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# Evaluation of physicochemical changes of spray-dried honey jackfruit (*Artocarpus heterophyllus* Lam.) powder during storage

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## Abstract

The present work was undertaken to investigate the effect of different packaging materials, namely polyethylene terephthalate (PET) and aluminium laminated polyethylene (ALP) on the physicochemical properties and microbiological stability of spray-dried honey jackfruit powder over seven weeks of storage at 38 ± 2°C and 90% relative humidity. The moisture content of honey jackfruit powder packaged in PET was doubled (12.32%) than of those packaged in ALP (5.31%). The water activity ($a_w$) of the powders were lower than 0.6 for both packaging materials, thus considered shelf-stable. Hygroscopicity increased up to 42.44 and 39.84% for powder packaged in PET and ALP, respectively. The angle of repose for powders flowability increased to 19° (ALP) and 28° (PET), which indicated that the powders flowability significantly decreased upon storage. The degree of caking for powder packaged in ALP (43.69%) was much less severe than that of PET (84.51%). Powder packaged in ALP showed good solubility (81.07 - 99.01%) and satisfactory microbiological results (< log 2.58 CFU/g). The results recommended that ALP packaging was better suited for keeping spray-dried honey jackfruit powder.

## Introduction

Jackfruit (*Artocarpus heterophyllus* Lam.) belongs to the family of Moraceae. It is an exotic fruit, which can be commonly found in tropical climate such as rain forests of India, Malaysia, Philippines, Eastern Africa, Brazil, and Florida. Jackfruit is also known as *nangka* in Malaysia, *jak* and *jaca* in the Philippines, *khanun* in Thailand, *khnor* in Combodia, *mak mi* in Laos, and *mit* in Vietnam (Shanmugapriya, 2011). Jackfruit is considered as the largest among edible fruits as it weighs 3.5 to 10 kg. Ripe jackfruit pulps have attractive golden yellow colour with a pleasant flavour. It is normally eaten raw, salted as pickle, cooked or eaten as a sweet. Jackfruit is a rich source of carbohydrates, minerals, carboxylic acid, dietary fibre, and vitamins such as ascorbic acid, thiamin, and riboflavin (Swami *et al.,* 2012). However, the shelf life of jackfruit is only for a few days at ambient conditions, leading to spoilage and postharvest losses.

Dehydration is a good choice for fruit preservation as it reduces moisture in fruits, thus inhibiting microbial growth and enzymatic activity (Jangam *et al.,* 2008). Spray-drying is a technique which involves spraying finely atomised solution droplets into a chamber where hot and dry air rapidly evaporates the solvent and converts the droplets into dry particulates (Jayasundera *et al.,* 2010). The spray-dried powder has longer shelf life than the fresh fruits, reduced in weight and volume, which resulted in easier transportation, storage, and packaging (Kha *et al.,* 2010). Spray-drying has been used to produce various types of fruit powders such as Jamun (Santhalakshmy *et al.,* 2015), Sapodilla (Chong and Wong 2015), Sarawak pineapple (Wong *et al.,* 2015), and banana (Wong *et al.,* 2018).

Some tropical fruits including banana and jackfruit are usually quite pulpy and pectinaceous to yield juices by simple pressing or centrifugation (Adao and Gloria, 2005). Thus, commercial pectinolytic enzymes are used to break down the fruit structure such as pectin, cellulose, and hemicelluloses into smaller particles. The enzyme liquefaction process eases the separation process, improves quality in terms of clarity, filterability, flavour, and colour of fruit juice (Tochi *et al.,* 2009).

According to Jaya and Das (2005), fruit powders are exposed to a wide range of environmental conditions such as light, temperature, humidity, and oxygen that can trigger several reaction mechanisms which eventually lead to food degradation during

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storage and distribution. Thus, dehydrated fruit powders require protection against ingress of moisture, oxygen, the loss of volatile flavouring, and colour. Storage study on mango powder has been reported by Jaya and Das (2005) using aluminium foil-laminated pouches stored under an accelerated storage environment (38 ± 2°C, 90% RH). Hymavathi and Khader (2005) investigated on the changes of nutrient and physicochemical properties of mango powders kept in metallised polyester/polyethylene and polyester poly pouches.

