CHAPTER IV

RESULTS AND DISCUSSION

4.1 Chemical compositions of hulled red jasmine rice

Chemical compositions of hulled red jasmine rice are shown in Table 4.1. The hulled red jasmine rice contained 15.19% db of amylose; thus, this hulled rice could be classified as low amylose rice which had approximately 10-20% db amylose (Juliano, 1985c). Considering the previous study regarding the chemical composition of hulled rice grown in Thailand, Bundit Leeharatanaluk (2548) investigated the effects of 42 different cultivation areas in Toong Kula area, Khon Kaen province, Thailand, on chemical compositions of KDML-105 rice. The author reported that the hulled rice contained 8.59-15.90% db of crude protein, 3.52-5.71% db of crude fat and 12.44-16.81% db of amylose. While the amylose content of the hulled red jasmine rice stayed within the range of the hulled KDML-105 rice, the amounts of protein and crude fat of the hulled red jasmine rice used in this study were lower than those of the hulled KDML-105 rice. These differences might be due to the differences between cultivars, cultivation area and cultivation methods.

Table 4.1 Chemical compositions of hulled red jasmine rice[(A)]

Chemical compositions	Hulled red jasmine rice
Carbohydrate[B]	84.14 $\pm$ 0.46 % db
Crude protein[C]	6.95 $\pm$ 0. 24 % db
Crude fat	3.38 $\pm$ 0.29 % db
Dietary fiber	4.24 $\pm$ 0.51 % db
Ash	1.26 $\pm$ 0.05 % db
Moisture	0.80 $\pm$ 0.50 % wb
Amylose[D]	15.19 $\pm$ 0.81% db

[A]Mean $\pm$ standard deviation of five replicates analyses

[B]Calculated by difference

[C]%Nitrogen $\times$ 5.95

[D]based on 100 g of dried flour from hulled rice

4.2 Effects of drying methods on qualities of freshly hulled red jasmine rice

From this part and beyond, "freshly hulled red jasmine rice" refers to the hulled rice obtained from paddy which was dried under different methods and dehusked. After dehusk process, the sample was packed in OPP/AL/LLDPE pouch and stored at -18°C prior to analysis.

4.2.1 Physicochemical properties of freshly hulled red jasmine rice

4.2.1.1 Moisture content and water activity

Moisture content and water activity of freshly hulled red jasmine rice are shown in Table 4.2. Even though the final moisture content of paddy in each drying method was controlled at 13-14% wb, sun-dried hulled rice had the significantly lowest moisture content and water activity ($p \leq 0.05$). In shade drying used as a control method and a second step in FB drying, the samples were kept at 27-33°C while the sun-dried paddy was generally exposed to higher temperature for 6 hours. Generally, temperature of warm air during sun drying was approximately 40-60°C (Inprasit and Noomhorm, 2001; International Rice Research Institute, 2006). The lower the air temperature, the higher relative humidity (RH) the air contained. The difference between temperature of the paddy and the surrounding air during sun drying was larger than that during shade drying. This larger temperature difference could lead to larger driving force of water vapor diffusion between the samples and surrounding air during sun drying. Water molecules in sun-dried samples could faster diffuse out of the samples (Brooker et al., 1975). During faster drying process, it could be more difficult to follow the change in moisture content and to determine proper drying duration. Therefore, the sun-dried samples might be slightly over-dried, leading to the lowest moisture content and water activity.

Table 4.2 Moisture content and water activity of freshly hulled red jasmine rice dried under different drying methods. (A, B)

Drying methods	Moisture content (% wb)	Water activity
Shade drying	$15.15^{a} \pm 0.40$	$0.769^{a} \pm 0.017$
Sun drying	$13.58^{c} \pm 0.19$	$0.702^{b} \pm 0.005$
FB drying	$14.16^{b} \pm 0.29$	$0.772^{a} \pm 0.011$

[A] Means with the same letter within the column are not significantly different ($p \leq 0.05$).

[B] Mean $\pm$ standard deviation of triplicate analyses

4.2.1.2 Thermal properties

Thermal properties of flours obtained from freshly hulled red jasmine rice are shown in Table 4.3. Statistical analysis showed that the FB-dried samples had the significantly highest T_o and T_p but had the significantly lowest ΔH_g ($p \leq 0.05$). During drying, FB-dried paddy was exposed to higher drying temperature (115°C) than those of shade-dried (27-33°C) and sun-dried samples (40-60°C). The grain temperature in FB dryer was 72.3$\pm$1.6°C which could induce thermal transitions of some chemical substances in rice grains, leading to different thermal properties of FB-dried sample. The effects of drying temperature on thermal properties have been previously reported by Tirawanichakul et al. (2004). The authors investigated the effects of paddy drying temperature used in FB dryer and initial moisture content of the paddy on qualities of milled rice. The results showed that an increase in paddy drying temperature resulted in a decrease in ΔH_g which corresponded to our study.

Table 4.3 Thermal properties of freshly hulled red jasmine rice dried under different drying methods. (A,B)

Drying methods	T_o (°C)	T_p (°C)	ΔT_g (°C)	ΔH_g (J/g)
Shade drying	$67.17^{c} \pm 0.06$	$72.88^{b} \pm 0.17$	$11.35^{a} \pm 0.23$	$7.92^{a} \pm 0.53$
Sun drying	$67.70^{b} \pm 0.08$	$73.10^{b} \pm 0.20$	$10.87^{b} \pm 0.07$	$7.57^{ab} \pm 0.36$
FB drying	$68.66^{a} \pm 0.19$	$73.82^{a} \pm 0.20$	$10.93^{b} \pm 0.08$	$6.80^{b} \pm 0.18$

[A] Means with the same letter within the column are not significantly different ($p \leq 0.05$).

[B] Mean $\pm$ standard deviation of triplicate analyses

4.2.1.3 Pasting properties

Pasting properties of flours obtained from freshly hulled red jasmine rice are shown in Table 4.4. Statistical analysis indicated that the samples dried by the FB dryer had the significantly lowest BD ($p \leq 0.05$). This could result from the different extent of physical modification of rice components due to the difference in drying temperature as described earlier. Previous studies from Wiset et al. (2003) and Borompichaichartkul et al. (2005) indicated that an increase in drying temperature resulted in a decrease in the sample's PV and BD ($p \leq 0.05$). However, in this study, drying methods insignificantly affected PV of the samples ($p > 0.05$). This could be because the paddy in those previous works was dried in more rigorous conditions than those applied in this study. In the studies of Wiset et al. (2003), the paddy was dried by a FB dryer at 100°C, 125°C and 150°C and then shade dried. In case of the studies of Borompichaichartkul et al. (2005), the samples were dried by a FB dryer at 115°C, 125°C, 135°C and 150°C, tempering for 30 minutes, and finally dried by a FB dryer at the same temperature as used in the first step. Therefore, in this study, the impact of drying methods on PV was not observed.

Table 4.4 Pasting properties of freshly hulled red jasmine rice dried under different drying methods.[(A, B)]

Drying methods	PT^{ns} (°C)	PV^{ns} (RVU)	BD (RVU)	SB^{ns} (RVU)
Shade drying	85.90 ± 0.74	181.12 ± 3.74	79.60^{a} ± 4.40	70.72 ± 2.90
Sun drying	86.24 ± 0.79	181.07 ± 5.35	74.98^{a} ± 6.61	70.72 ± 1.77
FB drying	86.65 ± 0.98	182.38 ± 3.73	63.95^{b} ± 3.46	69.42 ± 0.21

[A] Means with the same letter within the column are not significantly different ($p \leq 0.05$).

[B] Mean ± standard deviation of triplicate analyses

[ns] Means within the column are not significantly different ($p > 0.05$).

4.2.1.4 Swelling power

DSC and RVA results indicated that T_o and PT of the samples were approximately 67-69°C and 86-87°C, respectively. Therefore, swelling power of flour samples at 70°C and 90°C were analyzed as they indicated the extent of water absorption and swelling of starch granules at the beginning of thermal transition and at the abrupt increase in viscosity of the suspension, respectively. Swelling power at 70°C and 90°C of freshly hulled red jasmine rice obtained from shade drying, sun drying and FB drying are shown in Table 4.5. Statistical analysis showed that drying methods insignificantly affected swelling power of the samples ($p>0.05$). Even though drying methods insignificantly affected swelling power at 70°C, this parameter of FB-dried samples was the lowest. Thermally-induced changes of rice kernel microstructure during FB drying could decrease water absorption and swelling of the starch granules, which further reduced the extent of gelatinization. In other words, the FB samples required less energy to gelatinize than the samples dried by shade and sun drying. Therefore, swelling power at 70°C and ΔH_g of the FB-dried samples were lower than those of the other samples.

Table 4.5 Swelling power of freshly hulled red jasmine rice dried under different drying methods.$^{(A, B)}$

Drying methods	Swelling power (g/g sample db)	
	70°C^{ns}	90°C^{ns}
Shade drying	9.33 ± 1.21	16.92 ± 0.81
Sun drying	9.44 ± 1.91	15.50 ± 1.00
FB drying	8.62 ± 0.72	16.38 ± 0.74

^{A} Means with the same letter within the column are not significantly different ($p\leq 0.05$).

^{B} Mean ± standard deviation of triplicate analyses

^{ns} Means within the column are not significantly different ($p>0.05$).

4.2.1.5 Overall discussion based on thermal properties, pasting properties and swelling power of freshly hulled red jasmine rice

The results from DSC and RVA showed the same trend as FB-dried samples presented the highest gelatinization temperatures as indicated by T_o, T_p and PT. These occurrences could mainly result from the changes of two key components, rice starch and protein. According to the study of Inprasit and Noomhorm (2001), scanning electron microscopy (SEM) images of milled rice dried by different drying methods showed that the starch granules of FB-dried samples had less polygonal boundaries than shade-dried and sun-dried samples. The authors proposed that these morphological changes could result from the partial gelatinization/melting of starch granules in the samples dried in FB dryer. In addition, Tang et al. (2002) investigated the effects of drying conditions and tempering of paddy on surface hydrophobicity of rice protein. Paddy was initially dried at 60°C until the 4% or 5% (wb) moisture content was removed from the paddy. Some portions of paddy from each treatment were tempered at 60°C for 3 hours. The control samples were dried at 25°C without tempering. All samples were subsequently shade-dried at 21°C, 50% RH until final moisture content of the samples was approximately 12.5% wb. The oryzenin was extracted from rice flour and its surface hydrophobicity was investigated. The results showed that oryzenin extracted from the paddy dried at 60°C, with or without tempering, had the higher surface hydrophobicity than that of the control samples. This could indicate that oryzenin unfolded and denatured due to an exposure to high temperature during drying. High paddy drying temperature, about 65-95°C, could lead to a remarkable increase in surface hydrophobicity of rice protein (Ju et al., 2002). According to the previous studies on protein denaturation, it can be hypothesized that not only does the high temperature used in FB dryer affect rice starch granules, but it may also lead to the denaturation of rice protein. The protein may unfold and interact with partially gelatinized/melted starch polymers. This may further retard the gelatinization process of rice flour, resulting in an increase in gelatinization temperature (T_o, T_p, PT) and a decrease in ΔH_g. The interaction between starch and protein may restrict the swelling of starch granule during gelatinization, as a result, swelling power at 70°C decreased. The less swollen starch granules can be less disrupted by shear force during heating, consequently, BD decreased.

Apart from the hypothesis above, physicochemical properties of rice could also be affected by formation of amylose-lipid complex (Moritaka and Yasumatsu, 1972; Jaisut et al., 2008; Soponronnarit et al., 2008). According to a model proposed by Le Bail et al. (1999), moisture content and temperature are the key factors for the formation of amylose-lipid complex in starch. At low water content, approximately 19-25% wb, starch granules are difficult to swell during gelatinization. Amylose hardly leaches out of the granules. Formation of amylose-lipid complex thus mainly occurs inside the swollen granules if the molecular mobility induced by heat is sufficient. Jaisut et al. (2008) studied effect of initial moisture content, paddy drying temperature and tempering time on qualities of brown KDML-105 rice. The paddy with initial moisture content 28.2% db or 33.3% db (22% wb and 25% wb, respectively) was dried by 2-stage drying. In the first stage, the paddy was FB-dried at 130°C or 150°C to reduce moisture content to 23% db (19% wb) and then tempered for 30, 60 and 90 minutes. The samples were finally dried under ventilated ambient air until moisture content of the samples reached 16% db (14% wb). The results indicated that an increase in initial moisture content of paddy, drying temperature and tempering time led to an increase in amylose-lipid complex formation. However, in this study, even though moisture content of paddy was close to that of KDML-105 paddy in the study of Jaisut et al. (2008), drying conditions in the previous study was stronger than those used in current study. The paddy in the previous study was FB-dried at higher temperature and tempered for at least 30 minutes. During tempering, the FB-dried paddy was stored at high temperature which was equal to FB-dried grain temperature. Within this environment, many changes, including formation of amylose-lipid complex, could occur. Meanwhile, condition used for FB drying in current study might not induce great extent of amylose-lipid complex formation. Therefore, the effect of amylose-lipid complex on physicochemical changes of the samples during paddy drying in this research might be neglected.

