was an average length (mm) of 10 unbroken kernels of cooked rice sample prepared for the determination of textural property. All were determined in three replicates.

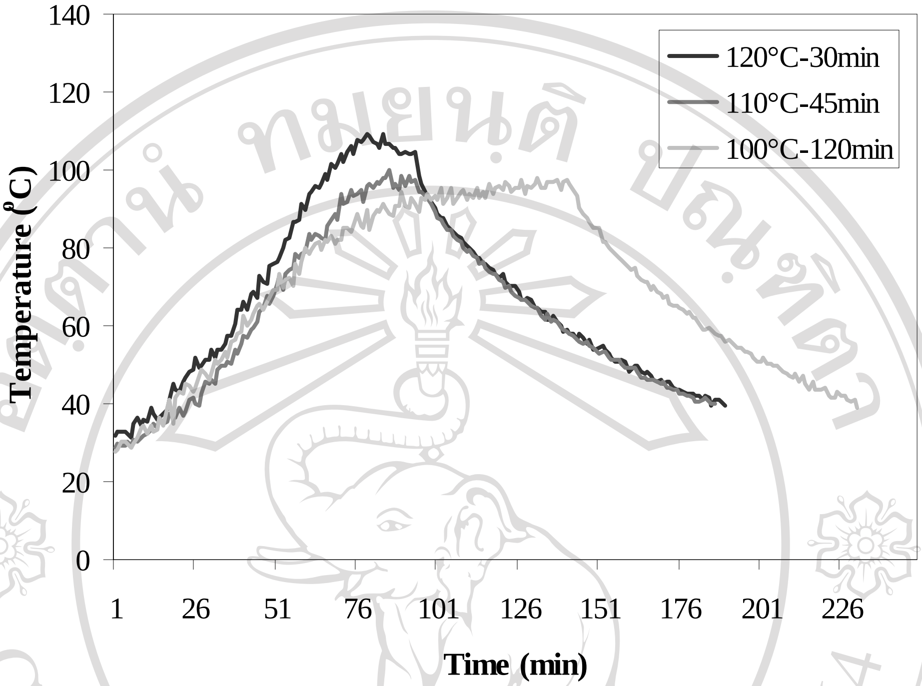

Figure 4.1 Temperature profiles of three extreme accelerated aging treatments. Data recorded at the center of milled rice containers.

4.2.5 Analysis of 2-Acetyl-1-pyrroline and n-Hexanal

The amount of 2-acetyl-1-pyrroline and *n*-hexanal representing aroma and off-odor compound in the rice samples were determined, following the method developed by Sriseadka *et al*. (2006). Milled rice sample was ground to pass through a 0.5 mm screen and the resulting flour, weighing exactly 1.000 g, was placed into a 20 ml headspace vial. An internal standard (1 µL of 0.50 mg/ml 2,6-dimethylpyridine in benzyl alcohol) was added into the vial which was then immediately sealed with a PTFE/silicone septum (Restek Corp., Bellefonte, PA) and an aluminum cap. Then the volatile compounds, 2-acetyl-1-pyrroline and *n*-hexanal, in the rice headspace were determined utilizing an Agilent Technologies (Wilmington, DE) gas chromatograph model 6890N equipped with headspace autosampler (Agilent Technologies model

G1888) and a fused silica capillary column, HP-5 (5% phenyl 95% dimethylpolysiloxane, 30 m × 0.53 mm i.d., 1.5 µm film thickness; J&W Scientific, Folsom, CA), was employed. Sample headspace vial was equilibrated at 120^{o}C for 9 min in the autosampler before the rice headspace was transferred to the injection port of the GC. The GC condition was set as follows: the column temperature program started at 50°C and increased at a rate of 1°C/min to 70°C, the injector and flame ionization detector (FID) temperatures were 230 and 250°C, respectively. Purified helium was used as carrier gas at a flow rate of 7mL/min. Amount of 2-acetyl-1-pyrroline in the rice samples was determined by using standard calibration curves and the relative amount of *n*-hexanal was derived from the ratio of the peak area of *n*-hexanal and 2,6-dimethylpyridine.