Polyethylene terephthalate (PET) is a type of polyesters produced by the reaction of dimethyl terephthalate and ethylene glycol (Marsh and Bugusu, 2007). PET provides a good barrier for heat, gases, moisture, mineral oils, solvents, and acids (Hui, 2005). Yu *et al.* (2015) reported that spray-dried bovine colostrum powder packed in PET showed a shorter shelf life as compared to those packaged in ALP. The lamination of aluminium films binds aluminium foil together with paper or plastic such as polyethylene or polypropylene is known as aluminium laminated polyethylene (ALP). Lamination of aluminium to plastic or paper enables heat sealability, provides excellent barrier for light, and reduces the permeability of oxygen (Abdel-Bary, 2003; Marsh and Bugusu, 2007). The individual components of ALP are recyclable.

In the present work, honey jackfruit powder was produced by adding maltodextrin to the aqueous honey jackfruit extract obtained after liquefaction with Celluclast® 1.5 L and Pectinex® Ultra SP-L followed by drying the mixture using a spray dryer. The present work was undertaken to evaluate the physicochemical changes and stability of spray-dried honey jackfruit powder packaged in different types of flexible packaging materials of ALP and PET pouches during accelerated storage (38 ± 2°C with 90% RH) over a 7-week period.

## Materials and methods

### *Materials*

Honey jackfruits were purchased from a local market in Cheras, Kuala Lumpur, Malaysia. Celluclast® 1.5 L and Pectinex® Ultra SP-L were purchased from Novozymes Switzerland AG (Dittingen, Switzerland). Maltodextrin (DE 10-12) was purchased from V.I.S. Foodtech Sdn. Bhd. (Selangor, Malaysia).

Two flexible packaging materials were used, namely (i) polyethylene terephthalate (PET) made from 12 µm polyethylene terephthalate (PET), 9 µm silicon oxide (SiOx), 15 µm nylon (NY) with 65 µm random copolymer polypropylene (R-CPP), and (ii) aluminium laminated polyethylene (ALP) made from 12 µm polyethylene terephthalate (PET) and 70 µm linear low density polyethylene (LLDPE) laminated with 7 µm aluminium (Al). The packaging materials were purchased from Good and Well Trading Sdn. Bhd. (Selangor, Malaysia). Unit pouches of ALP and PET measuring 9.0 × 15.0 cm with a thickness of 10 µm, and 8.0 × 11.0 cm with a thickness of 17 µm, respectively, were used for holding 15 g of the spray-dried honey jackfruit powder.

### *Spray-dried honey jackfruit powder preparation*

The honey jackfruits were cleaned and washed. Pulps were then separated from the peel. The pulps were then cut into small pieces (1 × 1 × 0.5 cm) following seed removal. They were then made into puree through blending at 22,000 rpm using a Waring blender (Osaka Chemical, Osaka, Japan) for 30 s until homogenous. Celluclast® 1.5 L (0.5% v/w) and Pectinex® Ultra SP-L (1% v/w) was added into the homogenised honey jackfruit puree. The mixture was incubated for 1.5 h at 50°C and 100 rpm using a water bath (Memmert Lab Companion, Germany). The enzyme in the treated puree was deactivated at 95°C for 5 min. The liquefied honey jackfruit puree was then sieved by using a muslin cloth to yield an aqueous honey jackfruit extract (Wong and Tan, 2017).

A 30% (w/w, fresh weight) of aqueous extract was prepared by dissolving puree in water. This was mixed with 30 g of maltodextrin (DE 10-12) which yielded a 1:1 blend. This mixture was then fed into the spray dryer. The inlet temperature, aspirator rate, pump rate, air flow rotameter, and the pneumatic nozzle cleaner speed of the spray dryer (Model B-290, Büchi, Switzerland) were kept constant at 160°C, 100%, 20%, 40 mm, and 6, respectively (Wong and Tan, 2017). The spray-dried honey jackfruit powder obtained was then stored in either ALP or PET pouches.