4.2.2 Quality characteristics of cooked freshly hulled red jasmine rice

4.2.2.1 Color

Color in Hunter L, a, b system of cooked freshly hulled red jasmine rice obtained from shade drying, sun drying and FB drying are shown in Table 4.6. Statistical analysis indicated that cooked shade-dried samples had the significantly lowest a value and b value ($p \leq 0.05$). Positive a value represented redness and positive b value represented yellowness. Hence, cooked shade-dried samples were palest. However, consumers might not detect this different. The difference between a value of shade-dried samples and the others could be due to variation of raw materials. However, drying method insignificantly affected L value which indicated darkness or lightness of the samples ($p > 0.05$).

Table 4.6 Color of cooked freshly hulled red jasmine rice dried under different drying methods.$^{(A, B)}$

Drying methods	L^{ns}	A	b
Shade drying	35.55 ± 3.29	5.46^{b} ± 0.43	3.83^{b} ± 0.01
Sun drying	34.40 ± 1.98	6.67^{a} ± 0.36	4.55^{a} ± 0.21
FB drying	34.42 ± 0.25	6.35^{a} ± 0.30	4.37^{a} ± 0.11

^{A} Means with the same letter within the column are not significantly different ($p \leq 0.05$).

^{B} Mean ± standard deviation of duplicate analyses

^{ns} Means within the column are not significantly different ($p > 0.05$).

4.2.2.2 Sensory analysis

Sensory characteristics of cooked freshly hulled red jasmine rice obtained from shade drying, sun drying and FB drying are shown in Table 4.7. Statistical analysis indicated that FB-dried samples had the significantly lowest fragrance ($p \leq 0.05$) and had the highest rancidity. Overall results showed that an increase in drying temperature led to a decrease in fragrance; in contrast, rancidity of the samples increased. The drying temperature in each drying method was previously indicated in section 4.2.2. According to previous studies based on GC-MS analysis, an increase in drying temperature led to a decrease in 2AP (Wongpornchai et al., 2004; Borompichaichartkul et al., 2005) while n-hexanal increased (Sunthonvit et al., 2003; Wongpornchai et al., 2004; Borompichaichartkul et al., 2005). These results were consistent with sensory analysis in current study. The volatile compound, 2AP, which provided desirable unique aroma in fragrant rice has low molecular weight. When the paddy samples were exposed to high temperature during FB drying, 2AP could be more volatile and diffused out of the samples, leading to a decrease in fragrance of cooked FB-dried hulled red jasmine rice. According to Sowbhagya and Bhattacharya (1976), heating could accelerate lipid autoxidation of paddy. The high drying temperature in FB dryer could urge lipid autoxidation and increase in n-hexanal content in the paddy samples. As a consequence, cooked FB-dried samples had the highest rancidity.

Table 4.7 Sensory characteristics of cooked freshly hulled red jasmine rice dried under different drying methods.$^{(A, B,)}$

Drying methods	Sensory Characteristics		
	Fragrance	Rancidity	Hardness^{ns}
Shade drying	$3.88^{a} \pm 0.58$	$1.56^{ab} \pm 0.50$	3.75 ± 1.00
Sun drying	$3.63^{ab} \pm 0.74$	$1.19^{b} \pm 0.75$	3.94 ± 0.86
FB drying	$3.06^{b} \pm 0.56$	$2.29^{a} \pm 0.65$	3.25 ± 0.93

^{A} Means with the same letter within the column are not significantly different ($p \leq 0.05$).

^{B} Mean $\pm$ standard deviation of the data in 10-point intensity scale, obtained from eight trained panelists

^{ns} Means within the column are not significantly different ($p > 0.05$).

In case of hardness, drying method insignificantly affected this attribute of the samples ($p > 0.05$) (Table 4.7). The relationship of pasting properties and texture of cooked rice was previously investigated. Ong and Blanshard (1995) analyzed correlation between texture of cooked rice and some physicochemical parameters of rice, including amylose and amylopectin content, DSC parameters and RVA parameters. The results indicated that SB had significantly positive correlation with hardness of cooked rice analyzed by a Texture Analyzer ($p \leq 0.01$). The RVA results and sensory analysis of the samples in this study tended to agree with the study of Ong and

Blanshard (1995). Even though drying methods insignificantly affected SB and hardness of the samples, FB-dried samples were received the lowest hardness scores from panelists and the lowest SB from RVA results. Therefore, SB could be recognized as an important index corresponded with eating quality of cooked rice (Tulyathan and Leeharatanaluk, 2007).

4.3 Effects of storage conditions on qualities of hulled red jasmine rice

4.3.1 Physicochemical properties of aged hulled red jasmine rice during

4.3.1.1 Moisture content and water activity

The results showed that, for all drying methods, greater extent of change in moisture content and water activity was observed in the samples packed in Nylon/LLDPE pouch (Fig. 4.1 and Fig 4.2). OPP/AL/LLDPE consists of aluminum foil layer which its water vapor transmission (WVTR) was nearly 0 g/m^2.24 hr whereas WVTR of Nylon film used in this study was 17.4 g/m^2.24 hr. As a result, OPP/AL/LLDPE is a better moisture barrier. Change of moisture content and water activity of the samples during storage depended on relative humidity of environment. When the samples packed in Nylon/LLDPE pouch were stored at ambient temperature (approximately 27-35^{o}C and 50-80% RH) (Fig. 4.3 and Fig 4.4), the samples would desorb moisture until their moisture content reached equilibrium (Grist, 1986). As a result, moisture content and water activity of the samples stored at ambient temperature tended to decrease as storage duration increased. However, for freshly sun-dried samples packed in Nylon/LLDPE and stored at ambient temperature, their initial moisture contents were approximately 13.58% wb which might be close to their equilibrium moisture content. Therefore, moisture content of sun-dried samples slightly changed during 12-month storage. As for the samples stored at 15^{o}C, relative humidity of air of this temperature was approximately 90%. Thus, the samples packed in Nylon/LLDPE pouch and stored at 15^{o}C could absorb moisture from this humid environment, leading to slightly increase in moisture content and water activity.

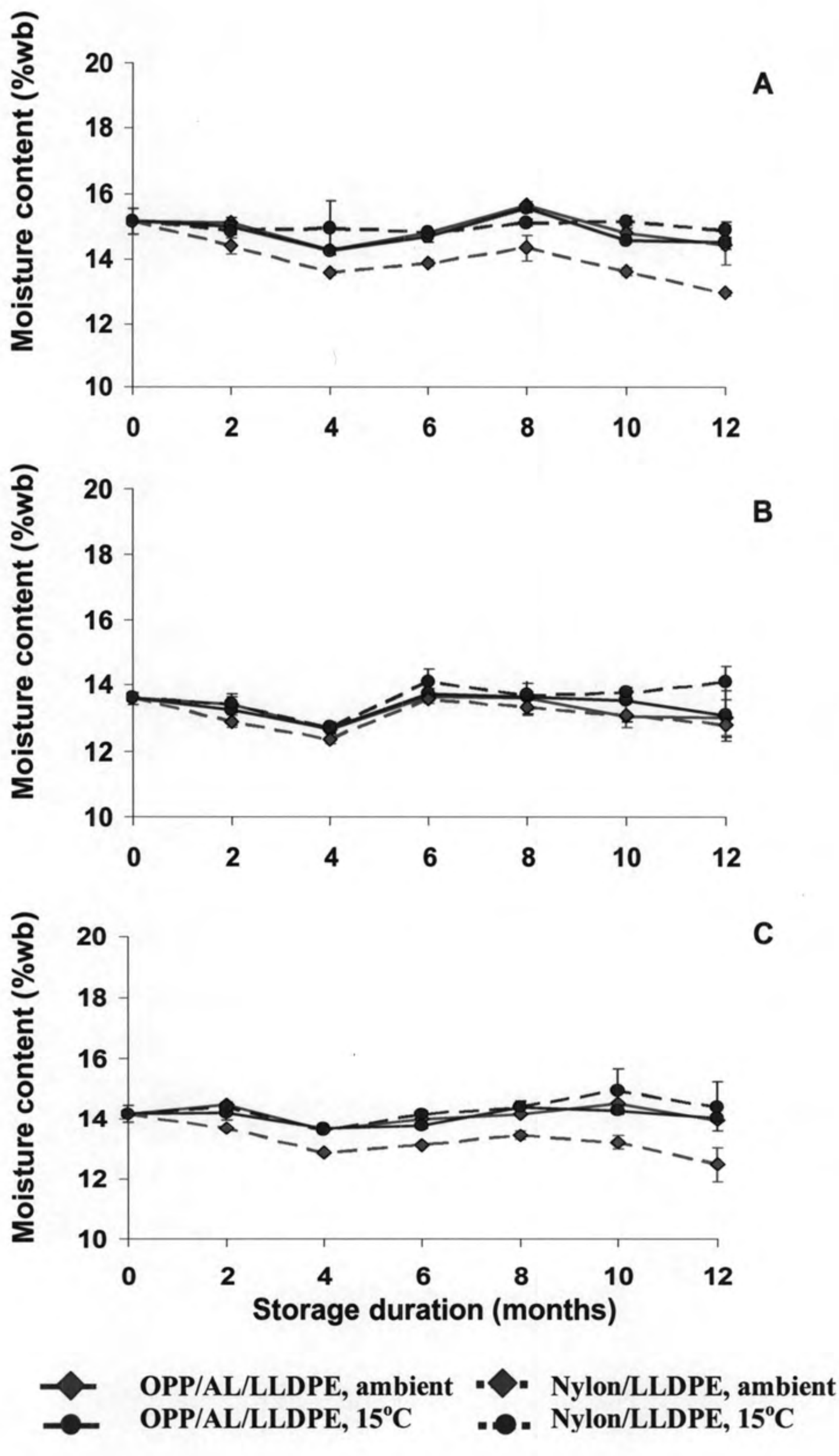

Figure 4.1 Moisture content of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

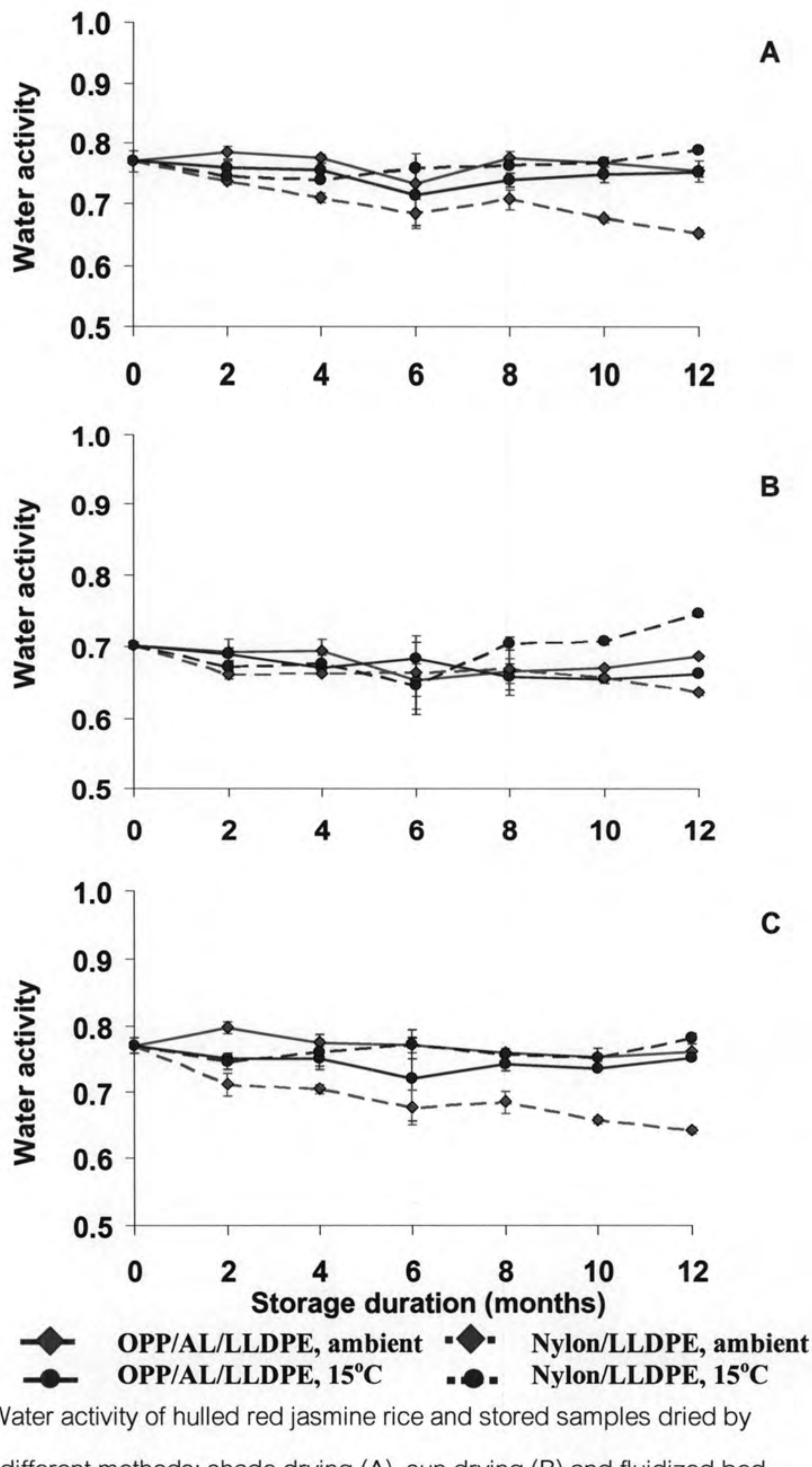

Figure 4.2 Water activity of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