4.2.6 Statistical Analysis

Physico-chemical properties and aroma data were analyzed using analysis of variance (ANOVA) to determine the effect of grain MC, temperature and duration. Duncan’s multiple range test ($P<0.05$) was done to separate the means. Correlation coefficients (*r*) between rice quality parameters were calculated when appropriate.

4.3 Results and Discussion

4.3.1 Pasting Property

Pasting property of accelerated aging rice, as measured from flour samples by RVA, is shown in Table 4.1. The accelerated aging treatments altered pasting behavior of the fresh rice and the effect was severe in high MC samples and samples treated with higher temperature and longer exposure duration. In general, pasting curves of accelerated aging rice were lifted up except for samples of both ordinary and high MC treated at 120°C-30 min and of high MC sample treated at 100°C-120 min in which peak viscosity decreased as compared to that of fresh rice. This decrease indicated the high severity in aging of these accelerated aging treatments. Pasting property parameters such as pasting temperature, final viscosity and setback were found to increase consistently with increasing exposure duration regardless of temperature levels, whereas peak viscosity, trough (for high MC samples) and breakdown showed a decrease trend after receiving higher temperature or longer duration treatments. This trend of changing was qualitatively similar to that of the naturally-aged rice samples (studied using the same sample set and discussed in Chapter 5) and was in agreement with those reported in literatures (Perdon et al., 1997 ; Sowbhagya and Bhattacharya, 2001; Zhou et al., 2003; Soponronnarit *et al*., 2008) wherein peak viscosity, trough and breakdown were observed to increase during the first few months of storage and then declined or even disappeared in prolonged storage period. This change reflected the complexity of aging process. However, results from this study implied that aging induction effects taking place in both accelerated aging and naturally aged rice were probably based on the same phenomenon.

Changes in pasting properties during aging have been reported to associate with changes in starch granule components (Martin and Fitzgerald, 2002; Fitzgerald, et al., 2003; Zhou et al., 2002, Zhou et al., 2003) with protein oxidation was accounted for as a key process. This change decreased hydrophilic property of the surface protein of rice starch granule, leading to limit its hydration and swelling capacity (Zhou et al., 2003). From the results of this present study, changes of pasting properties of accelerated aging rice samples could be explained. The accelerated aging processes would decrease hydration property of rice starch granule and consequently increase its rigidity. These changes occurred at enhanced rate in higher severe accelerated aging treatments. The increase in pasting temperature confirmed the reduction in their hydrophilic properties. The rising of peak viscosity observed in the less severe treated samples were attributed to the increase in rigidity of the granules that could withstand rupture during pasting. Less amylase activity due to storage (Dhaliwal et al., 1991) or denature of the enzyme by heat in this study would also contribute to this phenomenon. These aged granules, as compared to fresh rice granules, could be more resistant to shearing stress and could swell to a larger size in the limited amount of hot water during the RVA measurement. Increases in rate of accelerated aging, the rigidity of the starch granules continued to increase and could limit its swelling and disintegration which resulted in the lower value of peak

Table 4.1 RVA viscosity parameters of flour from freshly harvested KDML 105 milled rice as affected by accelerated aging factors (grain MC, temperatures and exposure durations).

