# Partial Characterization of Rice (*Oryza sativa* L.) cv. Khao Dawk Mali 105 as Affected by Accelerated-Aging Factors

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## ABSTRACT

*This study concerns the effect of accelerated-aging treatments on pasting properties, textural properties, solid loss, amylose content, cooked kernel elongation, color and the quantities of the key off-odor, n-hexanal, and the aroma-impact compound, 2-acetyl-1-pyrroline, of Thai Jasmine rice. Milled rice samples derived from freshly-harvested paddy with moisture contents of 13.4 and 16.6 percent wet basis were exposed to three designed sets of accelerated-aging conditions: 100°C for 60, 90 and 120 minutes, 110°C for 30 and 45 minutes, and 120°C for 15 and 30 minutes. Comparison between treated, untreated and naturally-aged samples revealed that accelerated-aging treatments enhanced the aging process of fresh rice samples, with the effect being significant in high-moisture-content rice and in higher temperature or longer exposure treated rice. The hardness and springiness of accelerated-aged cooked rice increased but its adhesiveness decreased. The accelerated-aged rice showed lower solid loss, higher yellowness, higher kernel elongation and pasting behavior similar to those of naturally-aged rice, though amylose content remained unchanged. The content of 2-acetyl-1-pyrroline and n-hexanal decreased in accelerated-aged rice, however, these were still higher than those of 6- to 12-month naturally-aged samples. The accelerated-aging technique designed in this study can be utilized for aging enhancement of Thai fragrant rice.*

**Key words:** Aromatic rice, Accelerated aging, Physicochemical property, 2-acetyl-1-pyrroline, n-hexanal

## INTRODUCTION

Demand for high quality fragrant rice has increased dramatically during the last decade. As one of the world's biggest rice suppliers, Thailand has been alert to pay more attention to improving the quality of its fragrant rice products. Among the rice varieties Thailand exports, Khao Dawk Mali (KDML) 105, known as Thai Jasmine rice in international markets, is the most important variety. This is due to its unique aroma character, which is accepted by most Asian consumers, as well as consumers in the United States (Meullenet et al., 2001) and in some European countries. In addition to the pleasant aroma of some fragrant rice varieties, textural property is another major determinant factor for the majority of rice consumers. Most Asian populations prefer rice with harder and fluffier texture (Juliano, 1985). This explains the practice that KDML 105 rice for sale to Asian people is stored for a certain period of time to allow the formation of the preferred textural quality. However, the aromatic quality of rice, as measured by the amount of the impact aroma compound 2-acetyl-1-pyrroline (Buttery et al., 1982; 1988; Adams and De Kimpe, 2006), decreases during storage (Laksanalamai and Ilangantileke, 1993; Widjaja et al., 1996; Wongpornchai et al., 2004; Yoshihashi et al., 2005). Also, costs that result from longer and varied storage periods are added to the overall cost of rice. A technique called accelerated aging is a postharvest technology that has been advanced to lower storage and marketing costs.

Accelerated aging of freshly-harvested paddy, using wet or dry heat treatment with suitable grain moisture content, had been reported to improve some quality attributes that could be comparable to those of naturally-aged rice (Gujral and Kumar, 2003; Soponronnarit et al., 2008). Such practice on the paddy, however, resulted in lower head rice yield in the subsequent milling process. This was caused by fissures generated from dehydration of the incomplete gelatinized starch in the rice endosperm. Discoloration of the rice occurs due to the diffusion of husk and bran pigments into endosperm of paddy during moistening and heating steps, as occurred in parboiled rice (Lamberts et al., 2006). As husk is a barrier of moistening, heating and drying processes, accelerated aging of paddy requires more space, energy and time during processing.

An alternate accelerated-aging method, using milled rice, is proposed in this study. This method enhances aging by heating milled rice that is loaded in a closed system to prevent loss of water from its kernel. This can be an efficient process since it has several advantages over that using paddy. However, few studies have reported its effectiveness of improving physicochemical properties related to cooking quality, especially the aroma characteristic of fragrant rice. In this study, freshly-harvested KDML 105 milled rice samples with different moisture contents were subjected to a designed series of accelerated-aging treatments. Then, some physicochemical properties as well as quality parameters such as texture, color, solid loss and viscosity were characterized. Additionally, quantities of some active volatiles that have prominent effect on aroma quality of rice, which are 2-acetyl-1-pyrroline and n-hexanal, were determined.