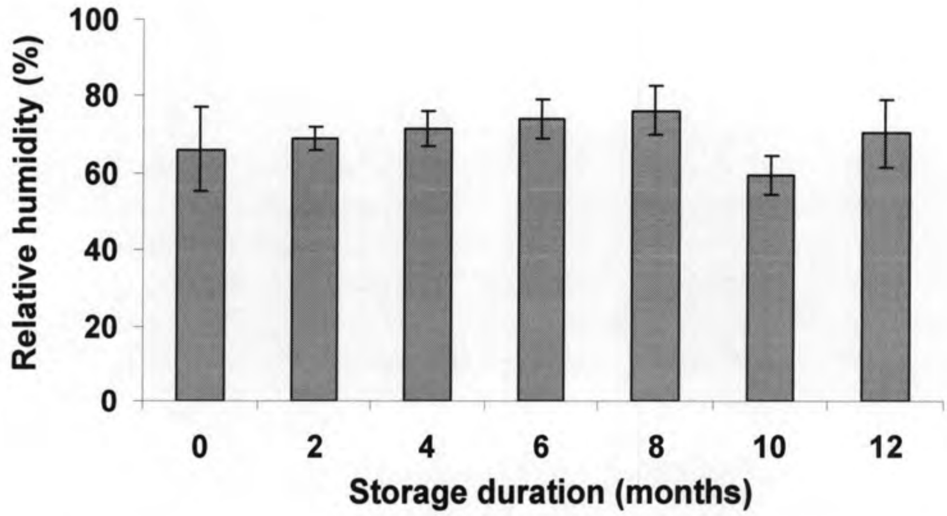

Figure 4.3 Average relative humidity in Bangkok Metropolis during rice storage duration starting in February, 2007 (Thai Meteorological department, 2008)

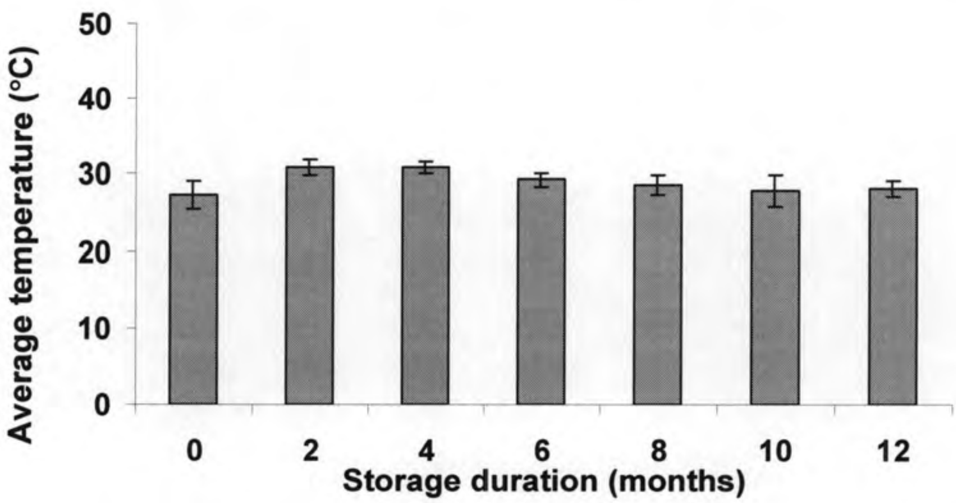

Figure 4.4 Average temperature of ambient air in Bangkok Metropolis during rice storage duration starting in February, 2007 (Thai Meteorological department, 2008)

4.3.1.2 Thermal properties

For any drying methods and packaging materials, T_o and T_p of flours from all samples tended to increased after storing for 6 or 8 months (Fig. 4.5 and Fig. 4.6). ΔT_g of all samples tended to decrease after storing for 6-10 months (Fig. 4.7). In case of ΔH_g, for any drying methods, packaging materials and storage temperature, ΔH_g of all samples tended to increase within the first 2 or 4 months of the storage, and then dramatically decreased after the samples were stored for 10 months and remained constant or slightly changed afterwards (Fig. 4.8). In an excess water system, ΔH_g referred to net endothermic changes resulting from starch granule swelling, crystallize melting and extensive hydration of starch molecules (Biliaderis, Maurice and Vose, 1980). An increase in ΔH_g after the samples were stored within the first 2 months could point out that gelatinization process of starch granules could occur more easily and more completely than that of fresh samples. On the contrary, an increase in gelatinization temperature, T_o and T_p with a decrease in ΔT_g and ΔH_g of the samples during long term storage could be interpreted as starch granule absorbed less amount of water and become more difficult to gelatinize. Degree of gelatinization of these samples thus decreased. The effects of storage temperature and duration on thermal properties have been previously investigated. According to the study of Zhou et al. (2003), the authors placed milled rice in air-tight glass bottles and stored at 4°C or 37°C for 16 months. The results indicated that an increase in storage temperature resulted in an increase in T_p and ΔT_g. The change of T_p in the previous study was corresponded to the results in the current finding, while the change of ΔT_g was not. This could be due to the differences in packaging, storage temperature and storage duration used in both studies.

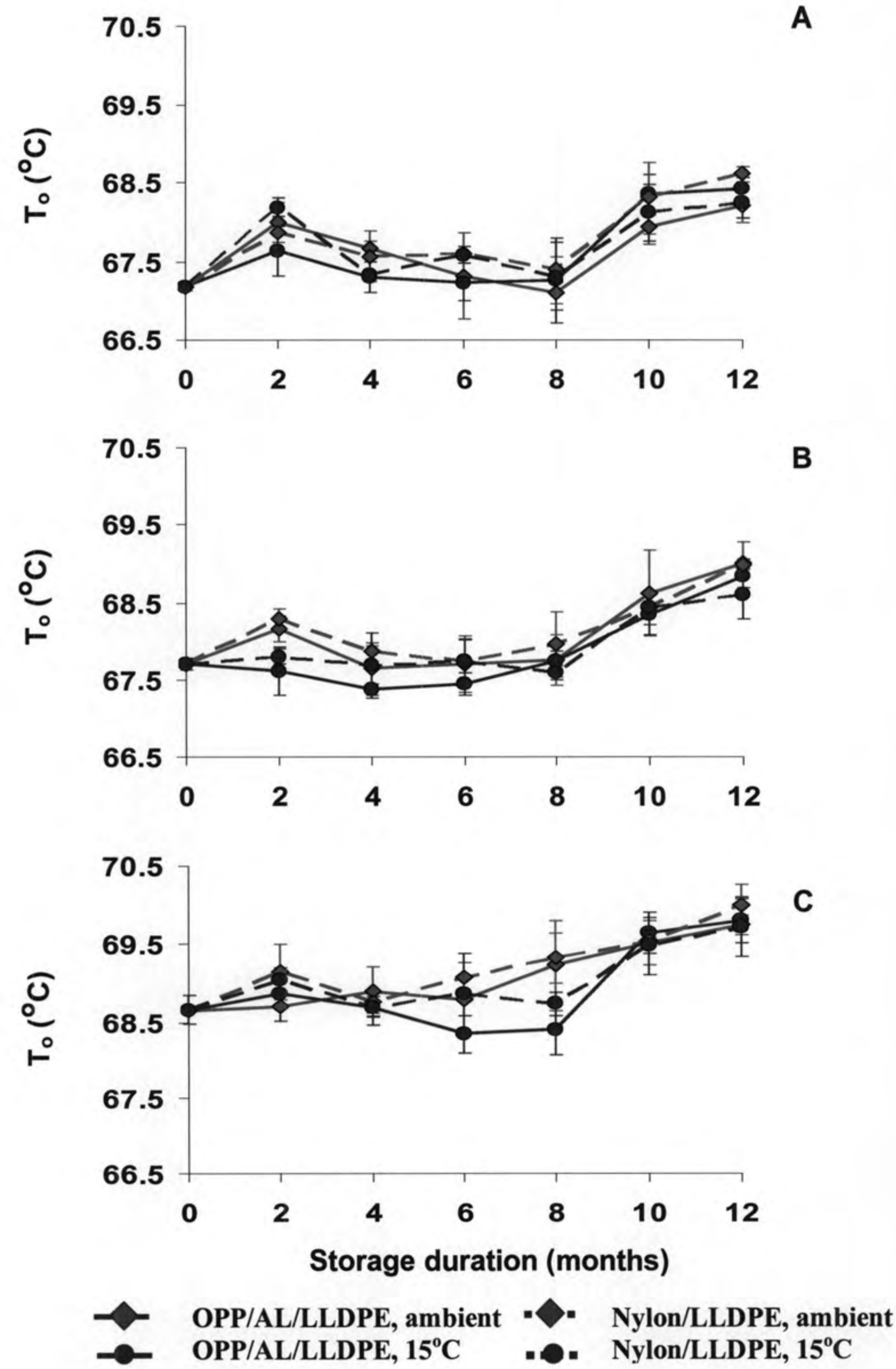

Figure 4.5 Onset temperature (T_o) of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

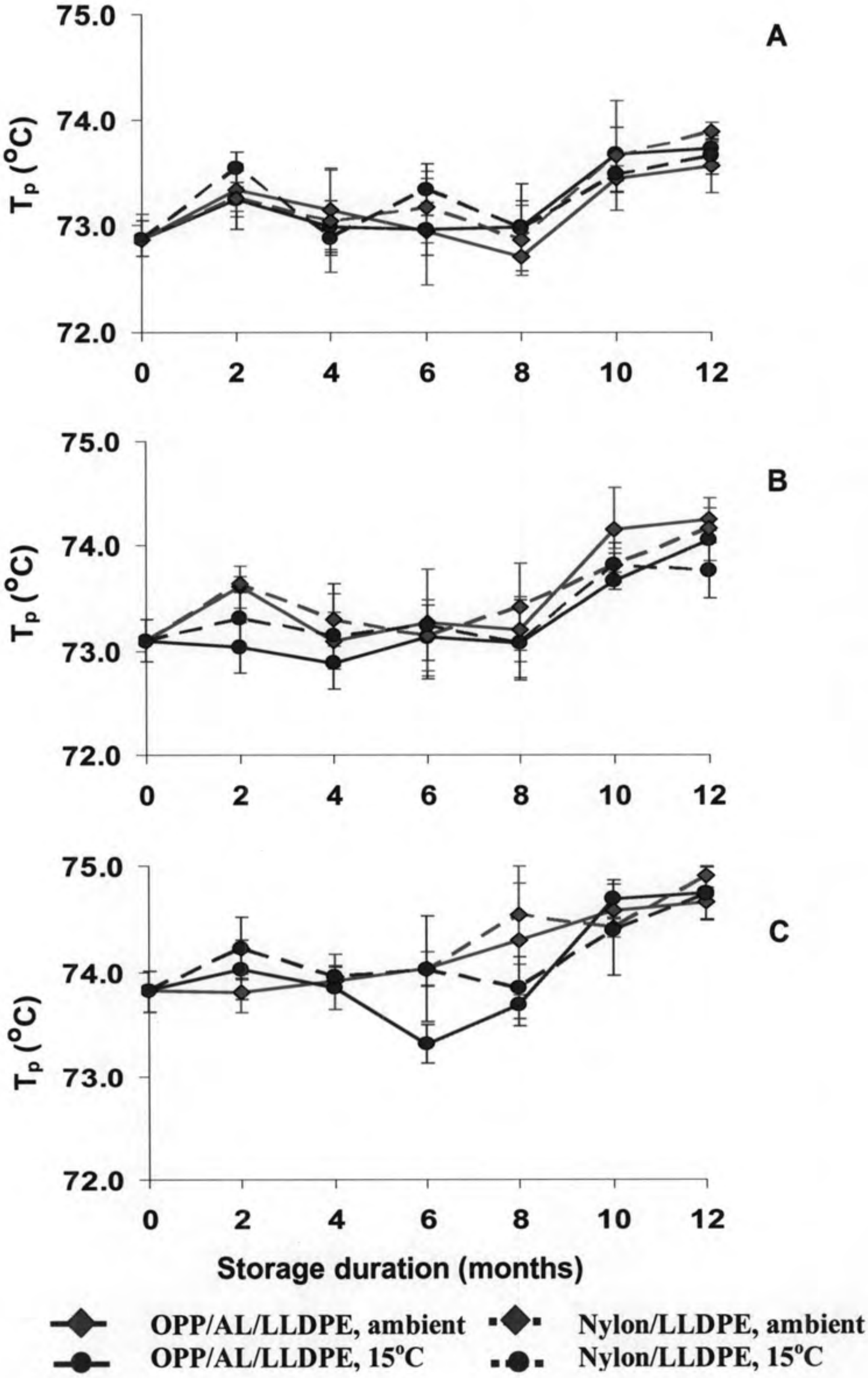

Figure 4.6 Peak temperature (T_p) of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