Grain moisture content (% wb)	Temperature –time (°C-min)	RVA viscosity parameters (cP)					
		Pasting temp. (°C)	Peak viscosity	Trough	Final viscosity	Breakdown	Setback
Fresh rice (control)		80.7±0.4^{h}	3335±32^{f}	2308±147^{bcd}	3433±126^{j}	1027±140^{fg}	98.0±125.4^{e}
13.4	100-60	83.8±0.8^{g}	3802±29^{bc}	2400±125^{bcd}	3670±115^{ghi}	1402±103^{abc}	-131.5±96.2^{f}
	100-90	85.4±0.8^{f}	4045±49^{a}	2540±148^{ab}	4021±138^{cde}	1505±108^{a}	-24.5e±93.3^{f}
	100-120	88.2±0.6^{c}	3616±81^{cde}	2647±111^{a}	4342±91^{a}	969±77^{g}	726.0±55.9^{c}
	110-30	84.6±0.7^{g}	3714±142^{bcde}	2431±204^{abc}	3709±164^{ghi}	1283±65^{bcd}	-5.2e±40.9^{f}
	110-45	85.5±0.4^{f}	3821±18^{b}	2390±95^{bcd}	3821±96^{efg}	1431±89^{ab}	0.3±80.2^{ef}
	120-15	83.9±0.2^{g}	3619±54^{cde}	2361±19^{bcd}	3589±20^{hij}	1258±72^{cde}	-29.5±54.7^{ef}
	120-30	88.9±0.4^{bc}	3101±275^{g}	2511±192^{ab}	4175±190^{abc}	589±84^{h}	1074.5±88.9^{b}
16.6	100-60	85.5±0.2^{f}	3724±80^{bcde}	2360±74^{bcd}	3768±87^{fgh}	1364±24^{abc}	44.7±62.6^{e}
	100-90	86.7±0.3^{d}	3655±46^{bcde}	2494±22^{ab}	4086±15^{bcd}	1161±34^{def}	431.5±58.9^{d}
	100-120	89.3±0.4^{b}	2893±58^{h}	243930^{abc}	4269±50^{ab}	454±68hi	1376.2±79.0^{a}
	110-30	85.7±0.2^{ef}	3739±10^{bcd}	2358±137^{bcd}	3730±106^{gh}	1381±147^{abc}	-9.0±116.2^{ef}
	110-45	86.4±0.3^{de}	3562±63de	2439±132^{abc}	3952±147^{def}	1123±70^{ef}	389.8±86.4^{d}
	120-15	85.4±0.4^{f}	3547±81^{e}	2222±94^{cd}	3506±80^{ij}	1325±67^{bc}	-41.3±70.3^{ef}
	120-30	90.4±0.2^{a}	2490±118^{i}	2169±90^{d}	3786±179^{fgh}	321±51^{i}	1295.8±107.7^{a}

Means (± SD) followed by the same letters in a column are not significantly different by DMRT (*P*<0.05)

viscosity. Increases in final viscosity and setback of the accelerated aging rice samples were found which were similar to those found in naturally-aged rice reported earlier by Perdon *et al*. (1997) and Zhou et al. (2003). The progressive increases in the final viscosity and setback reflected that the degree of retrogradation in rice samples increased after accelerated aging treatment.

4.3.2 Textural Property

Textural properties of cooked rice prepared from accelerated aging rice samples were investigated through texture profile analysis and the results are presented in Table 4.2. The accelerated aging treatments significantly changed texture profile analysis attributes of the fresh rice samples such as hardness, adhesiveness and springiness with an exception for cohesiveness. Cooked rice from milled rice receiving higher temperature or longer exposure duration (i.e., 120°C-30 min and 100°C-120 min) had significantly higher hardness, springiness and lower adhesiveness than fresh rice and rice from the lower temperature and shorter duration treatments. The effects of accelerated aging treatment were more pronounced in high MC grain than in the ordinary MC grain as observed in the greater hardness value of 100°C-90 min and 110°C-45 min of the high MC samples. Hardness increased by 9.2% and adhesiveness decreased by 60.2% in the most severe accelerated aging sample (high MC milled rice exposure at 120°C for 30 min) as compared with those of fresh rice. Gujral and Kumer (2003) reported that hardness, springiness and cohesiveness increased and adhesiveness decreased to different degrees after freshly harvested paddy having different MC was accelerated-aged by steaming. Harder or firmer texture of parboiled rice was also reported to relate with level of crystalline amylose–lipid complexes formed during parboiling and these complexes were stable during cooking process (Biliaderis et al., 1993; Ong and Blanshard, 1995; Priestley, 1977).

The increase in small value of hardness was attributed to the soft texture nature of the KDML 105 rice cultivar used in this study. As known, the KDML 105 rice cultivar is low in amylose content and its cooked kernel is characterized to be of soft texture. Results on a small increase in cooked rice hardness of paddy stored for 12 months as discussed in Chapter 5 confirmed this fact. The accelerated aging

Table 4.2 Texture profile analysis attributes of cooked rice from freshly harvested KDML 105 milled rice, as affected by accelerated aging factors (grain MC, temperatures and exposure durations).