## MATERIALS AND METHODS

### Sample preparation

The KDML 105 rice used in this study was cultivated in the growing season of 2005 at the Lampang Agricultural Research and Training Center, Rajamangala University of Technology Lanna, located in northern Thailand. 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 percent moisture content. The freshly-harvested paddy sample was divided into two portions. One portion was stored as paddy in jute sacks under ambient conditions and designated as a naturally-aged sample. The other portion was prepared for accelerated-aging treatment. The paddy was de-hulled by a McGill sample sheller and the resulting brown rice was milled for 30 seconds 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 used for subsequent treatments. The amylose content of the head rice sample was 17.59 percent (w/w). Protein (NX5.95) and lipid contents of the head rice as determined by AOAC (1999) standard methods were 7.64 and 0.88 percent, respectively.

### Accelerated-aging treatments

Prior to accelerated-aging treatments, the head rice sample was divided into two portions by a Boerner divider (Seedburo Equipment Co., Chicago, Illinois). The first portion was allowed to equilibrate in room atmosphere and the other portion was adjusted to have high moisture content by placing the samples in sealed plastic boxes containing distilled water at room temperature for seven days. The moisture content of both sample portions was determined in triplicate on the seventh day by drying the samples in an oven at 103°C for 17 hours. The moisture content was 13.4 percent for ordinary rice grains and 16.6 percent based on wet basis for high-moisture-content rice grains. Processing of the accelerated-aging rice was done by sealing 370 grams of rice in aluminum containers. These containers were then exposed to temperatures of 100°C for 60, 90 and 120 minutes, to 110°C for 30 and 45 minutes and to 120°C for 15 and 30 minutes. This heat exposure was done in an automatic autoclave (SS-320, Tomy Seico Co. Ltd., Wako, Saitama, Japan). After exposure, the rice samples were left covered in the aluminum containers and cooled for 2 hours at 21°C. The rice samples were then poured into zippered plastic bags and kept at 4°C for further analyses.

### Determination for pasting characteristics

Rice samples were ground to pass through a 0.5 mm screen (Cyclotec 1093 sample mill, Tecator, Hogenas, Sweden) and pasting characteristics of the flour samples were analyzed twice using a rapid visco analyzer (Model 4D, Newport Scientific, Warriewood, NSW, Australia). The flour samples, each weighing 3.00±0.01 g, this weight being adjusted based on a 12-percent moisture content, were placed in test canisters to which distilled water was added to each to make the weight of each 28.00±0.02 g. The samples were analyzed, as outlined by the AACC Approved Method 61-02 for the determination of pasting properties of rice, with a rapid visco analyzer (AACC, 2000). Recorded analysis results were pasting temperature, peak viscosity, viscosity at 95°C after holding (trough), viscosity at 50°C (final viscosity), breakdown based on peak viscosity minus trough and setback based on final viscosity minus peak viscosity.

**Determination for textural properties of cooked rice**

Textural properties of cooked rice samples were determined in five replicates, using a bench-top TA-XT*plus* texture analyzer (Texture Technologies Corp., Scarsdale, New York). A two-cycle compression, force versus distance, was programmed and a 40-mm diameter cylindrical probe attached to a 50 kg load cell was used. The probe was set at 5 mm above the base platform of the instrument and was allowed to travel 4.9 mm, return and repeat at a test speed of 1 mm/sec. Rice samples of 250 g were cooked at a rice-to-water volume ratio of 1:1.25 in a 1.1-liter rice cooker (Sharp model KSH-111). This step was followed by a 10-minute warming period. Samples of the cooked rice were taken by a spoon and the top 1-cm layer of each was discarded. Ten unbroken kernels from each sample were immediately arranged in a single layer on the base platform and subjected to texture profile analysis. The resulting 2-cycle test curves were then analyzed using the Texture Exponent 32 software (Stable Micro Systems, Godalming, UK). The texture profile analysis parameters recorded were hardness, being the peak force of first compression in grams, adhesiveness, being the negative force to pull probes from samples in g mm, cohesiveness, being the ratio of area under second compression to area under first compression and springiness, the ratio of distance traveled by the probe on the two curves, being related to sample recovery after first compression. All of these parameters were determined in three replicates.

