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Original Article

Influence of packaging and storage conditions on quality parameters and shelf life of solar-dried banana

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Abstract

Effects of packaging materials (metalized or polylactic acid, PLA, based pouches), storage temperatures (30-50°C) and time (up to 6 months) on quality of solar-dried banana were investigated. At 30°C in both packaging materials, change in moisture content, water activity (a_w) and hardness were minimal while darkening of the surface color progressed. No microbial spoilage was found. Hedonic scores of color, flavor, taste, texture and overall acceptance of the 6th month aged samples were lowest ($p \leq 0.05$). Based on the sensory test, product packed in both packaging materials had shelf life of 5 months at 30°C. Higher storage temperature greatly induced time-dependent decrease in moisture content and a_w with an increase in hardness, especially for the samples in PLA-based pouches. Fractional conversion model was used to predicted time-dependent change in total color difference (ΔE) ($R^2 \geq 0.84$). Temperature dependence of the rate constant followed Arrhenius-type relationship ($R^2 \geq 0.99$).

Keywords: solar-dried banana, polylactic acid, storage temperature, quality, shelf life

1. Introduction

In Thailand, dried banana is a popular fruit snack. The product has also been exported to many countries in Asia, Australasia, Europe and Northern America. Total export quantity of Thai dried banana in 2014 was approximately 597,000 tons, with a value of US$ 3.3 million (Office of the Permanent Secretary, 2014). By using a specific banana cultivar (Kluai Namwa ABB) as raw material and employing a slow drying process, the dried banana has unique flavors with moist and chewy texture. Honey coating may be applied to enhance desirable aromas and flavors. In case of the drying process, the peeled banana fruits are commonly placed on woven bamboo mesh and sun-dried, which can lead to high level of contamination from insects, dust and microbes. Alternatively, solar drying has gained more interest since it helps improve and control product quality, particularly by reducing the contamination problems (Soponronnarit *et al*., 1997). Solar-dried bananas have been commercially available in Thailand and have also been exported as a premium grade. In order to maintain the desirable attributes of this high quality product during storage, several factors, including packaging materials and storage temperature have to be concerned.

Biodegradable polymers have gained more interest as replacement sources of petrochemical-based plastics for food packaging. Polylactic acid (PLA) is linear, aliphatic polyester comprising of lactic acid monomer. It can be derived from

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many plant crops including corn, sugar beet, sugar cane and tapioca, via fermentation process (Robertson, 2014). Nowadays, PLA is one of the most popular biodegradable polymers due to its low cost, clarity and modest mechanical properties. However, PLA is brittle and has a high water vapor transmission rate, which limits its applications. (Bang & Kim, 2012; Nampoothiri *et al.*, 2010; Robertson, 2014). Many attempts have been made to improve its mechanical and barrier properties, particularly by blending PLA with other polymers and adding appropriate plasticizers (Nampoothiri *et al.*, 2010). As for its application as food packaging, PLA can be used as a film and a rigid bottle or tub (Robertson, 2014).

Although there have been many studies regarding the banana drying process (Dandamrongrak *et al.*, 2003; Leite *et al.*, 2007; Phoungchandang & Woods, 2000a, 2000b; Soponronnarit *et al.*, 1997), studies on the changes in quality of the dried banana during storage are still limited. Detailed studies on the application of the PLA-based packaging on selected food products are also scant. Objective of this study was to determine the effects of packaging materials (conventional metalized plastic films vs. PLA-based film), storage temperatures and duration on physical, microbiological and sensory properties of solar-dried banana. Kinetic study of the color change during storage was also performed. Data obtained from this study were successfully used to estimate shelf life of the product at a specific temperature.