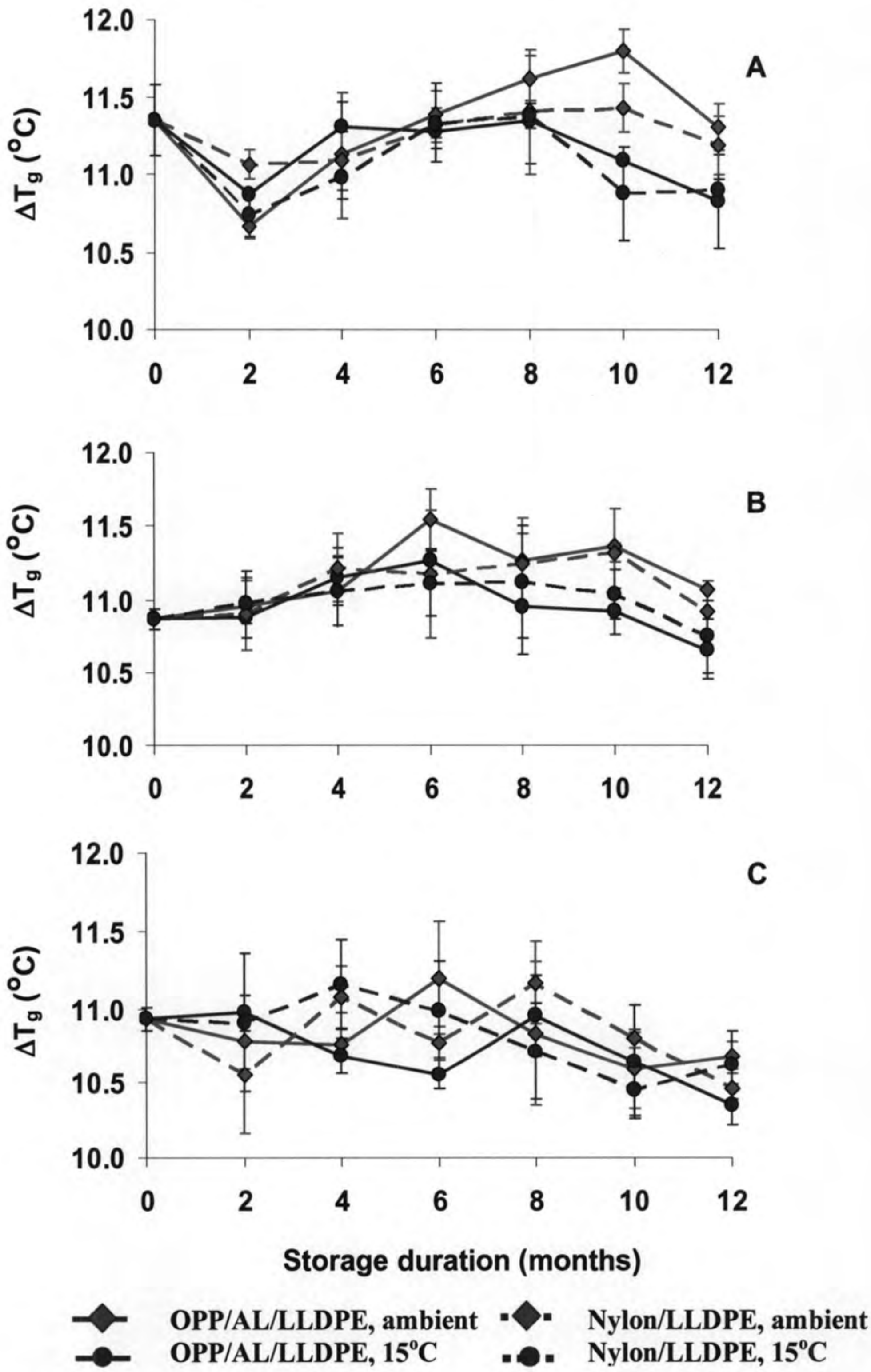

Figure 4.7 Range of gelatinization temperature (ΔT_g) of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

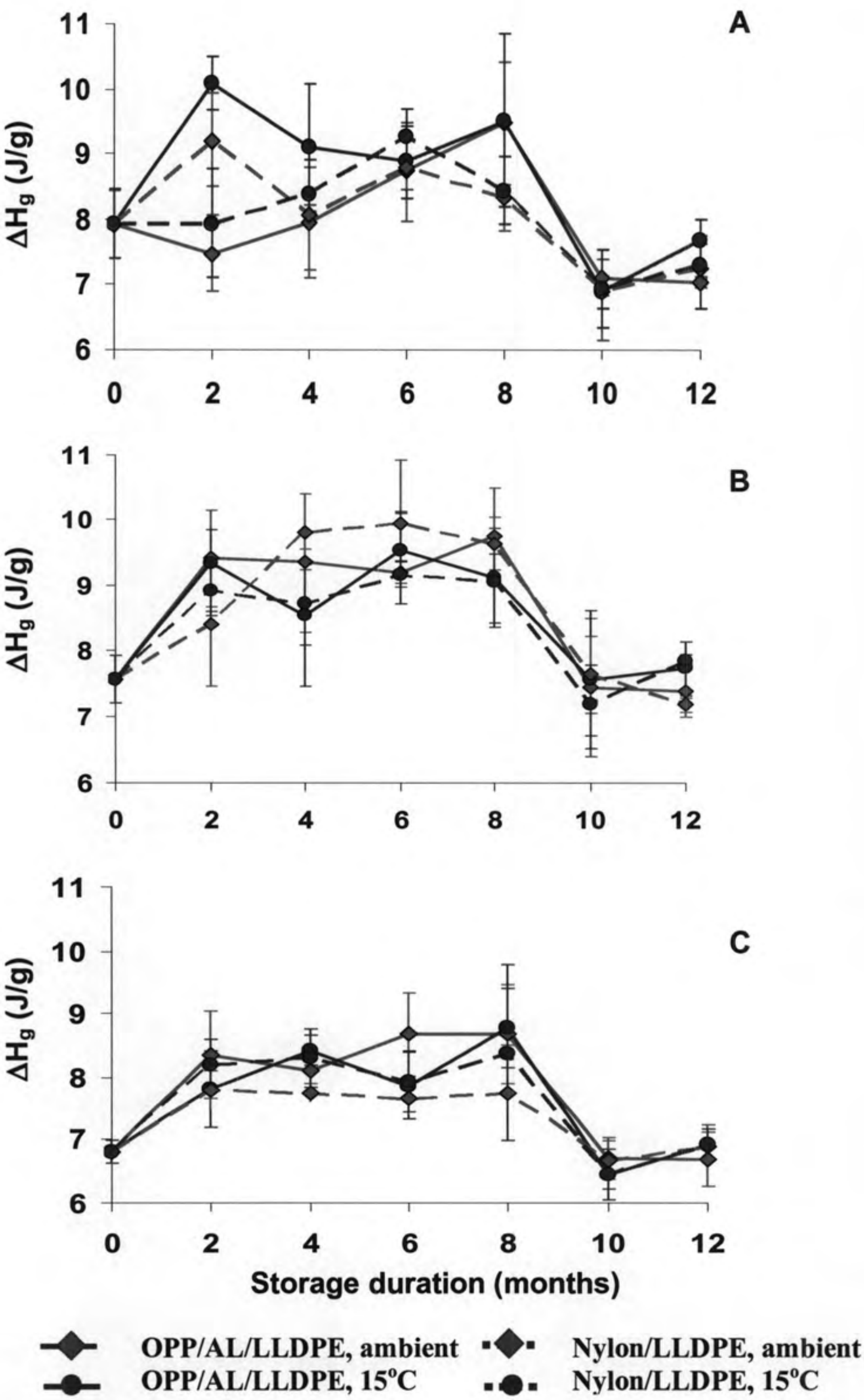

Figure 4.8 Enthalpy of gelatinization (ΔH_g) of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

4.3.1.3 Pasting properties

The time-dependent changes of the pasting properties of the rice flour were shown in Figure 4.9-4.12. For any drying methods and packaging materials, PT of flours from the samples stored at ambient temperature tended to increase after 4 or 6 months of storage (Fig 4.9) whereas PV and BD increased within the first 2 or 4 months, then decreased (Fig. 4.10 and Fig. 4.11). In case of SB, this parameter of rice paste gradually increased as storage duration increased for any drying methods, packaging materials and storage temperatures (Fig. 4.12). In addition, the changes of pasting properties of stored hulled rice could be delayed by low storage temperature as, during 12-month storage, PV and BD of the samples stored at 15°C still did not decrease. Besides, SB of the samples stored at 15°C slightly increased during storage. Consistent results were found in earlier studies. In case of effects of storage duration, the samples stored at ambient temperature (21-38°C) within the short period of time, approximately 4 months, had higher PV and SB than those of the fresh samples (Pearce et al., 2001; Wiset et al., 2003). However, the extent of storage duration led to a decrease in PV and BD, while SB still increased. (Sowbhagya and Bhattacharya, 2001; Zhou et al., 2003). The higher the storage temperature, the greater changes of RVA parameters were obtained (Wiset et al., 2003; Zhou et al., 2003). Conversely, when the samples were stored at low temperature (4°C) for either short or long period of time, PV and BD gradually increased during storage (Pearce et al., 2001; Zhou et al., 2003).

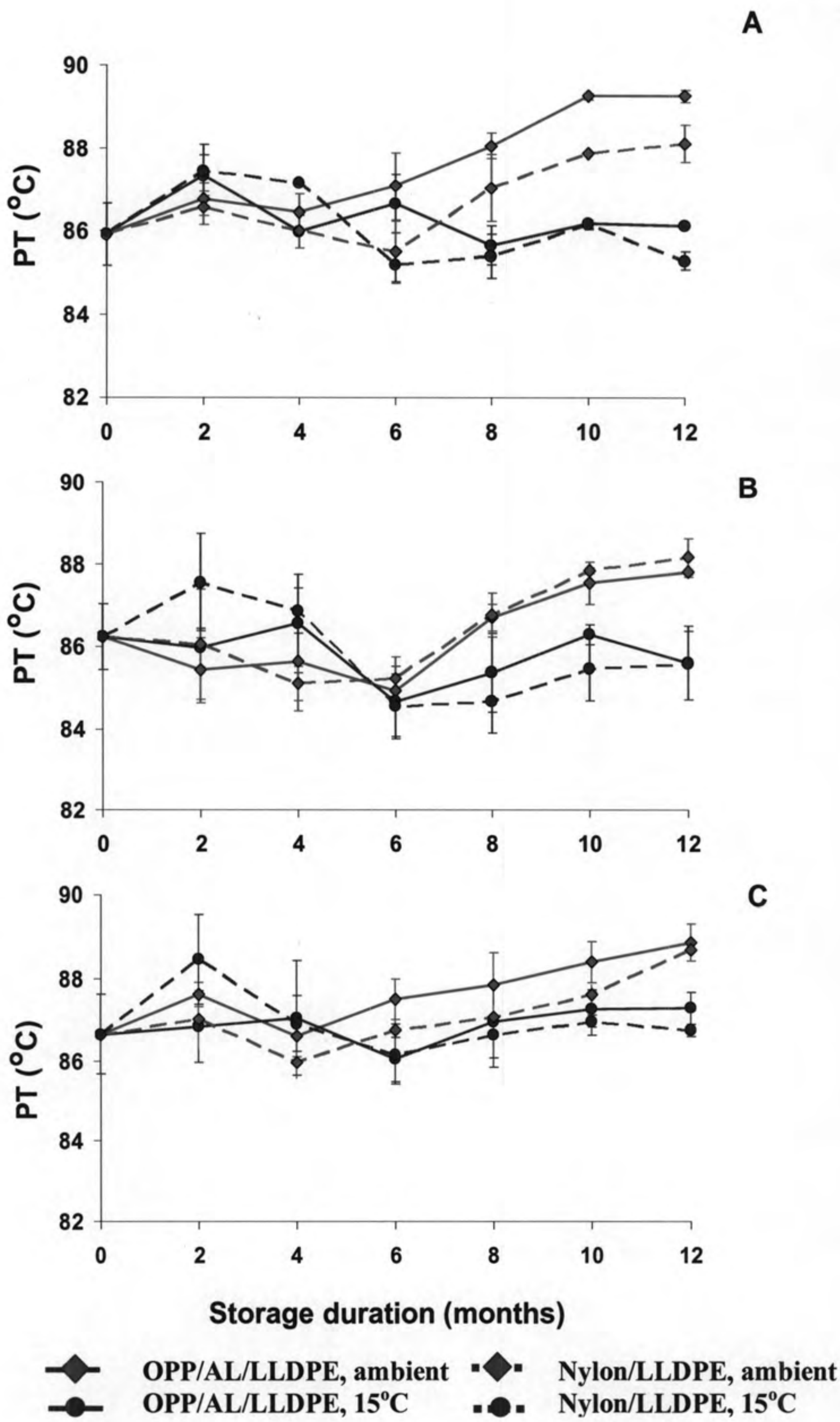

Figure 4.9 Pasting temperature (PT) of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