**Determination for solid loss, amylose content, kernel elongation and color**

Solid loss during cooking was determined by boiling 5.00 g of milled rice in a test tube containing 30 ml of distilled water for 15 minutes in a hot water bath of 99±1°C. The drained cooking water was oven-dried and weighed to determine the percent of solid loss. Amylose content was determined according to the method of Juliano et al. (1981). Kernel elongation was an average of 10 unbroken cooked rice kernels of samples prepared for determining textural properties. Rice sample color was measured using a Hunterlab color meter (ColorQuest® XE, Hunterlab, Reston, Virginia, USA), using the 1976 Commission Internationale de l' Eclairage $L^*$ $a^*$ and $b^*$ color system. Color parameters interpreted for $L^*$ and $b^*$ values describe the brightness and yellowness of samples, respectively. All of these characteristics were determined in three replicates.

**Analysis of 2-acetyl-1-pyrroline and n-hexanal**

The amounts of 2-acetyl-1-pyrroline (2AP) and n-hexanal, representing the impact aroma and off-odor compounds of the rice samples, were analyzed using the headspace-gas chromatography (HS-GC) method developed by Sriseadka et al., (2006). Milled rice samples were ground to pass through a 0.5 mm screen.

The resulting flour, weighing exactly 1.000 g was placed into a 20-ml headspace vial. An internal standard of 1 μL of 0.50 mg/ml 2,6-dimethylpyridine (DMP) in benzyl alcohol was added to the vial, which was then immediately sealed with a PTFE/silicone septum (Restek Corp., Bellefonte, Pennsylvania) and an aluminum cap. An Agilent Technologies (Wilmington, Delawre) gas chromatograph, model 6890N, equipped with headspace autosampler (Agilent Technologies model G1888) and a fused silica capillary column, HP-5, with a 5% phenyl-95% dimethylpolysiloxane 1.5 μm film thickness chemical coat and dimensions of 30 m × 0.53 mm i.d. (J&W Scientific, Folsom, California), was employed. Sample headspace vial was equilibrated at 120°C for 9 minutes 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 /minute to 70°C, the injector and flame ionization detector temperatures were 230°C and 250°C, respectively. Purified helium was used as carrier gas at a flow rate of 7mL/minute. Concentrations of 2AP in the rice samples were determined by using a standard calibration curve. The relative amounts of n-hexanal were derived from the ratio of the peak areas of n-hexanal and DMP, which was added to the rice samples as an internal standard.

**Statistical analysis**

Data regarding physicochemical properties and aroma quality were statistically analyzed using analysis of variance (ANOVA) to determine the effect of grain moisture content, temperature and heating 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.

## RESULTS AND DISCUSSION

Physicochemical property parameters related to cooking and eating quality, such as pasting and textural properties, color parameters $L^*$ and $b^*$, the impact volatiles 2AP and *n*-hexanal and kernel elongation of the naturally-stored KDML 105 rice (NA sample), are shown in Table 1. These parameters changed as a function of storage time and the resulting changes corresponded with those reported previously (Widjaja et al., 1996; Perdon et al., 1997; Sowbhagya and Bhattacharya, 2001; Zhou et al., 2002; Wongpornchai et al., 2004; Yoshihashi et al., 2005). These values were used as references for comparison with those obtained from the AA treatments.

Pasting properties of the NA and AA rice, as measured from flour samples by rapid visco analyzer, are shown in Tables 1 and 2, respectively. The AA treatments altered the pasting behavior of fresh rice by causing a severe effect on high-moisture-content samples and on those samples being subjected to higher temperature and longer exposure duration. In general, pasting curves of AA rice were elevated except for both ordinary and high-moisture-content samples treated at 120°C for 30 minutes and for high-moisture-content samples treated at 100°C for 120 minutes, of which the peak viscosity decreased compared to that of fresh

**Table 1.** Pasting properties, textural properties, color parameters ($L*$ and $b*$), key volatile compounds and kernel elongation of KDML 105 rice during storage as paddy for up to 12 months at ambient temperature.