### *Packaging and storage of spray-dried honey jackfruit powder*

The spray-dried honey jackfruit powder (15 g) filled in PET and ALP pouches were heat sealed with a continuous band sealer (GW-SF-21000B, Good and Well, Malaysia). Twenty-four sealed pouches (three batches of spray-dried honey jackfruit powder) from each packaging material were placed separately in two desiccators (30 cm) maintained at 90 ± 2% RH using saturated salt solution of potassium nitrate ($KNO_3$). The desiccators were then placed in two incubators maintained thermostatically at 38 ± 2°C in the dark. These conditions are often used for storage study of dry powder as indicated by Potter (1978), Kumar and Mishra (2004), and Pua *et al.* (2008). Evaluation of physicochemical changes and microbiological stability were determined weekly throughout the seven weeks storage. The data were recorded in triplicate for three batches of spray-dried honey jackfruit powder (Wong and Lim, 2016).

*Analytical methods*

*Water activity and moisture content*

A water activity meter (Novasina, LabMaster, Switzerland) was used to measure the water activity ($a_w$) of the samples. The moisture content of the powder was determined following the method from AOAC (1984).

*Water solubility index (WSI)*

The WSI was determined according to Kha *et al.* (2010). One gram of spray-dried honey jackfruit powder was dissolved in 10 mL of distilled water in a centrifuge tube. The centrifuge tube was then incubated in a water bath (Memmert Lab Companion, Jeio Tech, Selangor, Malaysia) for 30 min at 37°C. The samples were then centrifuged at 4,400 rpm for 10 min (Centrifuge Universal 320R, Hettich Zentrifugen, Tuttlingen, Germany). Supernatant formed at the top layer was collected in a pre-weighed aluminium cup and oven-dried at 150°C for 5 h. The solubility was calculated as the weight difference.

*Hygroscopicity*

Hygroscopicity of the spray-dried honey jackfruit powder was obtained following the method of Cai and Corke (2000). Saturated ammonium chloride solution ($NH_4CI$) at 80 ± 1% RH was put into an air-tight glass desiccator at 25 ± 1°C. Two grams of spray-dried honey jackfruit powder were weighed from each packaging materials into small weighing boats. The weighing boats were then placed into the desiccator for a week. The samples were weighed again and the hygroscopicity was expressed as grams of adsorbed moisture per 100 g dry powder (g/100 g).

*Degree of caking*

The degree of caking was measured according to Ramachandran *et al.* (2014). Five gram of spray-dried honey jackfruit powder was weighed and poured into a sieve (Zebra, Malaysia) with an opening of 25.4 mm. It was shaken constantly until the powder could no longer pass through the sieve. The remaining powder left on the sieve was weighed and recorded. The degree of caking (%) was calculated using Eq. 1.

$$\text{Degree of caking (\%)} = \frac{weight\ of\ powder\ after\ sieved\ (g)}{5g\ of\ jackfruit\ powder} \times 100\% \qquad \text{(Eq.1)}$$

*Flowability*

The flowability of spray-dried honey jackfruit powder was measured according to Chauhan and Patil (2013). Jackfruit powder was poured into a funnel with a narrow stem mounted 20 mm above a piece of paper. The powder was allowed through the funnel into a fine stream to form a conical heap. The top of the powder heap was to touch the end of the funnel stem. Then, the base of the powder heap was outlined with a pencil and the powder was removed. The radius was calculated, and the angle of repose (θ) was determined using Eq. 2.

$$\text{Tan}\ \theta = \frac{height\ of\ stem\ base\ (mm)}{\text{(radius of base of powder heap (mm)} - radius\ of\ funnel\ stem\ (mm)} \qquad \text{(Eq. 2)}$$

*β-carotene content*

The carotenoid extraction method performed was adapted from Kha *et al.* (2010) with slight modifications. β-carotene solution (5 - 25 µg/g) was used to construct the standard curve. Total β-carotene content of the spray-dried honey jackfruit powder was determined at 450 nm using a PRIM Light spectrophotometer (Secoman, France) and expressed based on β-carotene equivalents (µg/g powder).