2. Materials and Methods

2.1 Materials

Solar-dried bananas (*Musa* cv. Kluai Namwa ABB) were obtained from Jiraporn Food Limited Partnership, Phitsanulok, Thailand. Whole fruit of the ripe banana was dried in a solar dome, yielding the dried sample with round shape and weighing approximately 15 g/piece. No honey coating was applied. Metalized plastic film composed of the oriented polypropylene, metalized polyethylene terephthalate and linear low – density polyethylene layers was also obtained from the same company. This film type was regularly used by the manufacturer for packing dried banana. PLA-based film used in this study were the polymer blend, in which other flexible biodegradable polymer has been melted and mixed with PLA matrix in the co-rotating twin screw extruder before passing through the blown film line. The film was prepared in a laboratory scale in the Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University. Detailed characteristics of both films are shown in Table 1.

2.2 Sample preparation and storage

Each of the dried banana pieces was packed in a 5.5 cm × 14.0 cm pouch prepared from the metalized film or the PLA film. The packed samples were divided into three groups for the storage at 30±2°C (ambient temperature in Thailand), incubated at 40±1°C and 50±1°C. All samples were kept up to six months. Each individually packed banana piece was considered as an experimental unit.

2.3 Determination of physical, microbiological and sensory properties

Moisture content of the samples was determined by hot air oven method (AOAC, 2006). Water activity (a_w) of the samples was measured by water activity meter (AquaLab Series 3, Decagon, USA). Both measurements were done in triplicate. Surface color of the dried banana was measured in CIE L*, a*, b* system using chroma meter (Minolta CR-400, Konica Minolta Sensing, Japan). The measurement was done in triplicate using three pieces of dried banana. For each sample piece, color values at six positions were recorded. Total color difference (ÄE) was calculated with the following equation:

$$\Delta E = \left[\left(L_0^* - L_t^* \right)^2 + \left(a_0^* - a_t^* \right)^2 + \left(b_0^* - b_t^* \right)^2 \right]^{1/2} \quad (1)$$

where L_0^*, a_0^* and b_0^* were measured from the samples at the beginning of the storage (t = 0) and L_t^*, a_t^* and b_t^* were obtained from the stored samples at a specific storage time.

Texture of the samples was determined by Texture Analyzer (TA-XT2i, Stable Micro Systems, Surrey, UK). A 30 kg-load cell was used. The sample was cut with Warner-Bratzler blade with the test speed of 2 mm/s and 100% cutting distance. Hardness (maximum cutting force) was identified from the force-distance curve using Texture Expert software. Each sample piece was cut at two positions. The measurement was performed on six pieces of the banana samples (six replicates).

In case of microbiological analysis, total plate count as well as yeast and mold count of the samples were determined (Association of Official Analytical Chemists [AOAC], 2006). Coliform enumeration was performed with the most probable number (MPN) method (Feng *et al.*, 2002). The analyses were done in triplicate. As for the in-house sensory evaluation, acceptance test on surface color, aroma, taste, texture and overall acceptance of the dried banana samples was evaluated on 7-point hedonic scale by 30 local consumers aged 18-22 years. Those consumers were undergraduate students from the Department of Food Technology, Faculty of Science, Chulalongkorn University, and were familiar with dried bananas. According to Watts *et al.* (1989), 30-50 untrained panelists are acceptable for the in-house evaluation. Note, that both microbiological analysis and sensory evaluation were performed only for the samples stored at ambient temperature.

2.4 Kinetic model of the color change

Kinetics of the change in ΔE of the dried banana during storage was investigated. Data was fitted with the fractional conversion model (Equation 2), which was derived from first order kinetic model. This model was successfully used to predict the changes in color parameters in both Hunter L, a, b and CIE L*, a*, b* systems, as induced by processing and storage of fruits and vegetables (Ávila & Silva, 1999; Pinheiro *et al.*, 2013).

$$\Delta E = \Delta E_{\infty} + (\Delta E_0 - \Delta E_{\infty}) \cdot e^{-kt} \qquad (2)$$

where t is storage time (days), ΔE_{∞} is the equilibrium value (as t approaches infinity), ΔE_0 is initial value (at 0 day) and k is the reaction rate constant (1/days). Arrhenius model was used to describe the temperature dependence of the rate constant, k.

$$k = Ae^{(\frac{-E_a}{RT})} \qquad (3)$$

where A is pre-exponential constant (1/days); E_a is activation energy (kJ/mol); R is gas constant (kJ/ mol·K); T is storage temperature (K). All of the non-linear curve fitting was performed via OriginPro 8 software (OriginLab Corp., MA, USA).