Grain moisture content (% wb)	Temperature -time (°C-min)	Texture profile analysis attributes			
		Hardness (g)	Adhesiveness (g mm)	Springiness	Cohesiveness
Fresh rice (control)		14960±441^{e}	647.2±28.5^{f}	0.191±0.020^{d}	0.566± 0.028
13.4	100-60	15346±157de	521.8±21.0^{de}	0.196±0.007^{d}	0.569±0.004
	100-90	15506±336de	427.1±27.3^{cd}	0.192±0.009^{d}	0.565±0.003
	100-120	16138±317^{abc}	308.1±11.2^{ab}	0.209±0.010^{abcd}	0.572±0.004
	110-30	14908±541^{e}	501.0±99.5^{cde}	0.190±0.009^{d}	0.572±0.009
	110-45	15470±461de	446.3±50.5^{cd}	0.198±0.009^{d}	0.567± 0.006
	120-15	15308±118de	532.1±100.1^{de}	0.189±0.005^{d}	0.571± 0.007
	120-30	16237±474^{ab}	306.3±36.1^{ab}	0.226±0.008^{a}	0.584±0.009
16.6	100-60	15508±239de	466.5±81.7^{cd}	0.202±0.016^{cd}	0.577±0.013
	100-90	15706±285^{bcd}	394.0±63.7^{bc}	0.200±0.006^{cd}	0.573±0.008
	100-120	16272±234^{ab}	295.4±34.2^{ab}	0.219±0.009^{abc}	0.579±0.004
	110-30	15546±173^{cde}	494.3±35.0^{cde}	0.200±0.012^{cd}	0.582±0.006
	110-45	15841±338^{abcd}	486.9±40.7^{cde}	0.206±0.012^{bcd}	0.583±0.017
	120-15	15464±275de	575.7±86.5^{ef}	0.201±0.007^{cd}	0.586±0.011
	120-30	16339±270^{a}	257.5±16.6^{a}	0.224±0.010^{ab}	0.580±0.011

Means (± SD) followed by the same letters in a column are not significantly different by DMRT (*P*<0.05)

technique, therefore, showed the potential for modifying the textural properties of freshly harvested KDML 105 rice to be the character of aged rice without changing its typical soft texture.

4.3.3 Solid Loss, Kernel Elongation, Amylose Content and Color

Effects of grain MC, temperature levels and exposure durations on solid loss, amylose content and elongation of cooked kernel are shown in Table 4.3. Loss of rice solid during cooking was substantial reduced in rice exposed to high temperature and longer time. The reduction led to the decrease in adhesiveness of the accelerated aging cooked rice. Correlation analysis revealed the association between adhesiveness and solid loss (r = 0.70, $P<0.01$). The result agreed with the work conducted by Gujral and Kumer (2003) who found the decreases in value of solid loss and adhesiveness of cooked rice after paddy had received accelerated aging treatments. Reduction of solid loss value in KDML 105 paddy stored in ambient condition and in accelerated aging by dry heat process have also been reported (Soponronnarit *et al*., 2008). In the present study, the heat levels used for accelerated aging of milled rice could enhance rate of aging and brought about the starch granules to be more organized. These aged granules became less susceptible to disintegration which consequently decreased solid loss during cooking. Better integrity of the accelerated aged rice grain was confirmed by kernel elongation data indicated in Table 4.3 and also in 12-month naturally-aged samples discussed in Chapter 5. With less disintegration, hence, cooked kernels of accelerated aging and 12-month naturally-aged samples were significantly longer than those of their respective fresh rice. After accelerated aging treatments, amylose content in rice samples remained unchanged and thus did not account for any difference in solid loss or in textural and pasting properties of the samples.

Color parameters ($L*$, $a*$, $b*$, chroma and hue angle) are presented in Table 4.4. Yellowness ($b*$ value) of accelerated aging milled rice increased with increasing temperature, exposure duration and grain MC. The $b*$ value changed from 7.01 in fresh rice to the highest value (9.82) in rice receiving the most severe aging condition (high MC grain and exposure at 120°C-30 min). Although increase in yellowness was statistically significant, the $b*$ value were in the acceptable ranges as referred to the

Table 4.3 Solid loss, kernel elongation and amylose content of freshly harvested rice cv. KDML 105 as affected by accelerated aging factors (grain MC, temperatures and exposure durations).