*Colour characteristics*

The colour characteristics of the spray-dried honey jackfruit powder were determined by using Hunter Laboratory Colorimeter (Model SN 7877, Ultra-scan, Hunter Associates Laboratory, Virginia) calibrated with white tiles. The L*, a*, and b* values, where L* denotes lightness and darkness, a* denotes redness and greenness, and b* denotes yellowness and blueness of the initial spray-dried honey jackfruit powder; and the stored powders were analysed. The total colour difference (ΔE) was calculated using Eq. 3.)

$$\text{Difference in colour } (\Delta E) = \sqrt{(L_i - L_t)^2 + (a_i - a_t)^2 + (b_i - b_t)^2}\ ) \qquad \text{(Eq. 3)}$$

where, $L_i$, $a_i$, and $b_i$ = initial L*, a*, and b* values for the spray-dried honey jackfruit powder, and $L_t$, $a_t$, and $b_t$ = corresponding values for stored spray-dried honey jackfruit powder.

*Total plate count*

The total plate count method was modified from Lu *et al.* (2011). 3.375 g of Plate Count Agar (PCA powder) and 1.53 g of peptone powder were weighed and dissolved in 150 and 60 mL of distilled water, respectively. They were then separately placed into two bottles of 250 mL Schott bottles, and autoclaved (HVE-60, Hirayama, Japan) at 121°C for 15 min prior to pouring into agar plates. One gram of spray-dried honey jackfruit powder from each packaging material was dissolved in 9 mL of sterilised peptone water in a test tube. The solution in the test tubes were homogenised using a homogeniser (Ika, Malaysia). Then, 0.1 mL of the mixture was pipetted out and spread onto the PCA prepared. The agar plates were then sealed and incubated in an incubator (BF 500, Memmert, Germany) at 35°C for 48 h. The total viable colonies formed were counted after 48 h incubation, and the total number of viable cells was calculated using Eq. 4.

$$\text{Number of viable cells/g} = \frac{no\ of\ Colonies}{volume\ of\ inoculum\ x\ dilution\ factor} \quad \text{(Eq. 2)}$$

*Statistical analysis*

All the analyses were conducted in triplicates ($n = 3$), and results were expressed as mean values ± standard deviations. Different means values were analysed using Tukey's HSD and one-way analysis of variance (ANOVA) using Statistical Software SPSS 19.0 (SPSS Inc., Chicago, IL, USA). The confidence level was set at 95% ($p < 0.05$).

## Results and discussions

*Water activity*

Water activity measures the availability of free water in a food system, which is responsible for biochemical reactions (Quek *et al.,* 2007). High water activity indicates more free water available for biochemical reactions and thus, shorter shelf life. The values of water activity below 0.6 is generally considered as microbiologically stable (Quek *et al.,* 2007), and at 0.2 to 0.4 to ensure dried food product against browning, hydrolytical reactions, auto-oxidation, lipid oxidation, and enzyme activity (Marques *et al.,* 2007). As shown in Table 1, water activity of spray-dried honey jackfruit powder packed in PET and ALP were less than 0.6, thus considered microbiologically stable. However, spray-dried honey jackfruit powder packaged in PET was only stable for six weeks, while the log CFU for spray-dried honey jackfruit powder packaged in ALP were within the safe limits for over seven weeks.

Table 1 shows that the type of packaging materials significantly ($p < 0.05$) affected the water activity of spray-dried honey jackfruit powder. The water activity of spray-dried powder also increased from an initial of 0.16 ± 0.01 to 0.29 ± 0.01 $a_w$ for ALP, and 0.48 ± 0.03 $a_w$ for PET during storage. These results are in agreement with those reported by Wong and Lim (2016) for spray-dried papaya powder stored in ALP and PET under accelerated conditions for seven weeks; Henríquez *et al.* (2013) for drum dried apple peel powders packaged in high-density polyethylene (HDPE) and metallised films of high barrier (MFHB) stored for 120 days;

Table 1. Water activity, moisture content, and water solubility index of spray-dried honey jackfruit powder packaged in ALP and PET stored at 38 ± 2°C for seven weeks.