2.5 Statistical analysis

All experiments were done at least in triplicate. Effect of storage time on sensory characteristics of the dried banana was determined using randomized complete block design. Analysis of variance was performed and the differences among means were reported at 95% confidence level using Duncan's new multiple range test. SPSS Statistics 17.0 (IBM Corporation, New York, USA) was employed for the statistical analysis.

3. Results and Discussion

3.1 Changes in physical properties during storage at different temperature

Effects of storage time, temperatures and packaging materials on moisture content, water activity and texture of the dried banana were shown in Figure 1. For both packaging types, the change in those properties tended to be minimal for

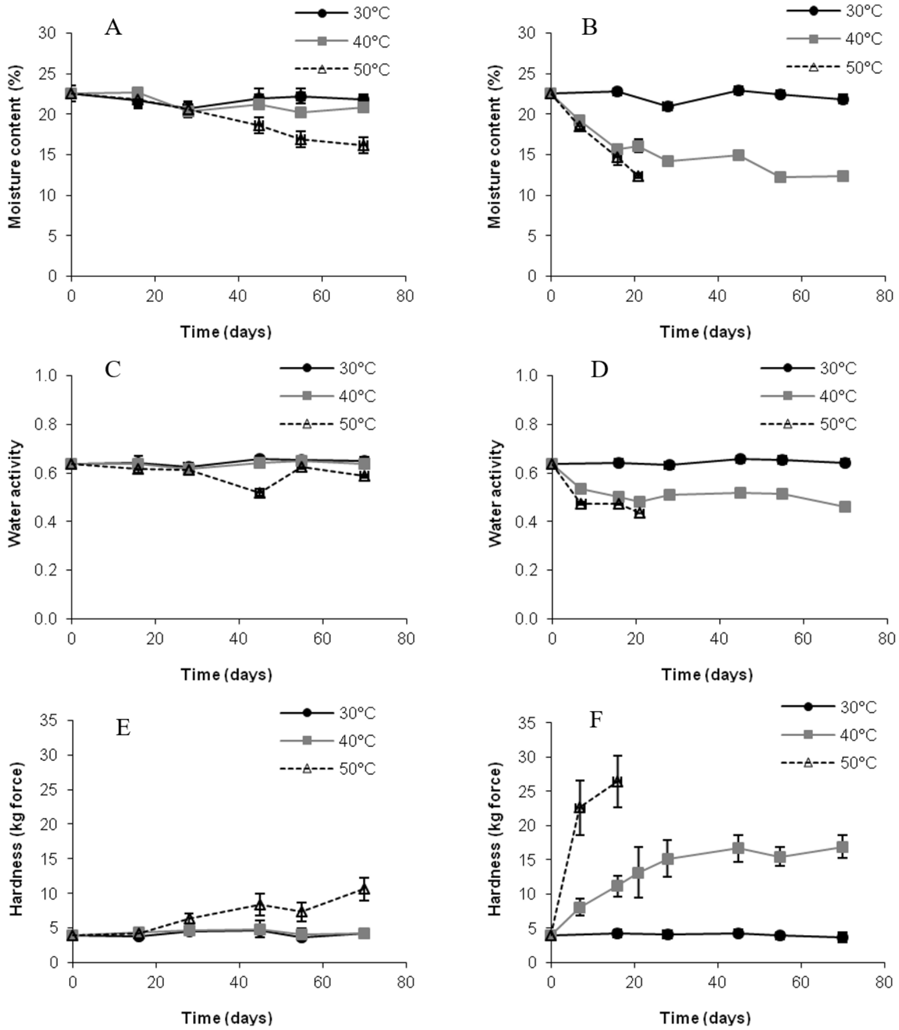

Figure 1. Moisture content, water activity and hardness of the solar-dried banana packed in metalized plastic pouch (A, C, E) or PLA-based pouch (B, D, F) and stored at different temperatures. Error bars extend one standard deviation above and below the mean.