Grain moisture content (% wb)	Temperature -time (°C-min)	Rice analysis attributes		
		Solid loss (%)	Kernel elongation (mm)	Amylose content (%)
Fresh rice (control)		6.21 ± 1.38^{a}	9.87 ± 0.12^{f}	17.59±1.40
13.4	100-60	5.56 ± 0.83^{abc}	10.34 ± 0.15^{cde}	17.11±1.09
	100-90	4.81 ± 0.37^{abcde}	10.61 ± 0.34^{bcd}	17.11±1.15
	100-120	3.28 ± 0.32^{cde}	11.08 ± 0.39^{ab}	16.66±0.80
	110-30	6.05 ± 0.13^{a}	10.18 ± 0.12^{def}	17.12±1.51
	110-45	5.79 ± 1.55^{a}	10.79 ± 0.29^{abc}	16.73±0.88
	120-15	6.75 ± 2.00^{a}	9.96 ± 0.17^{ef}	17.43±1.03
	120-30	2.85 ± 2.05^{e}	10.94 ± 0.16^{ab}	17.49±0.91
16.6	100-60	5.66 ± 1.69^{ab}	10.70 ± 0.18^{bc}	17.46±0.82
	100-90	5.04 ± 1.11^{abcde}	11.03 ± 0.09^{ab}	17.42±1.55
	100-120	3.10 ± 1.05^{de}	11.22 ± 0.19^{a}	17.06±1.69
	110-30	6.22 ± 1.25^{a}	10.71 ± 0.29^{bc}	17.36±1.01
	110-45	5.25 ± 1.09^{abcd}	11.00 ± 0.37^{ab}	17.70±1.21
	120-15	5.51 ± 1.01^{abc}	10.22 ± 0.15^{def}	17.49±1.58
	120-30	3.34 ± 0.50^{bcde}	11.09 ± 0.40^{ab}	17.00±1.14

Means (± SD) followed by the same letters in a column are not significantly different by DMRT (*P*<0.05)

Table 4.4 Color parameters (*L, *a**, *b**, chroma and hue angle) of KDML 105 freshly harvested milled rice as affected by accelerated aging factors (grain MC, temperatures and exposure durations).**

Grain moisture content (% wb)	Temperature -time (°C-min)	Color parameters				
		L * value (brightness)	*a** value (redness)	*b** value (yellowness)	chroma	hue angle
Fresh rice (control)		51.09±1.54	-0.91±0.06^{abc}	7.00±0.11^{gh}	7.07±0.10^{gh}	97.45±0.55^{ab}
13.4	100-60	52.96±1.38	-1.04±0.09^{d}	7.72±0.36^{defg}	7.79±0.38^{defg}	97.67±0.56^{ab}
	100-90	53.80±1.29	-1.02±0.08^{cd}	8.15±0.68^{cd}	8.21±0.68^{cd}	97.13±0.39^{abc}
	100-120	52.87±0.96	-0.98±0.04^{cd}	8.62±0.20^{bc}	8.68±0.20^{bc}	96.46±0.13^{bcd}
	110-30	51.83±2.60	-1.01±0.03^{cd}	7.53±0.27^{defgh}	7.60±0.27^{defgh}	97.61±0.32^{ab}
	110-45	52.97±1.14	-1.01±0.08^{cd}	8.05±0.48^{cde}	8.11±0.48^{cde}	97.15±0.41^{abc}
	120-15	51.79±1.90	-1.00±0.08^{cd}	7.22±0.06^{fgh}	7.29±0.06^{fgh}	97.88±0.65^{a}
	120-30	53.27±0.40	-0.97±0.04^{cd}	9.10±0.20^{b}	9.16±0.20^{ab}	96.09±0.27^{cd}
16.6	100-60	51.49±1.91	-0.95±0.04^{bcd}	7.30±0.59^{efgh}	7.37±0.58^{efgh}	97.48±0.83^{ab}
	100-90	52.05±0.78	-0.94±0.06^{bcd}	7.82±0.09^{def}	7.88±0.09^{def}	96.92±0.47^{abc}
	100-120	50.29±1.03	-0.82±0.05^{a}	8.78±0.15^{bc}	8.82±0.14^{bc}	95.34±0.39^{de}
	110-30	51.88±1.33	-0.96±0.03^{bcd}	7.00±0.35^{gh}	7.07±0.35^{gh}	97.83±0.56^{a}
	110-45	52.32±0.56	-0.95±0.03^{bcd}	7.39±0.19^{defgh}	7.45±0.18^{defgh}	97.33±0.37^{abc}
	120-15	50.70±2.06	-0.96±0.06^{bcd}	6.87±0.11^{h}	6.94±0.10^{h}	97.98±0.60^{a}
	120-30	50.57±1.68	-0.86±0.05^{ab}	9.82±1.07^{a}	9.85±1.06^{a}	94.32±1.84^{e}