| **Storage time (week)** | **Water activity ($a_w$)** | | **Moisture content (%)** | | **Water solubility index (%)** | |
|---|---|---|---|---|---|---|
| | **ALP** | **PET** | **ALP** | **PET** | **ALP** | **PET** |
| 0 | $0.16 \pm 0.01^{aA}$ | $0.16 \pm 0.01^{aA}$ | $2.42 \pm 0.03^{aA}$ | $2.42 \pm 0.03^{aA}$ | $99.01 \pm 0.64^{aA}$ | $99.01 \pm 0.64^{aA}$ |
| 1 | $0.17 \pm 0.01^{aA}$ | $0.20 \pm 0.00^{bB}$ | $2.84 \pm 0.02^{bA}$ | $4.79 \pm 0.02^{bB}$ | $97.09 \pm 0.58^{bA}$ | $95.09 \pm 0.47^{bA}$ |
| 2 | $0.18 \pm 0.01^{aA}$ | $0.25 \pm 0.01^{cB}$ | $3.15 \pm 0.07^{cA}$ | $5.94 \pm 0.01^{cB}$ | $96.07 \pm 0.04^{bA}$ | $91.17 \pm 0.51^{cA}$ |
| 3 | $0.20 \pm 0.01^{abA}$ | $0.34 \pm 0.00^{dB}$ | $3.83 \pm 0.07^{dA}$ | $6.82 \pm 0.02^{dB}$ | $90.23 \pm 0.38^{cA}$ | $85.14 \pm 0.28^{dB}$ |
| 4 | $0.23 \pm 0.00^{bcA}$ | $0.36 \pm 0.03^{dB}$ | $3.92 \pm 0.01^{dA}$ | $8.23 \pm 0.01^{eB}$ | $88.76 \pm 0.56^{dA}$ | $75.16 \pm 0.19^{eB}$ |
| 5 | $0.25 \pm 0.01^{cdA}$ | $0.40 \pm 0.01^{eB}$ | $4.32 \pm 0.02^{eA}$ | $9.63 \pm 0.01^{fB}$ | $85.03 \pm 0.04^{eA}$ | $70.12 \pm 0.47^{fB}$ |
| 6 | $0.27 \pm 0.01^{dA}$ | $0.42 \pm 0.02^{eB}$ | $4.91 \pm 0.05^{fA}$ | $10.66 \pm 0.03^{gB}$ | $84.90 \pm 0.28^{eA}$ | $65.14 \pm 0.46^{gB}$ |
| 7 | $0.29 \pm 0.01^{eA}$ | $0.48 \pm 0.03^{fB}$ | $5.31 \pm 0.05^{gA}$ | $12.32 \pm 0.03^{hB}$ | $81.07 \pm 0.18^{fA}$ | $60.32 \pm 0.46^{hB}$ |

Data are means ± standard deviations of triplicate analyses of the samples ($n = 3$). Means with different lowercase superscripts within a column are significantly different at $p < 0.05$. Means with different uppercase superscripts within a row are significantly different at $p < 0.05$.

Dak *et al.* (2014) for microwave-vacuum dried pomegranate arils during 90 days of storage in both ALP and high-density polypropylene (HDPP) pouches.

According to Pua et al. (2008), aluminium foil above 17 µm in thickness could be considered as a total barrier towards gases, moisture, and light. However, spray-dried honey jackfruit powder packaged in PET exhibited a greater extent of increase in water activity as compared to that of ALP with a thickness of 10 µm (Table 1). Dak et al. (2014) and Wong and Lim (2016) also reported that ALP showed a lesser increase in water activity as compared to HDPP and PET. Thus, ALP could be a more effective packaging material in preventing the increase of water activity.