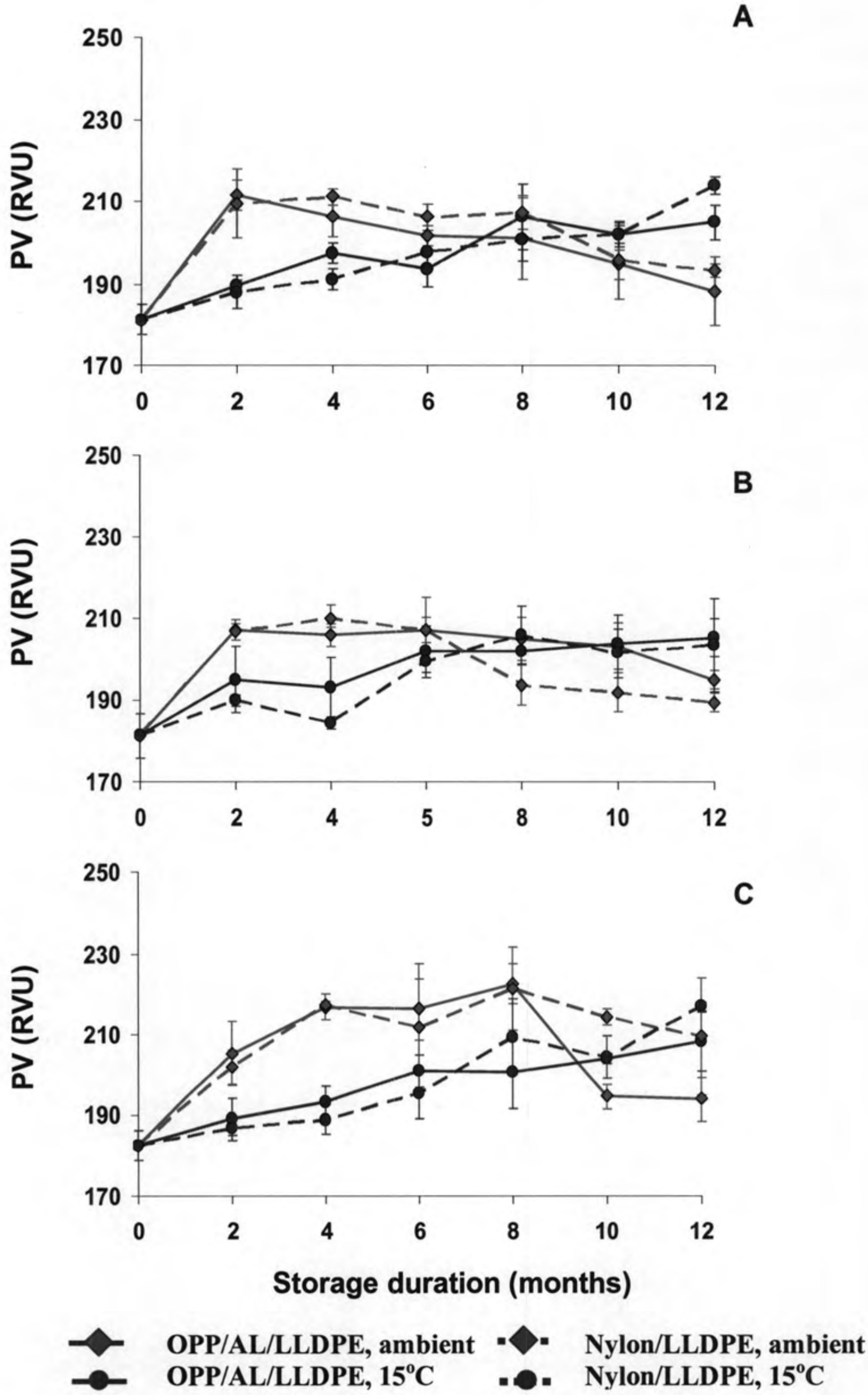

Figure 4.10 Peak viscosity (PV) of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

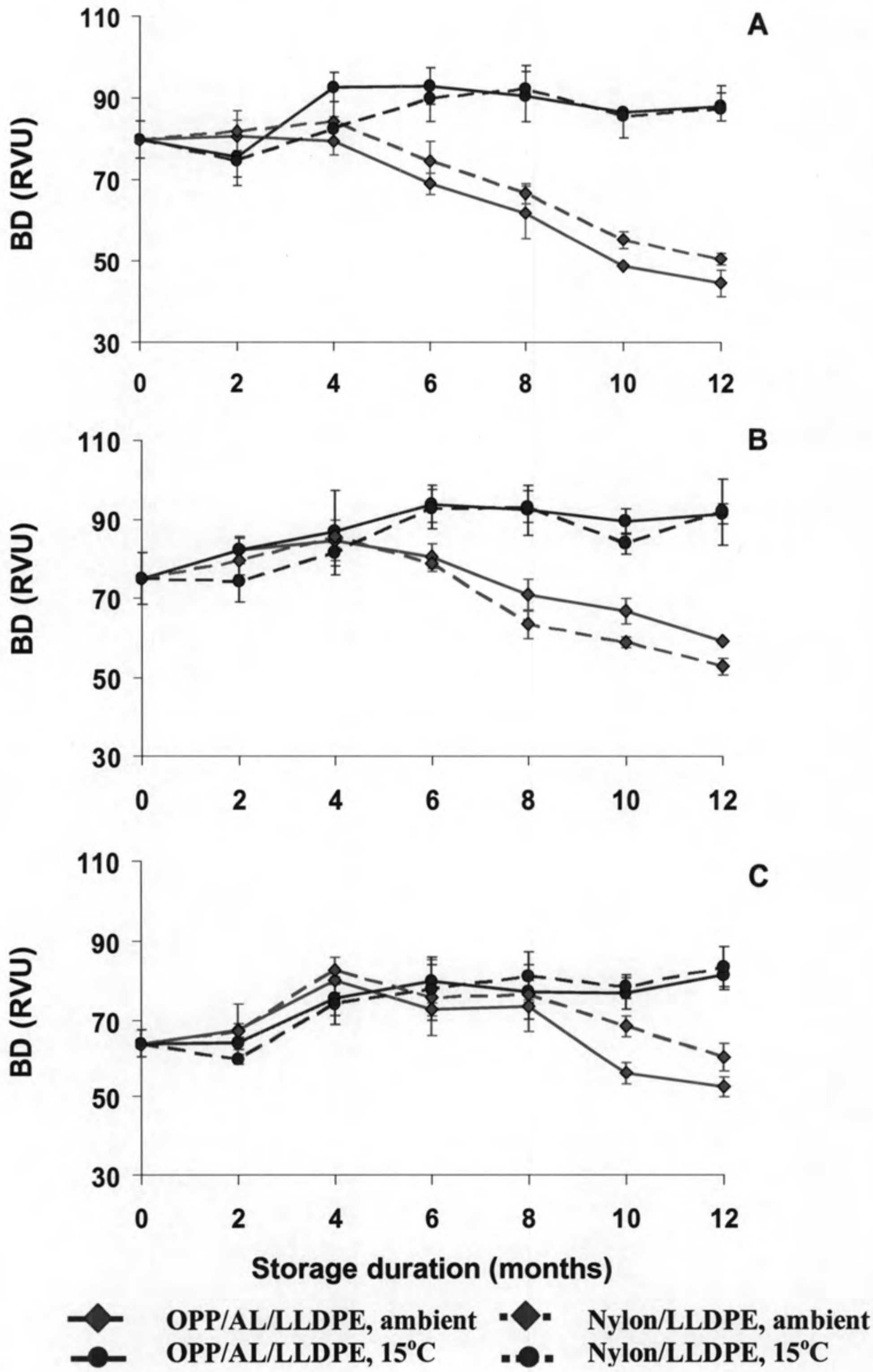

Figure 4.11 Breakdown (BD) of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

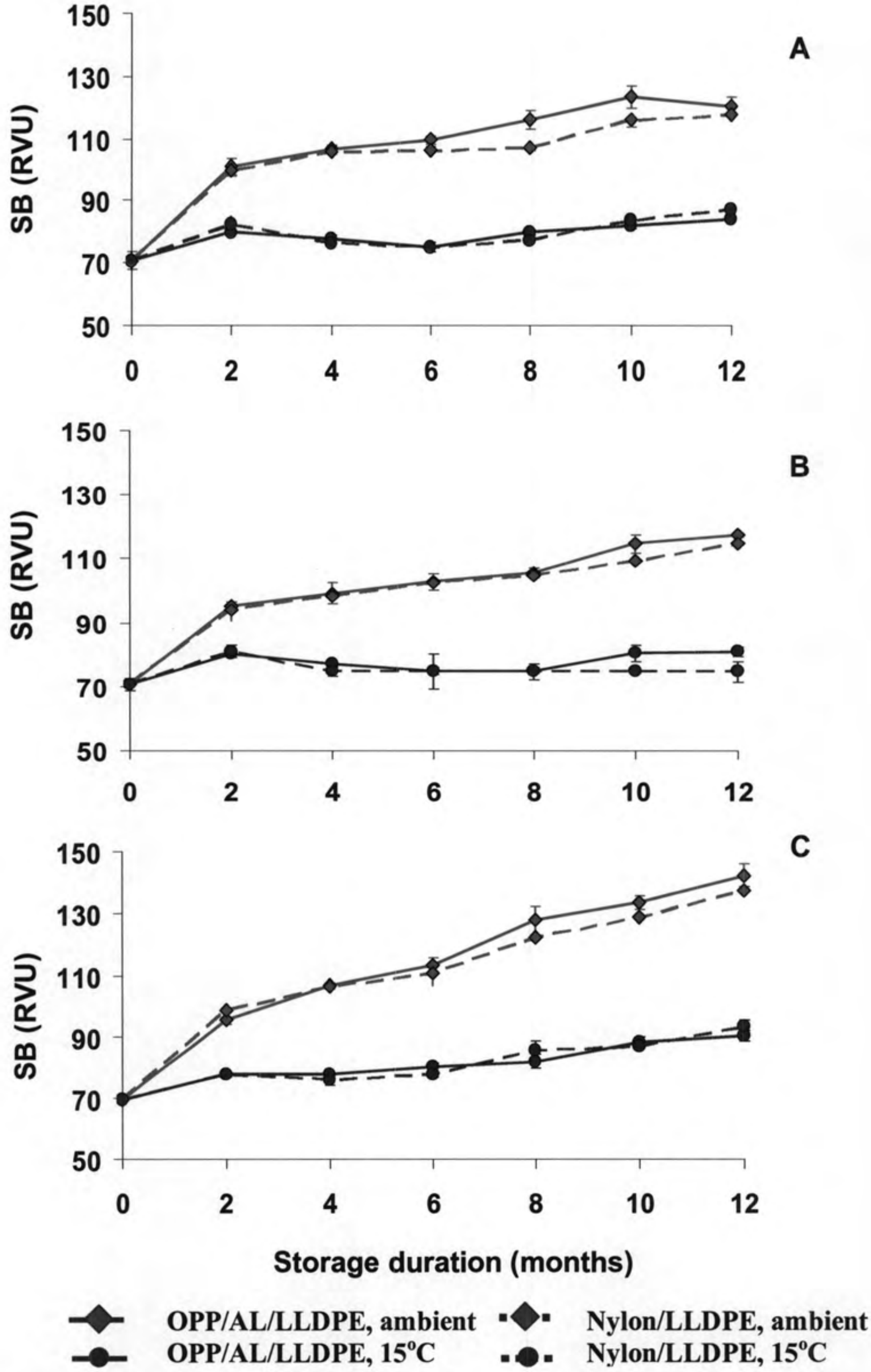

Figure 4.12 Setback (SB) of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

4.3.1.4 Swelling power

For any drying methods and packaging materials, swelling power at 70°C and 90°C of flours from the samples stored at ambient temperature tended to decrease after storing for 4 or 6 months. The swelling power at 70°C was not change within the last 6 months while the swelling power at 90°C was constant during the last 2 or 4 months of the storage duration (Fig 4.13 and Fig.4.14). In addition, the samples stored at 15°C had higher swelling power than those stored at ambient temperature. This trend was apparent for the swelling power at 90°C. The results were agreed well with the DSC and RVA results. In the samples stored for longer than 6 months, starch granule could absorb less amount of water and became difficult to swell; thus, gelatinization process of the samples was retarded. Therefore, gelatinization temperature (T_o, T_p and PT) of these samples stored at ambient temperature increased. Energy uptake during gelatinization process decreased; thus, ΔH_g decreased. The less swelling of starch granules during gelatinization, the lower PV of starch paste prepared from the samples stored at ambient temperature for 2 or 4 months was observed.