the samples stored at 30°C. For the conventional metalized plastic type, time-dependent changes of the properties were obvious at 50°C storage temperature; the samples stored for longer time tended to have lower moisture content and water activity, yet they had higher hardness. However, for the samples packed in PLA-based pouches, those changes were apparently shown at 40°C and occurred at faster rate, with greater magnitude, at 50°C. Moreover, at similar storage temperature and time, the changes in those physical properties occurred to greater extent for the samples packed in the PLA-based packaging. This might be due to the difference in water vapor transmission rate (WVTR) (Table 1). At the same temperature, PLA-based film had higher WVTR, resulting in greater extent of moisture loss, a_w reduction and hardening. Temperature dependence of WVTR has been described with Arrhenius equation (Mannapperuma & Singh, 1994). At higher storage temperature, WVTR of the films became greater, resulting in the greater rate of changes in moisture content, a_w and hardness of the dried banana. Labuza *et al.* (2004) stated that hardening texture of the dried fruits could result from moisture loss and a_w reduction, especially at a_w below 0.55. This was in an agreement with increasing hardness of the samples kept in PLA-based pouches and stored at 40°C and 50°C, having a_w ranged between 0.46-0.54, and 0.43-0.47, respectively, after seven days of storage. Note, that the determination of moisture content, a_w and hardness was done up to 3-week storage for the samples packed in PLA-based pouches and stored at 50°C. Beyond this storage time, the samples became too hard and were not suitable for the physical property analysis.

Color parameters and progress of color change (ΔE) of the dried banana packed in different materials and stored at different temperatures is depicted in Figure 2 and 3. Longer storage time and higher temperature resulted in decreasing L*, a* and b*, and eventually greater ΔE, indicating the darkening of the surface color. This could mainly be due to the non-enzymatic browning reaction, i.e. Maillard reaction. Unlike other physical properties, faster rate of the changes in L*, a* and b*, as well as ΔE increase, especially at 50°C storage, tended to be for the samples kept in the metalized plastic pouches. Maillard reaction could occur at a higher rate in the food with a_w value of 0.6-0.8 (Fennema, 1997). For the elevated storage temperatures, a_w values of the dried banana stored in the metallized pouches were mostly higher than 0.6 while those of the samples packed in the PLA-based pouches were 0.4-0.5. Therefore, for the latter packaging type, the reaction rate tended to be lower because of the limited free water remaining in those samples.

According to the changes in physical properties, overall data indicated that PLA-based pouch was not suitable for the dried banana samples stored at elevated temperature (higher than 30°C). Otherwise, rapid loss of moisture and hardening of texture could occur. Conventional metalized pouch could be a better choice for those conditions (e.g. high ambient temperature during summer season in tropical countries). For the storage at 30°C, both packaging type seemed to be useful for the dried banana samples. Detailed study of the change in dried banana quality during prolonged storage (up to 186 days) at this temperature is shown in the following section.