| Rice attributes | Storage time (months) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 2 | 4 | 6 | 8 | 10 | 12 |
| Pasting properties (cP) | | | | | | | |
| - peak viscosity | 3335±32d | 3659±68c | 3846±24a | 3766±80b | 3630±12c | 3305±23d | 3271±21d |
| - trough | 2308±147c | 2440±40b | 2601±60a | 2633±43a | 2574±63a | 2227±20c | 1936±42d |
| - final viscosity | 3433±126e | 3619±44d | 3840±40c | 4239±54a | 4124±35b | 3710±20d | 3621±14.d |
| - breakdown | 1027±140c | 1219±71ab | 1245±64ab | 1133±49bc | 1056±52c | 1078±21c | 1334±27a |
| - setback | 98.00±125.38c | -40.00±99.24d | -5.50±40.83cd | 473.22±44.73a | 494.00±22.85a | 405.17±7.78ab | 350.00±8.45b |
| - pasting temperature (°C) | 80.67±0.41d | 83.00±0.44c | 82.46±1.16c | 84.52±0.15b | 86.38±0.31a | 85.98±0.15a | 86.50±0.55a |
| Textural properties | | | | | | | |
| - hardness (g) ($P$<0.075) | 14960±440ab | 14853±297ab | 14462±458b | 14775±527ab | 14915±558ab | 15546±245a | 15488±361a |
| - adhesiveness (g. mm) | 647±28.51b | 581±88.86b | 473±66.10a | 417±9.24a | 401±29.64a | 440±33.41a | 436±80.32a |
| - springiness | 0.191±.0.020c | 0.205±0.011bc | 0.187±0.007c | 0.213±0.013ab | 0.224±0.009ab | 0.207±0.008bc | 0.231±0.007a |
| - cohesiveness | 0.566±0.028 | 0.561±0.005 | 0.541±0.013 | 0.547±0.002 | 0.558±0.009 | 0.575±0.018 | 0.555±0.007 |
| Color parameters | | | | | | | |
| - brightness ($L*$ value) | 51.09±1.53ab | 47.78±1.05d | 48.53±0.67cd | 50.22±1.07bc | 52.47±1.55a | 51.47±1.06ab | 50.17±0.73bc |
| - yellowness ($b*$ value) | 7.00±0.11f | 8.74±0.03de | 9.36±0.25bc | 9.44±0.25b | 8.52±0.15e | 8.99±0.08cd | 9.85±0.40a |
| Key volatile compounds | | | | | | | |
| - 2-acetyl-1-pyrroline (ppm) | 5.57±0.20a | 4.49±0.16b | 3.57±0.17c | 2.75±0.14d | 2.78±0.11d | 2.80±0.11d | 2.30±0.08e |
| - *n*-hexanal (area ratios of DMP) | 0.45±0.05e | 0.57±0.02d | 0.91±0.09ab | 0.84±0.08c | 0.75±0.02c | 0.95±0.03a | 0.99±0.03a |
| Kernel elongation (mm) | 9.87±0.12b | NA | NA | 10.12±0.25b | NA | 10.03±0.10b | 10.78±0.24a |

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

rice. This decrease of peak viscosity indicates the high impact on aging of these AA treatments. Pasting property parameters, such as pasting temperature, final viscosity and setback increased consistently with increasing exposure duration regardless of temperature levels. In contrast, peak viscosity, trough for high moisture content samples and breakdown had a decreasing trend after receiving higher temperature or longer duration treatments. This trend was similar to that of the naturally-aged samples and was in agreement with trends reported in literature (Perdon et al.,

**Table 2.** Rapid visco analyzer (RVA) viscosity parameters of flour from KDML 105 freshly-harvested milled rice samples as affected by accelerated-aging factors of grain moisture content, temperature and exposure duration.

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

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

1997; Sowbhagya and Bhattacharya, 2001; Zhou et al., 2003; Soponronnarit et al., 2008) in that peak viscosity, trough and breakdown increased during the first few months of storage and then declined, or even disappeared, during prolonged storage. This change reflected the complexity of the aging process. However, results from this study imply that aging effects taking place in both AA and NA rice are probably based on the same phenomenon.