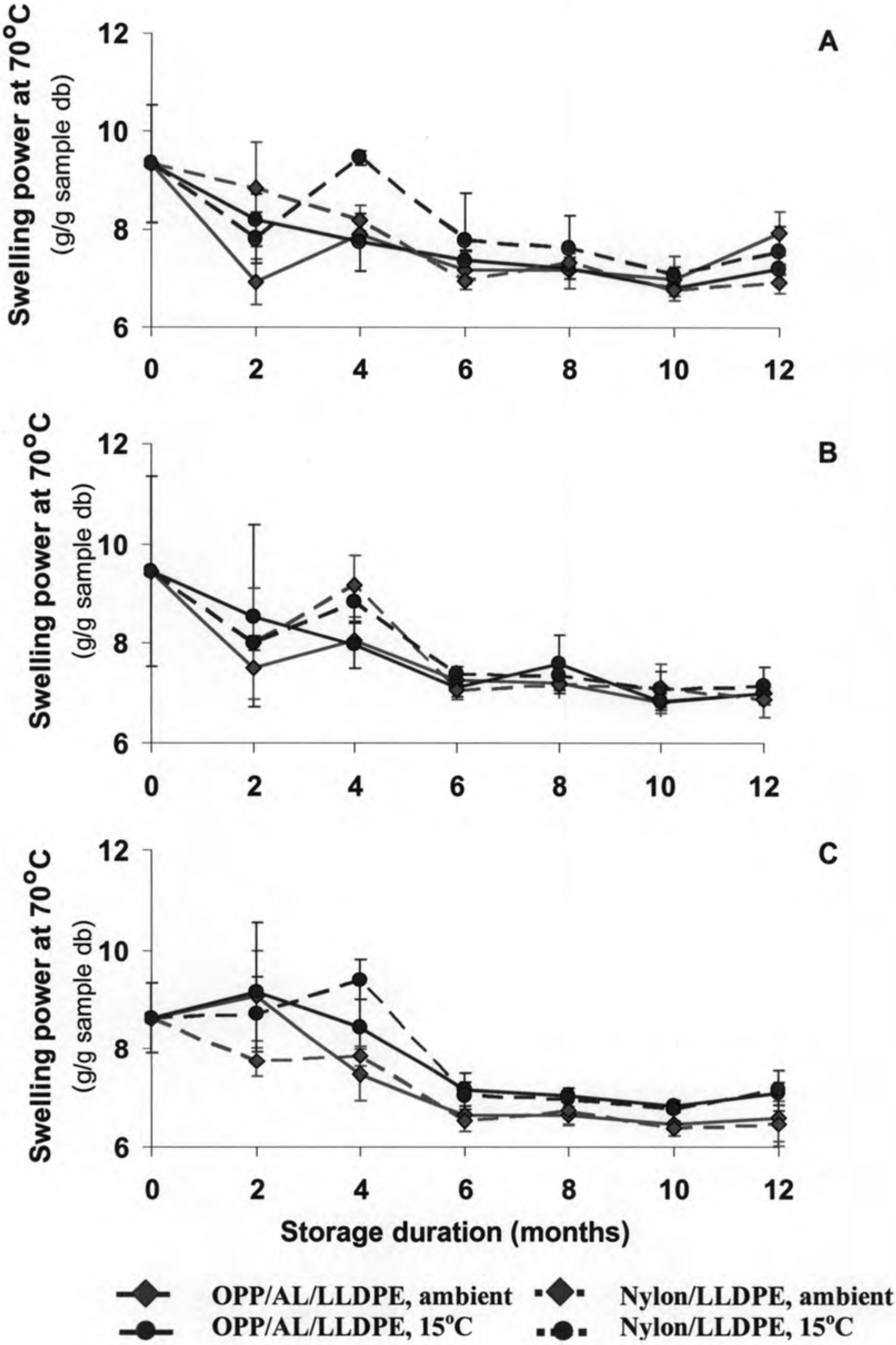

Figure 4.13 Swelling power at 70°C of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

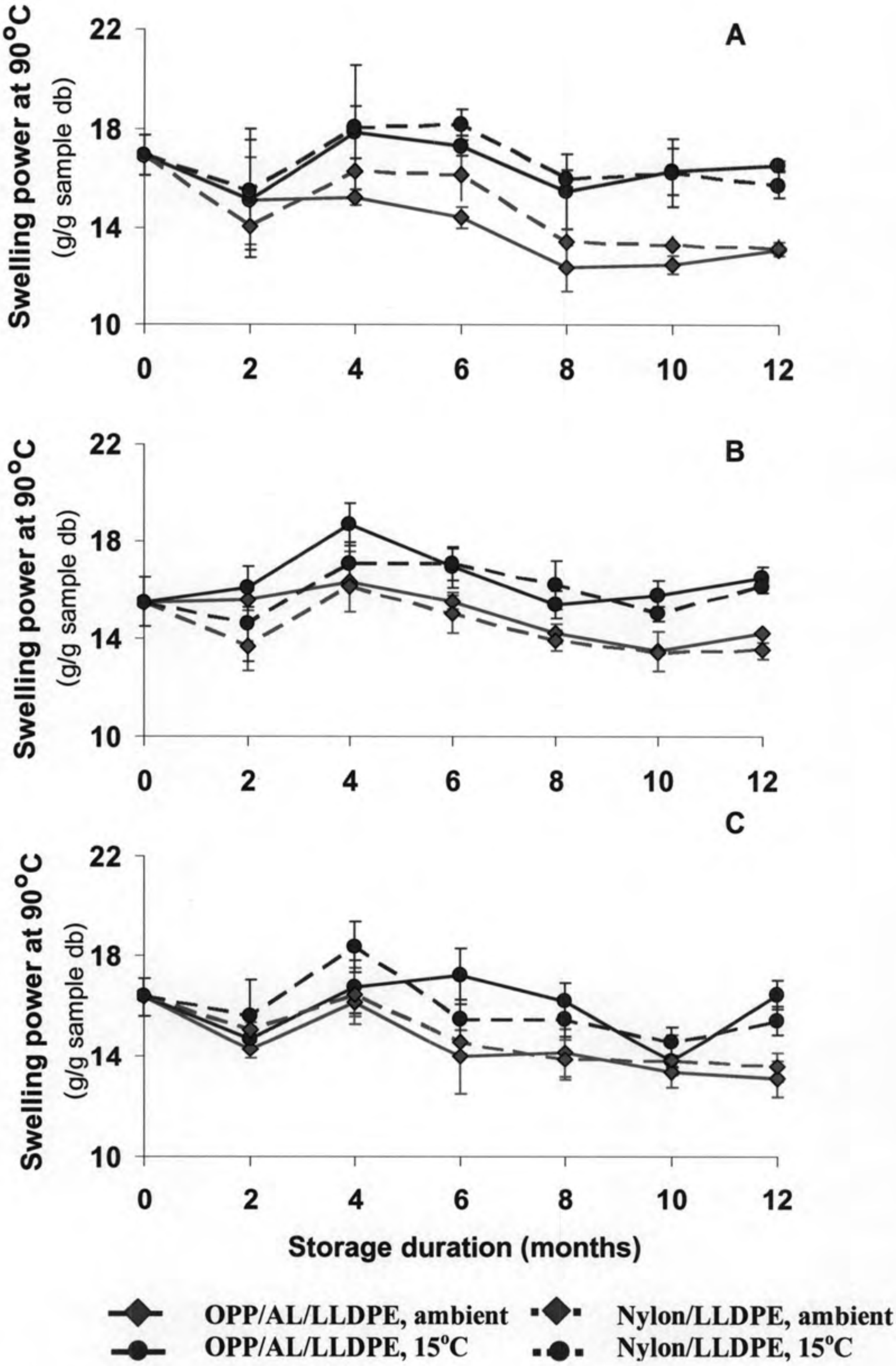

Figure 4.14 Swelling power at 90°C of hulled red jasmine rice and stored samples dried by different methods; shade drying (A), sun drying (B) and fluidized bed drying (C), during 12-month storage.

4.3.1.5 Overall discussion based on thermal properties, pasting properties and swelling power of aged hulled red jasmine rice

Previous studies proposed that the changes of pasting properties of rice during storage were mainly resulted from the structural changes of oryzenin, the main protein in rice grain (Moritaka and Yasumatsu, 1972; Sowbhagya and Bhattacharya, 2001; Martin and Fitzgerald, 2002; Zhou et al., 2002b; Zhou et al., 2003). According to the study of Chrastil (1990), milled rice grains were stored in a closed jar at 4°C or 40°C for 12 months. Oryzenin was extracted from each sample. Average molecular weight and the amount of cysteine and cystine in the extracted oryzenin were examined. The results indicated that average molecular weight of oryzenin increased during 12-month storage. In addition, the amount of cysteine decreased while cystine increased. The author hypothesized that the thiol group (-SH) of oryzenin was oxidized to form disulfide bridges (-SS-) during storage of rice kernels, resulting in an increase in average molecular weight of oryzenin. An increase in disulfide linkage during storage resulted in an increase in average molecular weight of oryzenin (Chrastil and Zarins, 1992) which could influence gelatinization process as previously reported in DSC, RVA and swelling power section (section 4.3.2-4.3.4).

In accordance with the results in the present study, following hypothesis is established. In the early stage of rice storage at ambient temperature (first 2-4 months), small increase in disulfide bridges might lead to the decrease in solubility of oryzenin. This could further reduce the starch-protein interactions during gelatinization (Teo et al., 2000). Moreover, a small increase in protein networks could reduce fragility of swollen starch granules; thus, the swollen granules are less susceptible to breakdown (Hamaker and Griffin, 1993). As a result, starch granules could absorb more water, swell to a greater extent during heating, gelatinize at a lower temperature and provide higher viscosity before being disrupted, leading to a decrease in PT and an increase in PV and ΔH_g; however, in this study, a decrease in T_o and T_p during early stage of rice storage at ambient temperature was not observed. During heating cycle of RVA analysis, samples were heated up from 50°C to 95°C under high shear force. Within this strong condition, the protein networks could be eventually disrupted during heating cycle. Swollen granules could be free. Without protection from protein networks, the swollen granules were able to breakdown. Therefore, the more swollen granules could have less resistant to shear force, so the BD increased. However, for a longer period of storage at ambient temperature (after 4 months), the greater extent of disulfide formation in protein molecules might cause the formation of large and strong protein networks. These networks could retard water absorption of starch granules; thus, swelling power and PV, ΔH_g and swelling power decreased. Gelatinization could start at a higher temperature. Therefore, PT, T_o and T_p increased. An elevation of T_o and T_p was obviously observed after the samples were stored for 8 months. The less swollen starch granules could be less disrupted by shear force during heating. Consequently, BD decreased.

Other possible mechanisms underlying the physicochemical changes of rice during storage are enzymatic activity and a formation of amylose-lipid complex. According to the study of Dhaliwal, Sekhon and Nagi (1991), paddy was dried using a forced-air circulation dryer at 35°C, packed in gunny sacks and stored at ambient temperature for 12 months. Activities of amylase, lipase and lipoxygenase (LOP) were investigated after the paddy was stored for 1, 6 and 12 months. The results indicated that amylase activity decreased during the first six month of the storage and remained constant afterwards. Therefore, effect of amylase activity on changes of physicochemical properties of the samples stored longer than 6 months might be neglected. As for lipase and lipoxygenase (LOP) activities, the results indicated that the activities increased during paddy storage. The amount of free fatty acids (FFA) also increased during storage. FFA could form complex with amylose. Increasing amount of amylose-lipid complex could further retard the water absorption and swelling of starch granules, leading to the physicochemical changes of the samples. Considering the important factors involved in amylose-lipid formation, previously suggested by Le Bail et al. (1999), both moisture content and storage temperature of the sample in this study were relatively low. Therefore, amylose-lipid complex could be difficult to form. As a result, a limited degree of amylose-lipid complex formation might not play an important role in the physicochemical changes of hulled red jasmine rice during storage.

As for SB, this parameter increased during storage at ambient temperature for 12 months. It can be hypothesized that the formation of disulfide linkage in oryzenin could lessen starch–protein interaction (Chrastil, 1990). During heating in RVA experiments, rice proteins could unfold and their reactive group could expose. The more exposure of the reactive groups, the greater extent of starch-protein interaction could occur. However, since disulfide linkage could stabilize structure of oryzenin, which was a globular protein, and prevent complete unfolding of the protein (Walstra, 2003), an increase in disulfide linkage during rice storage could retard starch-protein interaction during heating and cooling cycle. Therefore, protein and starch in rice flour could separately form gel upon a cooling cycle in RVA. This phenomenon could be responsible for an elevation of SB during rice storage.

In case of protein gelation, as the formation of disulfide linkages could be both intramolecular and/or intermolecular, an increase in disulfide linkages led to an increase in average molecular weight of oryzenin (Chrastil and Zarins, 1992) and hence the chain length of polypeptide (Wang and Damodaran, 1990). An increase in polypeptide chain length might limit the relative thermal motions of polypeptides, prevent the rupture of weak noncovalent interactions and stabilize protein gel network. A linear correlation between an average molecular weight of polypeptides in gel network and square root of gel hardness was reported (Wang and Damodaran, 1990). As a result, stronger network of oryzenin gel might be formed in the samples stored at ambient temperature for longer duration. Oryzenin gel could enhance the viscosity of rice flour in cooling cycle, leading to an increase in SB. As for starch gel, since starch-protein interaction decreased during storage, starch polymers, amylose and amylopectin, could reassociate and form highly ordered structure upon cooling. Consequently, rigidity of starch gel increased; thus, SB increased.