Means (± SD) followed by the same letters in a column are not significantly different by DMRT ($P<0.05$)

*b** value (9.85) of the 12-month natural aged samples (indicated in Table 5.3 of Chapter 5). For better visualization, the photographs of freshly harvested milled rice and their corresponding rice having 13.4 and 16.6% grain MC after aging with the most severe condition (120°C for 30 min) are shown in Figure 4.2.

*L**: 51.09; *a**:-0.91; *b**:7.00
Fresh rice (control)

*L**: 53.27; *a**:-0.97; *b**:9.10
Accelerated aging at 120°C – 30 min using milled rice 13.4% MC

*L**: 50.57; *a**:-0.86; *b**:9.82
Accelerated aging at 120°C – 30 min using milled rice 16.6% MC

Figure 4.2 Color of freshly harvested KDML 105 milled rice (control) and their corresponding rice of 13.4 and 16.6% MC after accelerated aging at 120°C for 30 min.

Increase in yellow color indicated that the non-enzymatic Maillard browning reaction had taken place on rice during the accelerated aging process and the reaction was enhanced under higher temperature and longer exposure duration. High severe aging also changed the fresh rice to be more reddish as designated by the increase in *a**value and decrease in hue angle, and the high MC grain was affected by the heat treatments in a greater extent as compared to that of low MC grain. This suggested that the effect of heat treatment on rice color change was pronounced in high MC grain. However, the results of the current study revealed that discoloration during accelerated aging of both MC samples were not much and did not exceed the color values obtained in naturally-aged rice (color values of naturally-aged rice in Chapter 5). Moreover, discoloration could be minimized if fresh rice was aged with low temperature (though using longer time). Grain brightness (*L** value) was not affected by the accelerated aging treatments. The *L** values ranged from 50.29 to 53.80 which was not significantly different from *L** value (51.09) of fresh rice. From the color results, it was evident that the accelerated aging technique showed its potential to change freshly harvested rice to be aged rice of acceptable color appearance.

4.3.4 Key Aromatic Compound, 2-Acetyl-1-pyrroline

The aroma impact compound, 2-acetyl-1-pyrroline, of rice cv. KDML 105 was quantified to assess the impact of accelerated aging treatments on amount of the compound released from or remained in the grain samples during processing. Grain MC, temperature levels and exposure durations affected the amount of 2-acetyl-1-pyrroline in rice samples (Figure 4.3). Regardless of grain MC, significant decrease of 2-acetyl-1-pyrroline from rice samples was observed when the exposure duration was prolonged from 15 to 30 min in 120°C and from 60 to 90 and 120 min in 100°C treatments while its values remained the same on rice heating at 110°C for 30 and 45 min. As regard to MC, high MC grains exposed to intermediate accelerated aging condition (i.e., 100°C for 90 min and 110°C for 30 and 45 min) had higher 2-acetyl-1-pyrroline content than those of low MC whereas the aroma values of both MC grain aged in less (i.e., 100°C for 60 min and 120°C for 15 min) and high severe conditions (i.e., 100°C for 120 min and 120°C for 30 min) were not significantly different. Reduction of 2-acetyl-1-pyrroline in accelerated aging samples was not much as compared to its reduction in natural storage rice. 2-Acetyl-1-pyrroline of the naturally-aged rice decreased dramatically from 5.57 ppm at the beginning of storage to 2.30 ppm in the 12-month stored sample (discussed in Chapter 5). This value was lower than those observed in the most severe accelerated aging condition. The quantity of 2-acetyl-1-pyrroline analyzed from the sample aged with 120°C for 30 min was relatively high (3.19 ppm) when compared to 2.30 ppm of the 12-month naturally-stored sample. Results also indicated that high percentage of the compound (79.0-99.3%) was retained in rice exposing to less or intermediate accelerated aging