Changes in pasting properties during aging have been reported to be associated with changes in starch granule components (Martin and Fitzgerald, 2002; Zhou et al., 2002; 2003; Fitzgerald et al., 2003), with protein oxidation being a key process. This change in starch granule components decreased the hydrophilic property of the surface protein of the rice starch granule, leading to the limitation of its hydration and swelling capacity (Zhou et al., 2003). As the results from this study, changes of pasting properties in NA and AA rice samples can be explained that both NA and AA processes would decrease the hydration property of the rice starch granule and consequently increase its rigidity. These changes occurred continuously in rice samples during natural storage and with enhanced rate in the AA treatments. The increase in pasting temperature of the NA and AA viscogram confirmed the reduction in starch granule hydrophilic properties. The increase of peak viscosity observed in the first 2 to 4 months of natural storage and in the less-severe AA condition was attributed to the increase in rigidity of granules that could withstand rupture during pasting. Lower amylase activity due to storage (Dhaliwal et al., 1991) or denaturing 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 rapid visco analyzer measurement. With increased storage time or the increasing intensity of AA, the rigidity of the starch granules continued to increase and, thus, could limit swelling and disintegration of starch granules, resulting in lower peak viscosity values. The progressive increases in final viscosity and setback reflected the degree of retrogradation increase in rice samples after AA treatments, which were similar to those that occurred in the NA rice stored for 6 to 12 months, as shown in Table 1.

Textural properties of cooked rice prepared from AA rice samples were investigated through texture profile analysis and the results are presented in Table 3. These AA treatments significantly changed the fresh rice texture profile analysis attributes of hardness, adhesiveness and springiness, an exception being cohesiveness. Cooked milled rice exposed to higher temperature with long durations of 120°C for 30 minutes and 100°C for 120 minutes had significantly higher hardness and springiness, but lower adhesiveness than fresh rice and those rice samples obtained from the lower temperature and shorter duration treatments. The effects of AA treatment were more pronounced in high-moisture-content grains than in ordinary-moisture content-grains. This is seen in the greater hardness of the high-moisture-content samples under 100°C for 90-minute and 110°C for 45-minute treatments. Hardness increased by 9.2 percent and adhesiveness decreased by 60.2 percent in the most severe AA conditioned sample, this being high-moisture-content milled rice exposed at 120°C for 30 minutes, as compared with those of fresh rice. These results are in accordance with those reported by Gujral and Kumer (2003) in that hardness, springiness and cohesiveness increased and adhesiveness decreased to different degrees during the accelerated aging of freshly-harvested paddy with varying moisture content by steaming. The small increase of hardness is probably because of the soft texture of the KDML 105 rice variety used in this study. It is well-known that KDML 105 rice variety is low in amylose content and its cooked kernel has a soft texture. The AA method used in this study, therefore, showed the potential of modifying the textural properties of freshly-harvested KDML 105 rice to those of aged rice without changing much of its typical soft texture.

**Table 3.** Texture profile analysis attributes of cooked freshly-harvested KDML 105 rice as affected by accelerated-aging factors of grain moisture content, temperature and exposure duration.

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

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

Effects of grain moisture content, temperature level and exposure duration on solid loss, elongation of cooked kernels, amylose content and color parameters of $L*$ and $b*$ are shown in Table 4. Solid loss during cooking was substantially decreased in rice exposed to AA treatments of higher temperature and longer time. This decrease led to the reduction in adhesiveness of the AA cooked rice, as indicated by the association between adhesiveness and solid loss, $r$ = 0.70, $P$<0.01. This result was in line with the work conducted by Gujral and Kumer (2003) who reported that loss of solid and adhesiveness of cooked rice decreased after paddy had received accelerated-aging treatments. Reductions of solid loss in ambient storage and accelerated-aged KDML 105 paddy were also reported by Soponronnarit et al., (2008). They stated that solid loss was reduced from 2.81 percent in unheated reference fresh rice to 1.78 percent in the most heated sample, in which the heating temperature was 150°C, grain moisture content was 33.2 percent dry basis and tempering time was 120 minutes. This reduction was almost equivalent to the 1.84 percent reduction noted in 6-month stored natural rice. The reduction was attributed to the strengthening of cell walls and to the complex formation between free fatty acid and amylose molecules, which could lower grain swelling and starch solubility during cooking. The heat levels used in this study for AA of milled rice were sufficient to enhance the rate of aging and to cause more-organized starch granules. These aged granules became less susceptible to disintegration which consequently decreased solid loss during cooking. Better integrity of NA and AA aged rice grains was confirmed by both NA and AA kernel elongation data shown in Tables 1 and 4. Hence, with less disintegration, cooked kernels of AA and 12-month NA samples were significantly longer than those of fresh rice. After AA treatments, amylose content in rice samples remained unchanged and, thus, could not account for any differences in solid loss or in textural and pasting properties of the samples.