*Moisture content*

Moisture content indicates the water composition in a food system, and it is an important factor in determining the powder quality (Moreira *et al.,* 2009). The results showed that the moisture contents of spray-dried honey jackfruit powders packaged in ALP and PET increased significantly ($p < 0.05$) upon storage (Table 1). The moisture content of spray-dried honey jackfruit powder packaged in PET was doubled (12.32%) than of those packaged in ALP (5.31%) by the end of seven weeks of storage. The moisture contents of spray-dried honey jackfruit powder packaged in ALP were below 10% after seven weeks of storage as shown in Table 1, which could be considered as microbiologically safe (Ng *et al.,* 2012). However, spray-dried honey jackfruit powder packaged in PET exhibited moisture contents above 10% after week 5. Similar results were obtained by Yu *et al.* (2015) and Wong and Lim (2016), whereby the moisture absorbed by spray-dried bovine colostrum powder and spray-dried papaya powder packaged in PET was higher than those packaged in ALP, respectively. These findings could be explained by the fact that the packaging materials used might not have provided an effective barrier against water vapour and oxygen (Costa *et al.,* 2013).

Wong and Lim (2016) reported that the moisture content of spray-dried papaya powder during accelerated storage (38 ± 2°C, 90% RH) gradually increased when packaged in PET and ALP, while the moisture content of mango soy fortified yogurt powder packaged in ALP and HDPP during accelerated storage (38 ± 1°C, 90 ± 1% RH) also increased as reported by Kumar and Mishra (2004). Pua *et al.* (2008) suggested that the increased in moisture content for drum-dried jackfruit powders packaged in both ALP and metallized co-extruded biaxially oriented polypropylene (BOPP/MCPP) over 12 weeks accelerated storage (38°C; 50, 75, and 90% RH) was due to the migration of water vapour from storage environment into the packaging material.

The water vapour transmission rate of PET of 17 µm was approximately $2.0 \times 10^{-6}$ kg/m$^2$/d, whereas the water vapour transmission rate of ALP which was laminated with 7 µm of aluminium was $1.21 \times 10^{-6}$ kg/m$^2$/d, at 38°C and 90% RH (Pua *et al.,* 2008). From Table 1, the moisture gained by spray-dried honey jackfruit powder packaged in ALP was less than PET. This result showed that ALP packaging had a lower value of water vapour transmission rate and exhibited a higher protective barrier against moisture content as compared to PET. According to Steele (2004), the packaging materials will affect the quality of food product when it is placed at a storage environment below or above its equilibrium point.

*Water solubility index (WSI)*

Water solubility index is the measure of ability of powder to dissolve in water where higher percentage indicates a higher solubility of powder in water. A good powder will wet quickly, sink and disperse in the solution without agglomeration (Santhalakshmy *et al.,* 2015). Increasing the storage durations showed a significant ($p < 0.05$) decrease in water solubility for spray-dried honey jackfruit powders packaged in both ALP and PET from an initial of 99.01 to 81.07% and 60.32%, respectively (Table 1). This may have occurred because of the sugar crystallisation that happened due to the relative humidity and storage temperature (Liu *et al.,* 2010; Costa *et al.,* 2013).

The spray-dried honey jackfruit powders were less soluble (60.32 - 99.01%) than the spray-dried passion fruit powders (98.61 - 99.15%) stored at room temperature for 180 days as reported by Endo *et al.* (2007). However, powders obtained in the present work were more soluble than spray-dried gac powder (36.91 - 38.25%) obtained by and Kha *et al.* (2010).

Spray-dried honey jackfruit powder packaged in ALP showed good solubility (> 80%) upon storage for seven weeks (Table 1), and thus, were regarded as useful and functional (Caliskan and Nur Dirim, 2013). However, powders packaged in PET exhibited solubility below 80% upon storage from week 4 to 7. Hence, it can be concluded that ALP was a better packaging, which could retain the water solubility of the spray-dried honey jackfruit powders.