Significantly positive correlation between SB and hardness of cooked rice was reported (Bundit Leeharatanaluk, 2548; Ong and Blanshard, 1995). Hence, an increase in SB of the samples might imply that cooked hulled red jasmine rice prepared from the samples stored at ambient temperature could have higher hardness comparing to cooked fresh rice. When rice was cooked, ratio of cooking water to rice was generally 2:1 or 1:1. Moisture content of cooked rice was approximately 68-74% wb (USDA, 2006). With this level of moisture content, concentration of starch in cooked rice kernels was higher than that in RVA samples, which was approximately 10% wb. As a consequence, structure of starch gel within cooked rice might differ from that of rice paste obtained from RVA experiment. Keetels, Vliet and Walstra (1996) proposed a model of starch gel prepared from concentrated starch suspension, which was 15% or 30% wb. During heating, swelling of individual granules was restricted by limited available space to swell, leading to a tightly-packed system of the starch granules. Small amount of amylose leached out and formed thin layer of gel. Entanglement of short branches amylopectin was also present in those limited swollen granules. The less swelling of starch granules, the more stiffness of tightly-packed starch gel could form (Steeneken, 1989; Keetels, et al., 1996). According to the changes of thermal and pasting behaviors of the hulled rice during storage shown in the earlier section, the results pointed out that degree of gelatinization of the stored samples decreased. During cooking of the aged rice kernels with longer storage time, the starch granules could absorb less amount of water. Granules swelling would be more restricted. Disruption of crystalline structure of starch granules during cooking would remarkably decrease. The more physical entanglements of starch polymers in starch granules could be present. Therefore, starch gel with higher stiffness could form. In addition, the longer period of rice storage duration, the stronger network of oryzenin gel could form. The formation of starch and protein gels could enhance the hardness of the cooked hulled rice. Thus, the samples stored at ambient temperature could provide cooked rice with firmer texture than that of fresh samples which had lower degree of gelatinization.

The hypothesis regarding the effects of disulfide linkages on thermal and pasting properties of hulled red jasmine rice confirmed by investigating the effects of 2-mercaptoethanol treatment on those properties of the samples. The results were discussed in the following section.

4.3.1.6 Effects of 2-mercaptoethanol treatment on thermal and pasting properties of aged hulled red jasmine rice

The time-dependent changes of thermal and pasting properties of hulled red jasmine rice packed in OPP/AL/LLDPE and Nylon/LLDPE pouch showed the same trend. These changes of samples stored at ambient temperature were apparent than those of the samples stored at 15°C. Hence, only the samples packed in Nylon/LLDPE pouch and stored at ambient temperature for 12 months were selected to verify the hypothesis that structural changes of oryzenin played an important role on the changes of thermal and pasting properties of hulled red jasmine rice during storage. The 2-mercaptoethanol, a reducing agent which was able to reduce disulfide linkage, was added into the samples with 0.36% v/w. Thermal and pasting properties of each sample were analyzed using DSC and RVA, respectively. As for DSC experiment, for any drying methods, the samples treated with 2-mercaptoethanol had lower T_o and T_p but higher ΔT_g and ΔH_g than those of non-treated samples (Table 4.8 and Fig.4.15). The RVA results showed that, for any drying methods, the samples treated with 2-mercaptoethanol had lower PT and SB than those of non-treated samples, but higher PV and BD (Table 4.9 and Fig.4.16). Corresponding RVA results were reported as follows. Martin and Fitzgerald (2002) examined RVA results obtained from milled basmati rice stored at 4°C and the stored samples treated with Tricine-dithiothreitol (Tricine-DTT) buffer, a reducing agent. The results showed that stored samples treated with Tricine-DTT provided the similar RVA curves as those obtained from the fresh samples. Consistent results also obtained from the studies of Bundit Leeharatanaluk (2548) and Zhou et al. (2003) who observed the RVA results of the stored rice flour prepared from milled rice and treated with β-mercaptoethanol. However, PV of stored samples treated with a reducing agent in those previous studies was lower than that of fresh samples whereas, in the present study, PV of the treated samples was higher than that of fresh samples. This could be because the samples used in those previous studies were milled rice while, in this study, hulled rice was employed. Hulled rice still contains bran layers which resembled as a barrier of rice kernel to absorb water (Marshall, 1994). Rice flour prepared from hulled rice also contains embryo which could absorb water and affect their physicochemical properties. When flours from stored hulled rice was treated with 2-mercaptoethanol, disulfide linkage of proteins in bran layers and embryo was also be reduced. Protein networks in those parts could also be disrupted, resulting in a greater hydration and swelling of starch granules. As a result, PV of stored hulled rice treated with 2-mercaptoethanol was higher than that of freshly hulled rice. In addition, the larger extent of granule swelling and the greater degree of gelatinization could occur in treated sample, the higher ΔH_g of the treated samples was thus observed.

Table 4.8 Effect of 2-mercaptoethanol treatment on thermal properties of hulled red jasmine rice packed in Nylon/LLDPE pouch and stored at ambient temperature for 12 months [(A)]

Sample		T_o (°C)	T_p (°C)	ΔT_g (°C)	ΔH_g (J/g)
Shade drying	freshly	67.17 ± 0.06	72.88 ± 0.17	11.35 ± 0.23	7.92 ± 0.53
	12-month storage	68.62 ± 0.09	73.89 ± 0.10	11.19 ± 0.19	7.26 ± 0.15
	12-month storage + 2-mercaptoethanol	67.42 ± 0.19	72.63 ± 0.17	11.23 ± 0.10	8.13 ± 0.28
Sun drying	freshly	67.70 ± 0.08	73.10 ± 0.20	10.87 ± 0.07	7.57 ± 0.36
	12-month storage	68.99 ± 0.30	74.17 ± 0.30	10.92 ± 0.14	7.18 ± 0.14
	12-month storage + 2-mercaptoethanol	67.64 ± 0.21	72.91 ± 0.26	11.44 ± 0.22	8.23 ± 0.26
FB drying	freshly	68.66 ± 0.19	73.82 ± 0.20	10.93 ± 0.08	6.80 ± 0.18
	12-month storage	70.00 ± 0.26	74.90 ± 0.10	10.46 ± 0.10	6.89 ± 0.35
	12-month storage + 2-mercaptoethanol	68.89 ± 0.07	73.75 ± 0.10	10.89 ± 0.15	7.20 ± 0.27

[A] Mean ± standard deviation of triplicate analyses

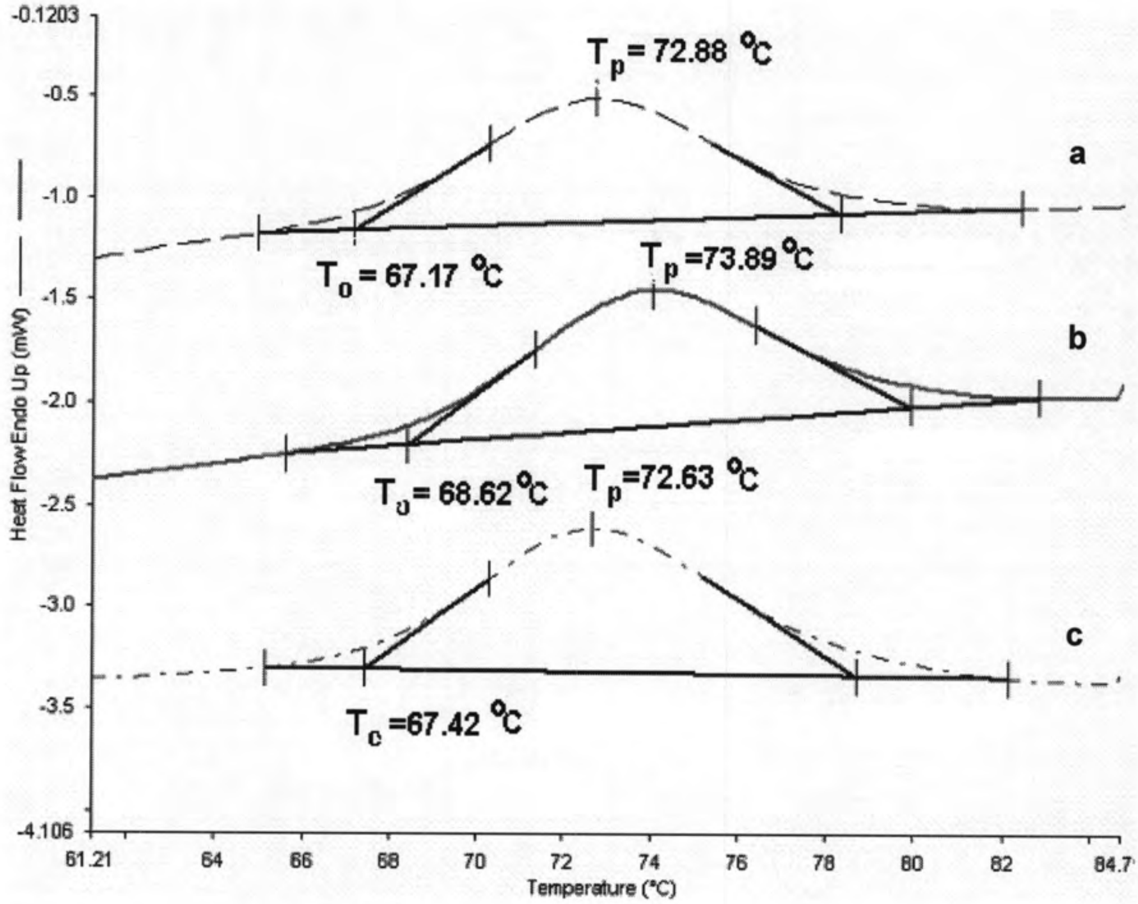

Figure 4.15 Effect of 2-mercaptoethanol on DSC thermograms of hulled red jasmine rice, packed in Nylon/LLDPE pouch; fresh sample (a ----), sample stored at ambient temperature for 12 months (b ——), sample stored at ambient temperature for 12 months and treated with 2-mercaptoethanol (c –·–).

Table 4.9 Effect of 2-mercaptoethanol treatment on pasting properties of hulled red jasmine rice packed in Nylon/LLDPE pouch stored at ambient temperature for 12 months [(A)]

	Samples	PT (°C)	PV (RVU)	BD (RVU)	SB (RVU)
Shade Drying	freshly	85.90 ± 0.74	181.12 ±3.74	79.60 ± 4.40	70.72 ± 2.91
	12-month storage	88.12 ± 0.46	193.16 ± 1.61	50.50 ± 1.53	118.06 ± 2.28
	12-month storage + 2-mercaptoethanol	84.58 ± 0.11	226.97 ± 1.21	118.75 ± 5.69	87.17 ± 0.79
Sun drying	freshly	86.24 ± 0.79	181.07 ± 5.35	74.98 ± 6.61	70.72 ± 1.77
	12-month storage	88.15 ± 0.45	189.28 ± 2.37	52.67 ± 2.18	114.89 ± 1.83
	12-month storage + 2-mercaptoethanol	83.85 ± 1.03	221.61 ± 6.05	116.28 ± 4.90	87.83 ± 0.92
FB drying	freshly	86.65 ± 0.98	182.38 ± 3.73	63.95 ± 3.46	69.42 ± 0.21
	12-month storage	88.70 ± 0.05	209.56 ± 14.75	60.56 ± 3.68	137.50 ± 1.08
	12-month storage + 2-mercaptoethanol	85.37 ± 0.78	249.06 ± 2.92	122.33 ± 2.25	111.11 ± 2.54

[A] Mean ± standard deviation of triplicate analyses

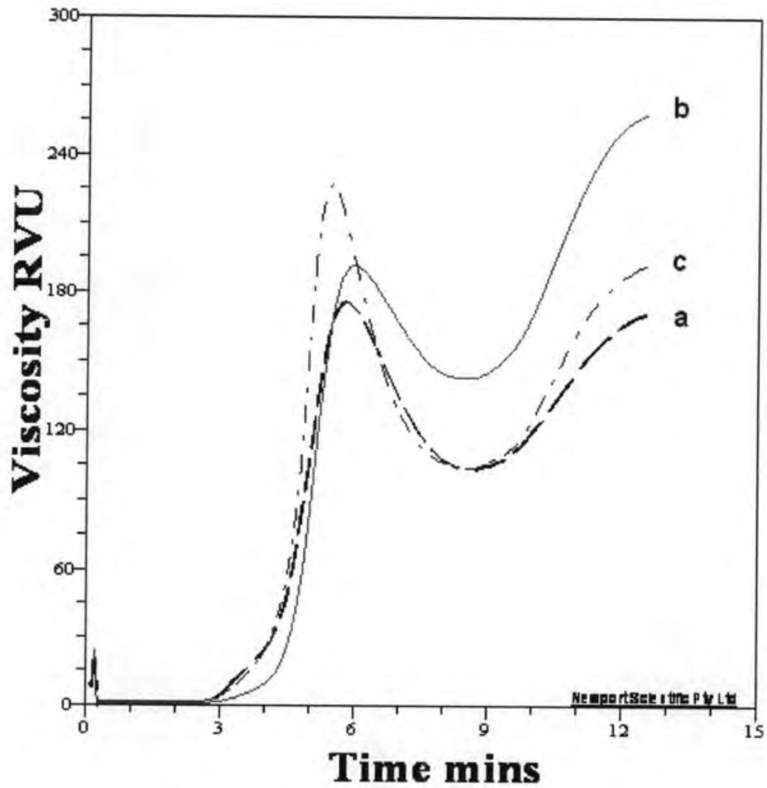

Figure 4.16 Effect of 2-mercaptoethanol on RVA curves of hulled red jasmine rice, packed in Nylon/LLDPE pouch; fresh sample (a ----), sample stored at ambient temperature for 12 months (b ——), sample stored at ambient temperature for 12 months and treated with 2-mercaptoethanol (c –·–).