**Table 4.** Solid loss, amylose content, kernel elongation and color parameters *L** and *b** of KDML 105 freshly-harvested milled rice as affected by accelerated-aging factors of grain moisture content, temperature and exposure duration.

| Grain moisture content (% wb) | Temperature-exposure duration (°C-min) | Solid loss (%) | Amylose content (%) | Kernel elongation (mm) | *L** value (brightness) | *b** value (yellowness) |
|---|---|---|---|---|---|---|
| Fresh rice | | 6.21±1.38a | 17.59±1.40 | 9.87±0.12f | 51.09±1.54 | 7.00±0.11gh |
| 13.4 | 100-60 | 5.56±0.83abc | 17.11±1.09 | 10.34±0.15cde | 52.96±1.38 | 7.72±0.36defg |
| | 100-90 | 4.81±0.37abcde | 17.11±1.15 | 10.61±0.34bcd | 53.80±1.29 | 8.15±0.68cd |
| | 100-120 | 3.28±0.32cde | 16.66±0.80 | 11.08±0.39ab | 52.87±0.96 | 8.62±0.20vbc |
| | 110-30 | 6.05±0.13a | 17.12±1.51 | 10.18±0.12def | 51.83±2.60 | 7.53±0.27defgh |
| | 110-45 | 5.79±1.55a | 16.73±0.88 | 10.79±0.29abc | 52.97±1.14 | 8.05±0.48cde |
| | 120-15 | 6.75±2.00a | 17.43±1.03 | 9.96±0.17ef | 51.79±1.90 | 7.22±0.06fgh |
| | 120-30 | 2.85±2.05e | 17.49±0.91 | 10.94±0.16ab | 53.27±0.40 | 9.10±0.20b |
| 16.6 | 100-60 | 5.66±1.69ab | 17.46±0.82 | 10.70±0.18bc | 51.49±1.91 | 7.30±0.59efgh |
| | 100-90 | 5.04±1.11abcde | 17.42±1.55 | 11.03±0.09ab | 52.05±0.78 | 7.82±0.09def |
| | 100-120 | 3.10±1.05de | 17.06±1.69 | 11.22±0.19a | 50.29±1.03 | 8.78±0.15bc |
| | 110-30 | 6.22±1.25a | 17.36±1.01 | 10.71±0.29bc | 51.88±1.33 | 7.00±0.35gh |
| | 110-45 | 5.25±1.09abcd | 17.70±1.21 | 11.00±0.37ab | 52.32±0.56 | 7.39±0.19defgh |
| | 120-15 | 5.51±1.01abc | 17.49±1.58 | 10.22±0.15def | 50.70±2.06 | 6.87±0.11h |
| | 120-30 | 3.34±0.50bcde | 17.00±1.14 | 11.09±0.40ab | 50.57±1.68 | 9.82±1.07a |

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

Yellowness, the $b^*$ value, of AA milled rice increased with increasing temperature, exposure duration and grain moisture content. The $b^*$ value of the high-moisture-content fresh rice changed from 7.01 to a high value of 9.82 in the 120±C 30-minute treatment. Although this increase in yellowness was statistically significant, the $b^*$ values were only in acceptable ranges as regards to the reference $b^*$ value of the 12-month naturally-aged sample indicated in Table 1. The increase in yellow color was attributed to the Maillard reaction taking place in the AA process. The AA technique did not affect brightness, the $L^*$ value, of the milled rice samples. The $L^*$ values of these milled samples ranged from 50.29 to 53.80 and were not significantly different from the $L^*$ value of 51.09 of fresh rice. These results indicate the effectiveness of the AA technique in changing freshly-harvested rice to aged rice without altering much of its color.

Quantities of the aroma-impact compound, 2AP, which remained in the KDML 105 grain samples after AA processes, were determined in order to assess the effect of each of AA treatment on rice aroma quality. Grain moisture contents, temperature levels and exposure durations could affect the amount of 2AP in rice samples, as shown in Figure 1A. Regardless of grain moisture content, a decrease in 2AP content was observed when the exposure duration was prolonged. The 2AP content of NA rice decreased dramatically from 5.57 ppm at the beginning of storage to 2.30 ppm in 12-month stored samples (Table 1). This 2.30-ppm value was lower than those observed when the most severe AA condition was applied to rice samples. This fact suggests that rice aging can be accelerated to obtain a desired textural property while still maintaining high aroma quality in terms of 2AP content.