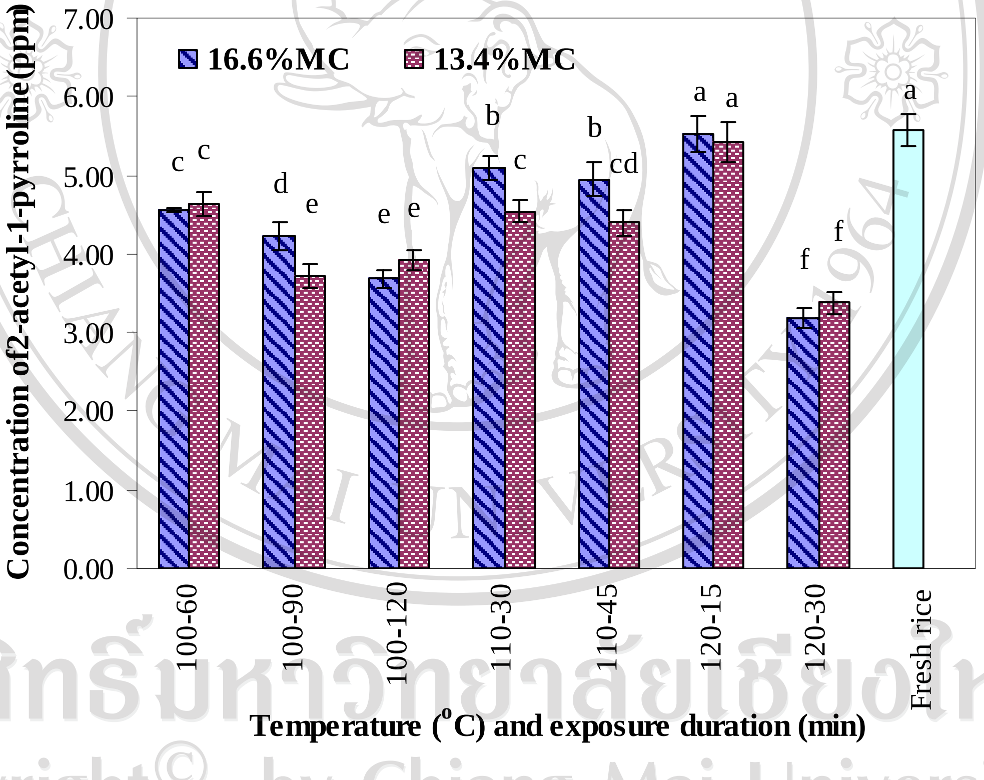

Figure 4.3 Quantity of 2-acetyl-1-pyrroline of KDML 105 freshly harvested milled rice as affected by accelerated aging factors (grain MC, temperatures and exposure durations). Vertical bars (±SD) with the same letters are not significantly different by DMRT (*P*<0.05).

condition and there was no significant difference in 2-acetyl-1-pyrroline content between the low MC samples heating at 100°C for 90 and 120 min. This suggested that there was high amount of the aroma compound which naturally formed a complex with other rice constituents and such a complex formed required higher temperature or longer time to be released from the rice grain. Yoshihashi et al. (2005) suggested that 2-acetyl-1-pyrroline in aromatic rice may be present in two forms, with the starch-bound form require higher extraction temperature comparing to that of its free form. This fact suggests that rice can be accelerated aged for a desired textural property while maintaining its relatively high aroma intensity in terms of 2-acetyl-1-pyrroline content.

4.3.5 Key Stale Odor Compound, *n*-Hexanal

The relative amount of a key off-odor compound, *n*-hexanal, generated during accelerated aging process was quantified in comparison with that of fresh rice sample. After accelerated aging treatment, high MC grain showed lower area ratios of *n*-hexanal/DMP as compared to those of fresh and low MC grain samples (Figure 4.4). At a given temperature level, the area ratios tended to be low when exposed with longer period, though the effects of temperature levels and exposure durations were not found to be significantly different at $P<0.05$ level (with an exception for the high value observed in low MC sample heated at 120°C for 15 min). The probable reason for these variable results is that the higher temperature and longer exposure time during accelerated aging process could be sufficient for degradation of the enzymes responsible for lipid deterioration which consequently less rancid odor precursors produced. These conditions could also accelerate volatilization of the highly volatile compounds including *n*-hexanal from the rice samples, leaving the grains with lower levels of the *n*-hexanal and other lipid breakdown products. Thus, high content of *n*-hexanal in low MC sample heated with 120°C for 15 min may be attributed to insufficient heating time. In contrast to naturally-aged samples in Chapter 5, the area ratios of *n*-hexanal/DMP were observed to increase with storage time from the initial value of 0.45 to 0.99 in the 12-month stored sample (Figure 5.4). The *n*-hexanal