3.2 Changes in the quality of solar-dried banana stored at ambient temperature

Selected physical properties of the dried banana kept at 30°C are depicted in Figure 4. For both packaging materials, moisture content and water activity of the samples fluctuated. Yet the parameter stayed within a narrow range (20-24% moisture; a_w between 0.63-0.66). Longer aged samples, i.e. 152-186 days (corresponding to 5-6 months), tended to have firmer texture. As shown in Figure 2-3, surface darkening obviously occurred in storage even at the ambient temperature. In case of microbiological analyses, all samples had total plate count less than 250 cfu/g, yeast and mold count less than 2,500 cfu/g and coliform count up to 9.2 MPN/g. The results indicated no spoilage of the dried banana during 186 days (approximately six months) storage. Dried, ready-to-eat raw food, including dried fruits, with acceptable quality should contain less than 10^6 cfu/g of yeast and less than 10^4 cfu/g of mold (Health Protection Agency, 2009; Stannard, 1997). For both packaging films used, hedonic scores of the surface color of the 152th and 186th day aged samples significantly decreased comparing to those of the 0-day samples ($p \leq 0.05$) (Table 2). This could be due to extensive browning indicated by elevated ΔE values after 112 days (approximately four months) of storage (Figure 2). For all of the 186-day aged samples, hedonic scores of all sensory attributes were significantly lower than those at 0-day ($p \leq 0.05$). These could be related to excessive darkening, texture hardening, development of some off-flavors and undesirable tastes, i.e. bitter-

Table 1. Characteristics of plastic films used in this study.

Type	Total thickness (μm)	Water vapor transmission rate (g/m^2·day)	Oxygen transmission rate (cm^3/m^2 day)
Metalized film	67	0.8	15
PLA-based film	70	120	365

Note: Water vapor transmission rate was determine at 37.8°C, 90% relative humidity while oxygen transmission rate was determine at 23°C, 0% relative humidity.