Relative amounts of the key off-odor compound, n-hexanal, generated during the AA process or in the period of natural storage, were also determined in terms of the area ratios of *n*-hexanal and DMP. After AA treatments, high-moisture-content grains showed lower amounts of *n*-hexanal compared to those of fresh and low moisture content grain samples (Figure 1). At a given temperature level, the amount of *n*-hexanal tended to be lower with a longer exposure duration, though the effects of temperature levels and exposure durations were not significantly different at $P<0.05$ level, except for the high value observed in the low-moisture-content sample heated at 120°C for 15 minutes.

This result suggests that a higher temperature and a longer exposure time during the AA process can accelerate volatilization of highly-volatile compounds, including *n*-hexanal, from the rice samples, leaving these rice grains with lower levels of *n*-hexanal and other lipid breakdown products. Thus, the highest content of *n*-hexanal in low moisture content sample heated at 120°C for 15 minutes may be attributed to insufficient heating time. For NA samples, the content of n-hexanal increased with increasing storage time from the initial value of 0.45 to 0.99 in 12-month stored samples (Table 1). The *n*-hexanal content of 4- to 12-month aged samples was almost three times higher than the average *n*-hexanal content of the AA samples, in which the degradation of lipids during storage was limited. Thus, this study showed that aged rice produced from this modified AA process had low amounts of the prime off-odor compound, *n*-hexanal, and suggests the advantage and usefulness of the AA process technique.

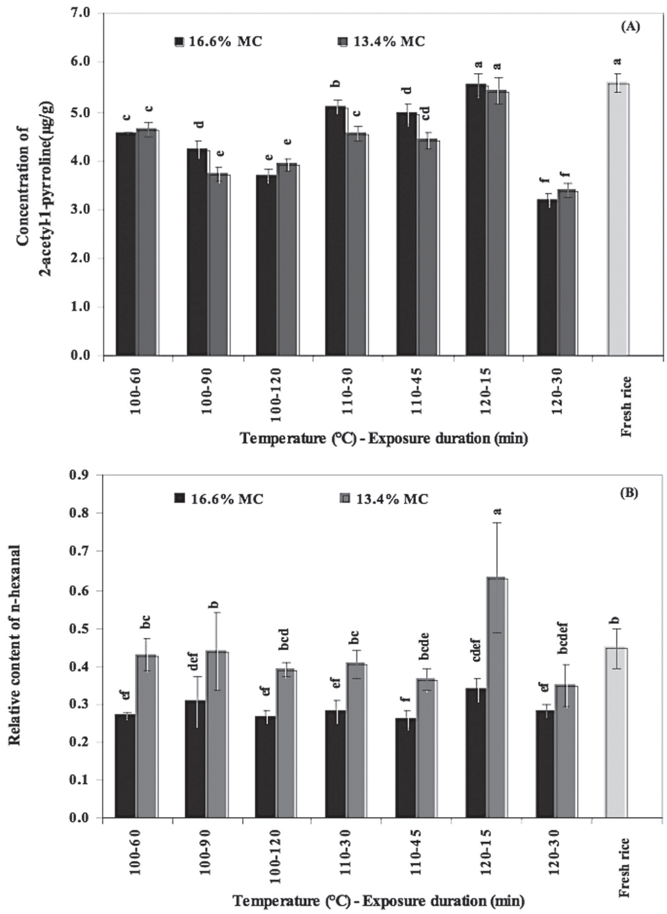


**Figure 1.** Quantity of 2-acetyl-1-pyrroline (A) and area ratio of *n*-hexanal to DMP (B) of KDML 105 freshly-harvested milled rice as affected by accelerated-aging factors of grain moisture content, temperature and exposure duration.

## CONCLUSION

This study showed that physicochemical properties related to cooking and eating quality of freshly-harvested Thai Jasmine milled rice could be altered to the characteristics qualitatively identical to those of naturally-aged rice by employing the AA technique. Fresh aromatic milled rice can be aged mildly, moderately or highly within a short time, depending on the level of the three factors, i.e., moisture content, temperature and duration, used in the AA operation. The technique, therefore, has proven to have a high potential to rapidly modify freshly-harvested rice to be rice of desirable cooking and eating properties while still maintaining aroma quality.

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