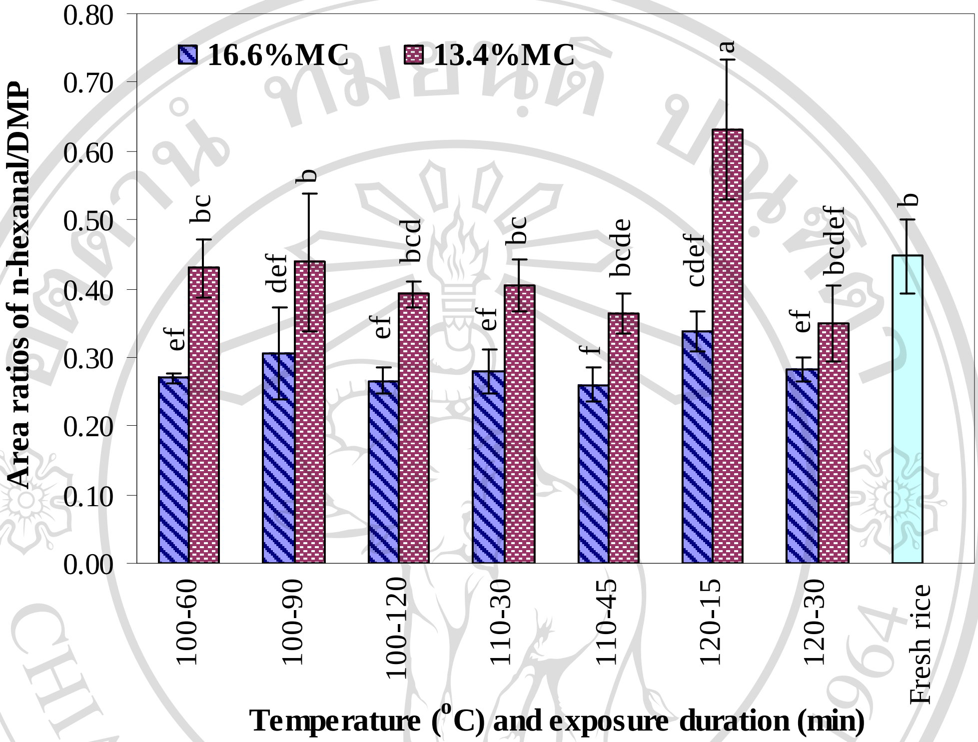

Figure 4.4 **Area ratios of *n*-hexanal to DMP of KDML 105 freshly harvested milled rice as affected by accelerated aging factors (grain MC, temperatures and exposure durations). Vertical bars (±SD) with the same letters are not significantly different by DMRT (*P*<0.05).**

content of 4-12-month aged samples was almost two to three times higher than that of the accelerated aging samples. Degradation of lipids during storage of rice resulting in high *n*-hexanal content (Zhou et al., 2002; Wongpornchai *et al*., 2004) or high fat acidity (Yoshihashi et al., 2005) has been reported. Results from this present study revealed that aged rice produced from accelerated aging process has relatively low amount of the prime off-odor compound, *n*-hexanal, suggesting an advantage and usefulness of the accelerated aging technique.

4.4 Conclusions

This study revealed that physico-chemical properties related to cooking and eating quality of freshly harvested rice cv. KDML 105 could be altered to the characteristics qualitatively identical to those of naturally-aged rice by employing this accelerated aging technique. The fresh aromatic rice could be aged within a short time to mild, intermediate and severe degree, depending on the level of the three aging factors (MC, temperature and duration) assigned in the accelerated aging operation. The technique, therefore, is proven to have high potential to modify freshly harvested rice to be rice of having cooking and eating properties of stored rice while maintaining its aroma quality.