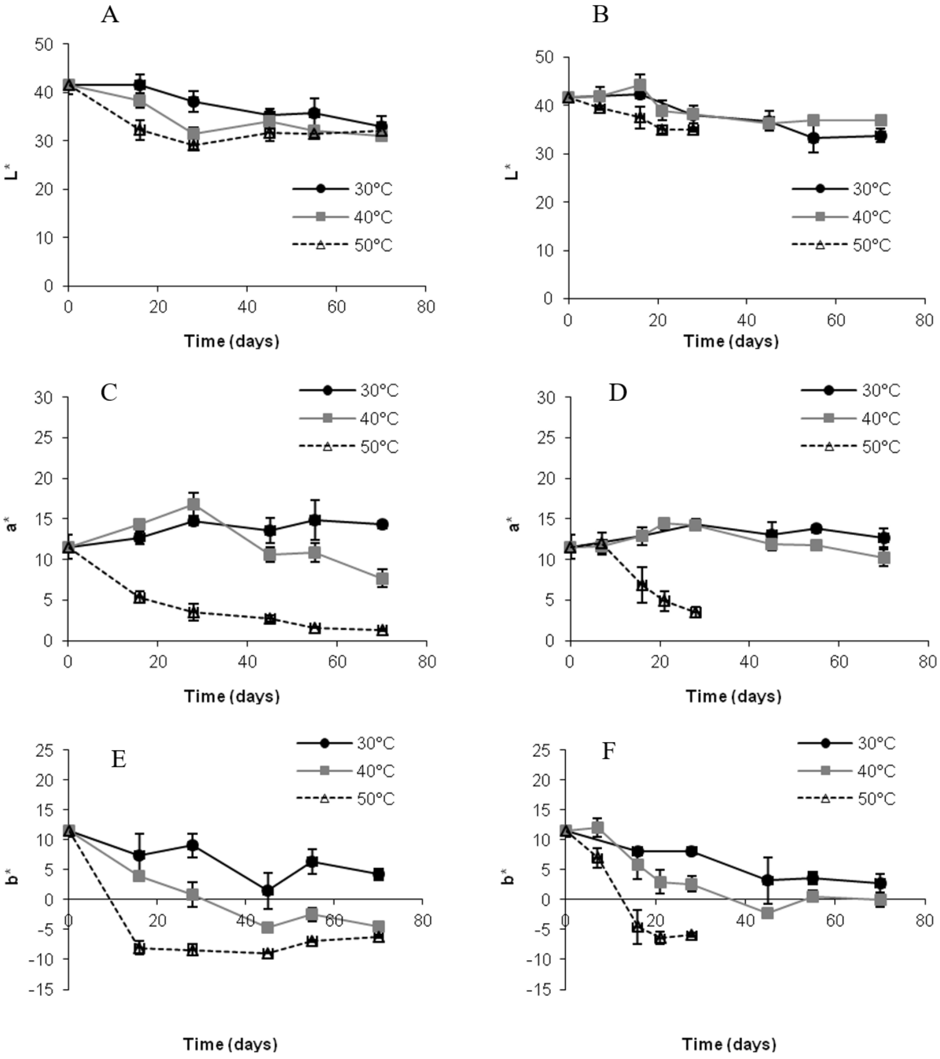

Figure 2. Color parameters in CIE L*, a*, b* system of the solar-dried banana packed in metalized plastic pouch (A, C, E) or PLA-based pouch (B, D, F) and stored at different temperatures. Error bars extend one standard deviation above and below the mean.

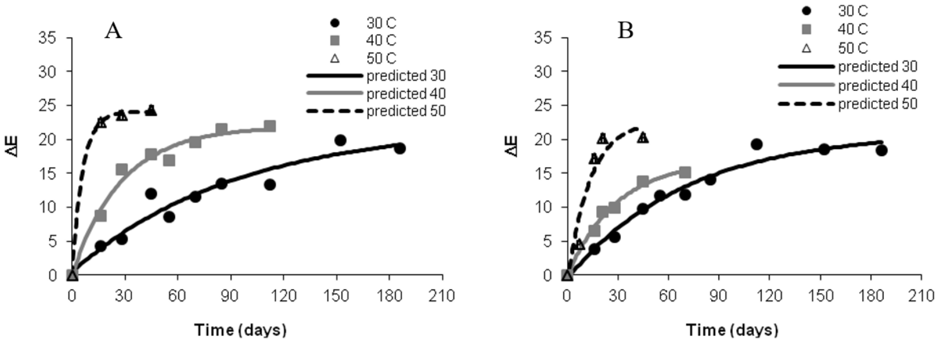

Figure 3. Color change (ΔE) of the solar-dried banana packed in metalized plastic pouch (A) or PLA-based pouch (B) and stored at different temperatures. Connecting line represents the data fitted with fractional conversion model.

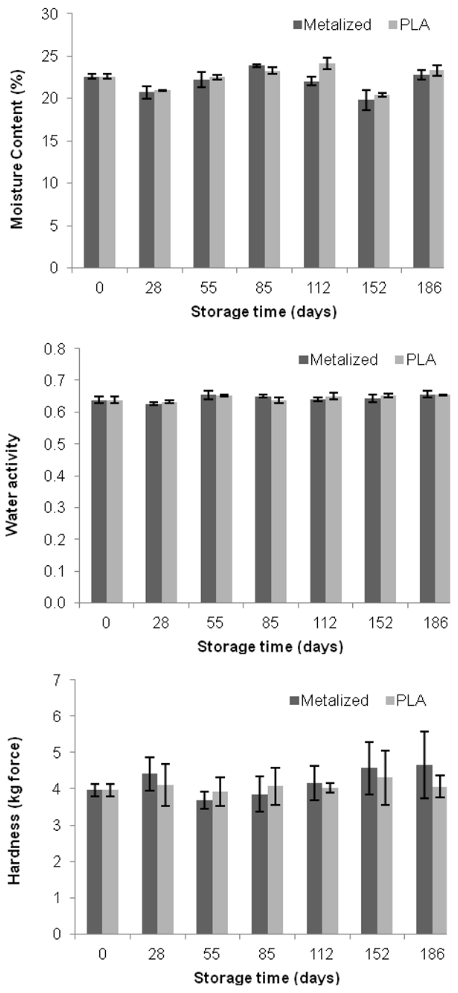

Figure 4. Moisture content, water activity and hardness of the solar-dried banana kept in different packaging films and stored at ambient temperature up to 186 days. Error bars extend one standard deviation above and below the mean.

ness, commented by some consumers. Moreover, those hedonic scores were approximately 4.0 (neither like nor dislike) or even lower ('dislike' zone). This could indicate that the samples stored for that long were not accepted by consumers.