When the 12-month stored samples were treated with 2-mercaptoethanol, disulfide linkages in rice protein were reduced. Protein networks were disrupted, yielding free sulfhydryl group. Starch granules liberated to absorb water and swell to a greater extent; thus, gelatinization could start at a lower temperature. Consequently, T_o, T_p and PT of the 2-mercaptoethanol treated sample were lower while PV was higher than that of non-treated samples. Without oryzenin network surrounding starch granules, swollen starch granules might be more susceptible to breakdown; thus, the treated samples had higher BD than that of non-treated samples. Moreover, 2-mercaptoethanol treatment led to reduction of disulfide linkages. This could lead to a decrease in chain length of polypeptides; thus, hardness of oryzenin gel decreased. Cleavage of disulfide linkage could cause a further unfolding of protein (Walstra, 2003). The more unfolding of protein, the more reactive groups were exposed. As a result, starch-protein interaction increased. The rearrangement of starch polymers during cooling cycle in RVA was disrupted, yielding starch gel with less ordered structure during cooling cycle. Therefore, SB of treated samples decreased.

4.3.2 Quality characteristics of cooked aged hulled red jasmine

Sun-dried hulled red jasmine rice was selected to investigate effects of storage conditions on sensory characteristics of the samples. This was because sun drying was generally operated in Thailand. Therefore, this type of samples could represent the real products in the market. Moreover, only the samples stored at ambient temperature were employed. The reason was that the samples stored at ambient temperature showed greater extent of change in thermal properties, pasting properties and swelling power than the samples stored at 15°C within the same period of time. Hence, the changes of sensory characteristics of samples stored at ambient temperature could also be more apparent and become easier to be detected by panelists while these changes of the samples stored at 15°C might be delayed by low storage temperature.

4.3.2.1 Color

The effects of packaging materials and storage duration on the color, in Hunter L, a, b system, of cooked sun-dried hulled red jasmine rice are shown in Table 4.10. For samples packed in OPP/AL/LLDPE and Nylon/LLDPE pouches, L and a value, which indicated darkness and redness, of the sun-dried samples stored at ambient temperature up to 12 months were fluctuated. In case of b value which referred to yellowness, b value of the samples packed in OPP/AL/LLDPE pouches did not significantly change during storage ($p>0.05$) whereas for the samples packed in Nylon/LLDPE pouches, yellowness of the samples was significantly lower than the fresh samples after stored for 4 months ($p\leq0.05$). However, consumers might not recognize the difference in color among the samples.

Table 4.10 Color of cooked sun-dried hulled red jasmine rice packed in different packaging materials and stored at ambient temperature up to 12 months$^{(A, B)}$

Packaging materials	Storage duration (months)	L	A	b
	0	$34.40^{bc} \pm 1.72$	$6.67^{a} \pm 0.44$	$4.55^{ab} \pm 0.52$
OPP/AL/LLDPE	2	$35.77^{ab} \pm 1.14$	$5.50^{bcd} \pm 0.77$	$4.04^{bc} \pm 0.71$
	4	$33.70^{c} \pm 1.31$	$6.73^{a} \pm 0.99$	$4.65^{a} \pm 0.79$
	6	$37.13^{a} \pm 2.52$	$5.42^{cd} \pm 0.64$	$4.16^{abc} \pm 0.56$
	12	$34.25^{bc} \pm 1.63$	$6.07^{b} \pm 0.54$	$4.31^{ab} \pm 0.43$
Nylon/LLDPE	2	$34.18^{bc} \pm 1.61$	$5.66^{bcd} \pm 0.40$	$3.79^{bc} \pm 0.44$
	4	$33.88^{c} \pm 2.36$	$6.02^{bc} \pm 0.59$	$3.75^{c} \pm 0.30$
	6	$33.97^{c} \pm 1.11$	$5.68^{bcd} \pm 0.47$	$3.73^{c} \pm 0.51$
	12	$34.90^{bc} \pm 1.79$	$5.36^{d} \pm 0.61$	$3.73^{c} \pm 0.61$

^{A} Means with the same letter within the column are not significantly different ($p \leq 0.05$).

^{B} Mean $\pm$ standard deviation of duplicate analyses

4.3.2.2 Sensory analysis

QDA scores for sensory characteristics of cooked sun-dried hulled red jasmine rice stored at ambient temperature are shown in Table 4.11. As for aroma of the samples, the results indicated that the samples packed in Nylon/LLDPE pouches and stored for 6 and 12 months had the significantly lowest fragrance ($p \leq 0.05$) while having the significantly highest rancidity ($p \leq 0.05$). Moreover, the panelists started recognizing significant difference of rancidity from the samples packed in Nylon/LLDPE pouches, and stored for 4 months ($p \leq 0.05$) whereas the significant difference of rancidity from the samples packed in OPP/AL/LLDPE pouches was revealed for the 12-month stored samples ($p \leq 0.05$). The results indicated that an increase in storage duration led to a decrease in fragrance, but resulted in an increase in rancidity of the cooked hulled rice. OPP/AL/LLDPE pouch could better preserve fragrance and prevent the oxidative rancidity in the samples. Effects of storage conditions on volatile compounds of rice using an instrumental examination, such as GC-MS and HS-GC, were earlier investigated and reported agreeable results as follows. An increase in storage temperature and duration led to a greater deterioration of 2AP, but resulted in an increase in quantity of n-hexanal (Shin et al., 1986; Wongpornchai et al., 2004; Yoshihashi et al., 2005; Tulyathan and Leeharatanaluk, 2007). The main causes of the formation of n-hexanal in hulled rice during storage were reported as lipolysis and oxidation of rice lipids. Both reactions depend on storage temperature (Shin et al., 1986). An increase in storage duration resulted in an increase in lipase and lipoxigenase activity which led to the greater formation of n-hexanal (Dhaliwal et al., 1991). Moreover, an exposure to light accelerated autoxidation of rice which was stored at ambient temperature (Sowbhagya and Bhattacharya, 1976). Laminated OPP/AL/LLDPE bag was proposed as the most suitable packaging to prevent the loss of 2AP and retard the formation of off-flavor compounds in rice during storage (Tulyathan et al., 2008). The results in those previous studies were corresponded to our findings. As the amount of 2AP decreased while n-hexanal increased with increasing storage duration, the cooked hulled rice prepared from stored samples had lower fragrance but had higher rancidity than those prepared from the fresh samples. Since laminated OPP/AL/LLDPE film was a better barrier than Nylon/LLDPE film, fragrance of the samples packed in OPP/AL/LLDPE pouch and stored up to 12 months was comparable to that of the fresh samples while the significant differentiation of rancidity of the samples packed in OPP/AL/LLDPE pouch was delayed to 12 months.

Table 4.11 QDA scores for sensory characteristics of cooked sun-dried hulled red jasmine rice packed in different packaging materials and stored at ambient temperature up to 12 months.[(A, B)]

Packaging materials	Storage duration (months)	Sensory Characteristics		
		Fragrance	Rancidity	Hardness
	0	$3.63^{a} \pm 0.74$	$1.19^{c} \pm 0.75$	$3.94^{e} \pm 0.86$
OPP/AL/LLDPE	2	$4.06^{a} \pm 0.62$	$1.25^{c} \pm 0.65$	$4.44^{de} \pm 0.50$
	4	$4.13^{a} \pm 0.69$	$1.13^{c} \pm 0.74$	$4.94^{cd} \pm 0.42$
	6	$4.06^{a} \pm 0.68$	$1.56^{c} \pm 0.50$	$5.50^{bc} \pm 0.60$
	12	$3.69^{a} \pm 0.80$	$3.69^{b} \pm 0.46$	$7.25^{a} \pm 0.85$
Nylon/LLDPE	2	$3.94^{a} \pm 0.73$	$1.19^{c} \pm 0.92$	$4.38^{de} \pm 0.52$
	4	$3.75^{a} \pm 0.53$	$3.44^{b} \pm 0.68$	$5.31^{bc} \pm 0.46$
	6	$2.63^{b} \pm 0.74$	$4.88^{a} \pm 0.58$	$5.69^{b} \pm 0.65$
	12	$2.25^{b} \pm 0.71$	$4.75^{a} \pm 0.89$	$7.31^{a} \pm 0.65$

[A] Means with the same letter within the column are not significantly different ($p \leq 0.05$).

[B] Mean $\pm$ standard deviation of the data in 10-point intensity scale, obtained from eight trained panelists

In case of hardness of cooked hulled red jasmine rice, for any packaging materials, the samples stored at ambient temperature for 12 months had the significantly highest hardness ($p \leq 0.05$) (Table 4.11). Overall results indicated that an increase in storage duration led to an increase in hardness of the cooked samples. The consistent results were reported. According to the study of Tulyathan and Leeharatanaluk (2007), milled KDML-105 rice was stored in PP bags at ambient temperature (30-35°C) for 8 months. Hardness of cooked samples was measured using a Texture Analyzer with 6-mm-diameter probe. Statistical analysis indicated that hardness of cooked samples significantly increased during aging process ($p \leq 0.05$). Significantly positive correlation between SB and hardness measured by an instrument was reported ($p \leq 0.01$) (Ong and Blanshard, 1995; Tulyathan and Leeharatanaluk, 2007). According to this study, this trend is also applicable for SB and hardness data obtained from sensory panelists.

In order to examine whether consumers would accept cooked hulled red jasmine rice, affective test of fresh sun-dried samples and sun-dried samples packed in Nylon/LLDPE pouches at ambient temperature for 6 and 12 months were investigated by 34 consumers using 5-point hedonic scale (Table 4.12). In this part of sensory analysis, sun-dried samples packed in Nylon/LLDPE pouches at ambient temperature were selected because Nylon/LLDPE film was generally used by rice manufacturers; thus, this type of samples could be a good representative for the commercial hulled rice. Moreover, in the selected conditions, greater changes of the physicochemical properties of the samples including negative changes, such as the loss of fragrance and the increase in rancidity, could take place. Therefore, if consumers still accept this treatment, the other treatments with better packaging materials and lower storage temperature should also be accepted by consumers as well. According to statistical analysis, there was no significant difference in color, aroma and overall acceptance among all tested samples ($p>0.05$). In case of hardness, there was a significant difference between hedonic score of the cooked hulled rice prepared from fresh sun-dried samples and that of the cooked hulled rice prepared from the samples stored for 6 months ($p\leq0.05$). However, hedonic score of the cooked hulled rice prepared from the samples stored for 12 months was not significantly different from that of the fresh samples and the samples stored for 6 months ($p>0.05$). This significant finding could be due to individual preference of each consumer. Consumers might be divided into two groups. The first group preferred cooked rice with soft texture and the other preferred a firmer texture. Thus, the cooked rice prepared from fresh and 12-month stored samples received high scores as they provided the softest and the firmest texture, respectively. However, all sensory characteristics received hedonic scores higher than 2.5. Therefore, consumers still accepted cooked sun-dried hulled red jasmine rice even packed in Nylon/LLDPE bag and stored for 12 months. As the changes of thermal and pasting properties of hulled red jasmine rice could be delayed by storing the hulled rice at low temperature, it could point out that the samples stored at

$15^{\circ}C$ should be more acceptable by consumers in terms of hardness. As for aroma of the samples, although the trained panelists could detect the significant difference of rancidity from the samples packed in Nylon/LLDPE pouches at ambient temperature since 4 months of the storage ($p \leq 0.05$), consumers still accepted this attribute even for the 12-month stored samples. Therefore, it might be unnecessary to use OPP/AL/LLDPE pouch as packaging material for hulled red jasmine rice. Moreover, as price per unit of OPP/AL/LLDPE bag was generally higher than Nylon/LLDPE. If the producers select Nylon/LLDPE film as packaging material together with vacuum packing, the cost of packaged hulled red jasmine rice will be reduced.

Table 4.12 Hedonic scores for sensory characteristics of cooked sun-dried hulled red jasmine rice packed in Nylon/LLDPE pouch and stored at ambient temperature up to 12 months.[A, B]

Storage duration (months)	Sensory Characteristics			
	Color^{ns}	Aroma^{ns}	Hardness	Overall acceptance^{ns}
0	3.5 ± 0.6	3.6 ± 0.8	$3.9^{a} \pm 0.8$	3.8 ± 0.7
6	3.8 ± 0.9	3.4 ± 0.9	$3.3^{b} \pm 0.9$	3.4 ± 0.8
12	3.8 ± 0.9	3.4 ± 1.0	$3.6^{ab} \pm 0.9$	3.4 ± 0.9

[A] Means with the same letter within the column are not significantly different ($p \leq 0.05$).

[B] Mean $\pm$ standard deviation of the data in 5-point hedonic scale, obtained from 34 consumers.

[ns] Means within the column are not significantly different ($p > 0.05$)