Overall results showed that packaging type did not greatly affect quality of solar-dried banana during storage at 30°C. Microbiological properties were not the most important parameters for shelf life determination of the dried banana. Critical parameters were physical properties/sensory attributes (i.e. color and texture). Based on the sensory evaluation, the solar-dried banana with acceptable quality could be kept in both packaging films up to 152 days (5 months) at 30°C. Shelf life of the samples at some other storage temperatures could be calculated based on the kinetic study of ΔE, which is reported in the following section.

3.3 Kinetics of the color change

The ΔE data were well fitted with the fractional conversion model ($R^2 \geq 0.838$) (Figure 2). The related kinetic parameters are shown in Table 3. Storage temperature and packaging materials did not greatly influence DE_{∞} parameter. The value ranged from 22-24 and 17-23 for the samples packed in metalized-type and PLA-based pouches, respectively. Although k values of the samples stored in both types of packaging materials were quite similar at 30°C and 40°C, the k value of the samples packed in the metalized-type pouches was much higher than that stored in the PLA-based pouches. This could indicate that the browning reactions occurred faster in the metalized packaging at elevated temperature as previously discussed. The k values represented the temperature-dependent behavior, which was reasonably fitted with Arrhenius equation ($R^2 \geq 0.992$). Arrhenius parameters of the ΔE changes in the aged samples packed in both films are reported in Table 4.

Table 2. Hedonic scores of solar-dried bananas during storage at 30°C.

Attribute	Film type	Storage time (days)						
		0	1	2	3	4	5	6
Surface color	Metalized	5.50 ± 1.14^{a}	5.50 ± 1.04^{a}	5.30 ± 1.11^{a}	4.93 ± 1.39^{ab}	4.90 ± 1.93^{ab}	4.53 ± 1.46^{b}	3.63 ± 1.40^{c}
	PLA	5.50 ± 1.14^{a}	5.50 ± 1.11^{a}	5.10 ± 1.21^{ab}	4.43 ± 1.48^{bc}	4.70 ± 1.37^{b}	3.97 ± 1.35^{cd}	3.43 ± 1.55^{d}
Aroma	Metalized	5.50 ± 1.25^{ab}	5.10 ± 1.27^{ab}	5.43 ± 1.17^{a}	5.13 ± 1.35^{ab}	5.07 ± 1.01^{ab}	4.67 ± 1.29^{b}	3.97 ± 1.54^{c}
	PLA	5.50 ± 1.25^{a}	5.00 ± 1.36^{a}	5.34 ± 1.00^{a}	4.70 ± 1.17^{ab}	4.83 ± 1.41^{a}	4.90 ± 1.45^{a}	4.07 ± 1.57^{b}
Taste	Metalized	5.36 ± 1.21^{a}	5.37 ± 1.35^{a}	5.50 ± 1.07^{a}	4.97 ± 1.30^{ab}	5.10 ± 1.47^{ab}	4.57 ± 1.19^{bc}	4.03 ± 1.56^{c}
	PLA	5.36 ± 1.21^{a}	5.70 ± 1.09^{a}	5.63 ± 1.19^{a}	4.93 ± 1.41^{ab}	4.57 ± 1.48^{bc}	4.90 ± 1.45^{ab}	3.90 ± 1.63^{c}
Texture	Metalized	5.23 ± 1.43^{a}	5.00 ± 1.68^{a}	5.13 ± 1.27^{a}	4.67 ± 1.45^{ab}	5.17 ± 1.66^{a}	4.40 ± 1.57^{ab}	3.93 ± 1.31^{b}
	PLA	5.23 ± 1.43^{ab}	5.17 ± 1.11^{ab}	5.33 ± 1.35^{a}	4.10 ± 1.35^{cd}	4.43 ± 1.55^{bc}	4.73 ± 1.26^{abc}	3.60 ± 1.52^{d}
Overall acceptance	Metalized	5.63 ± 1.00^{ab}	5.20 ± 1.47^{ab}	5.43 ± 1.01^{a}	4.93 ± 1.05^{ab}	5.10 ± 1.32^{ab}	4.57 ± 1.25^{bc}	4.03 ± 1.21^{c}
	PLA	5.63 ± 1.00^{ab}	5.50 ± 1.01^{a}	5.50 ± 1.22^{a}	4.73 ± 1.14^{b}	4.53 ± 1.48^{b}	4.73 ± 1.36^{b}	3.70 ± 1.37^{c}

Notes: Data were reported as mean ± standard deviation of the 7-point hedonic scores from 30 local consumers.
Means with different letters within the same row are significantly different ($p \leq 0.05$).

Table 3. Kinetic parameters from fractional conversion model for ΔE changes during storage of solar-dried bananas.

Parameters	Metallized film			PLA-based film		
	30°C	40°C	50°C	30°C	40°C	50°C
ΔE_∞	22.1±3.8	21.9±1.1	24.1±0.3	21.1±1.8	16.9±1.3	22.7±5.0
ΔE_0	0.4±1.5	0.0±1.3	0.0±0.4	-0.5±1.1	-0.1±0.7	-1.4±3.7
k (1/days)	0.011±0.004	0.036±0.006	0.167±0.018	0.014±0.003	0.034±0.006	0.075±0.043
R^2	0.914	0.969	0.999	0.962	0.982	0.838

Note: Data were reported as mean ± standard deviation (n=3).

As concluded in the Section 3.2 that shelf life of the samples stored at 30°C was five months (150 days). The ΔE value at this storage time can be used as a critical cut-off point to determine the shelf life at other temperatures. For instance, critical ΔE value calculated from the fractional conversion model is 17.79 for metalized packaging. Using this cut-off DE, estimated shelf life at 40°C, which is a possible ambient temperature during summer season, can be estimated as 47 days in this packaging material. However, this approach is not appropriate for the samples in PLA-based packaging since DE is not the only key parameter for shelf life estimation at elevated temperature (higher than 30°C). Severe hardening during storage should also be considered (Figure 1). For an industrial application, temperature-controlled storage (≤ 30°C) is recommended for dried banana packed in PLA-based packaging marketed in tropical countries, especially during summer season. However, the product exported to temperate regions, including Europe and Northern America, should be stable at ambient temperature of those countries.

4. Conclusions

Overall results indicated feasible application of PLA-based biodegradable packaging for the solar-dried banana. Despite higher WVTR and OTR, results from the determination of physical, microbiological and sensory properties confirmed that this biodegradable film could be used to replace the conventional metalized plastic film for the dried banana stored at ≤ 30°C. Shelf life of this product in both packaging materials at 30°C was estimated at five months. However, due to the severe hardening of the aged samples, the PLA-based packaging was not suitable for the elevated temperature storage (higher than 30°C) of the dried banana. Kinetic behaviors of the ΔE were studied using fractional conversion model and Arrhenius equation. The resulting kinetic parameters could be used to estimate shelf life of the product in the metalized plastic pouch at elevated temperature.

Table 4. Arrhenius parameters of ΔE changes during storage of solar-dried bananas at 25-45°C.

Parameters	Metallized film	PLA-based film
E_a (kJ/mol)	111.20	68.37
A (1/days)	1.49×10^{17}	8.65×10^{9}
R^2	0.992	0.999

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