*Hygroscopicity*

Hygroscopicity represents the ability of powder to absorb moisture from the surroundings and cause stickiness (Tonon *et al.,* 2008). As shown in Table 2, the hygroscopicity of spray-dried honey jackfruit powder packaged in ALP and PET increased from 25.65 - 39.84 and 25.65 - 42.44%, respectively. There was no significant ($p > 0.05$) increase between the hygroscopicity of jackfruit powder packaged in ALP and PET from week 0 to week 1, and from week 2 to week 3. A larger increase of hygroscopicity for the powder packaged in PET (Table 2) could be resulted from the different water concentration gradient between the powder and storage environment. These results are in accordance with those spray-dried papaya powders reported by Wong and Lim (2016), and higher than those spray-dried *Amaranthus* reported by Cai and Corke (2000). Thus, it can be concluded that ALP with a lower water vapour transmission rate ($1.21 \times 10^{-6}$kg/m$^2$/d) was a better packaging material for spray-dried honey jackfruit powders, as the water vapour available to be absorbed by the powder was lesser, leading to a lower hygroscopicity values (Pua *et al.,* 2008).

### *Degree of caking*

Caking is a collapse phenomenon due to stickiness whereby particles form permanent aggregates and harden into solid structure. It usually occurs during the production of dehydrated foods as the plasticisation of particle surface lead to a decrease in surface viscosity for adhesion. As shown in Table 2, the degree of caking for spray-dried honey jackfruit powders packaged in PET was nearly doubled (84.51%) to that of powders packaged in ALP pouches (43.69%) at the end of the storage. This is in agreement with the results reported by Liu *et al.* (2010), Yu *et al.* (2015), and Wong and Lim (2016) for spray-dried tomato powder, spray-dried bovine colostrum powder, and spray-dried papaya powder, respectively.

Based on Table 2 and Figure 1, spray-dried honey jackfruit powder packaged in PET exhibited a higher degree of caking by the end of seven weeks of storage. Spray-dried honey jackfruit powder packaged in ALP was still in powdered form, while that packaged in PET had clumped together by the end of week 7. Spray-dried honey jackfruit powder packaged in ALP dissolved immediately while that in PET could not dissolve when the powder was reconstituted with distilled water. It can thus be concluded that ALP was a better packaging material as compared to PET for storage of the spray-dried jackfruit powder as the powder stored in ALP exhibited lesser degree of caking. ALP was able to exclude water vapour and prevent its content to be affected by surrounding temperature (Liu *et al.,* 2010).

Figure 1. Spray-dried honey jackfruit powder packaged in ALP (left) and PET (right) after seven weeks of storage.

Table 2. Hygroscopicity, degree of caking, flowability, and β-carotene content of spray-dried honey jackfruit powder packaged in ALP and PET stored at 38 ± 2°C for seven weeks.

| Storage time (week) | Hygroscopicity (%) | | Degree of caking (%) | | Flowability (°) | | β-carotene content (μg/g) | |
|---|---|---|---|---|---|---|---|---|
| | ALP | PET | ALP | PET | ALP | PET | ALP | PET |
| 0 | $25.65 \pm 0.06^{aA}$ | $25.65 \pm 0.06^{aA}$ | $12.84 \pm 0.41^{aA}$ | $12.84 \pm 0.41^{aA}$ | $35.14 \pm 0.13^{aA}$ | $35.14 \pm 0.13^{aA}$ | $0.21 \pm 0.03^{aA}$ | $0.21 \pm 0.02^{aA}$ |
| 1 | $25.97 \pm 0.02^{aA}$ | $26.97 \pm 0.63^{aA}$ | $16.56 \pm 0.97^{bA}$ | $28.94 \pm 0.08^{bB}$ | $38.64 \pm 0.68^{bA}$ | $40.47 \pm 0.13^{bA}$ | $0.19 \pm 0.05^{aA}$ | $0.17 \pm 0.01^{aA}$ |
| 2 | $28.43 \pm 0.14^{bA}$ | $29.73 \pm 0.46^{bA}$ | $28.34 \pm 1.50^{cA}$ | $37.54 \pm 0.28^{cB}$ | $39.54 \pm 0.13^{bA}$ | $44.57 \pm 0.03^{cB}$ | $0.17 \pm 0.02^{aA}$ | $0.14 \pm 0.03^{aA}$ |
| 3 | $29.78 \pm 0.53^{bA}$ | $31.57 \pm 0.67^{bA}$ | $31.47 \pm 1.45^{dA}$ | $43.44 \pm 0.92^{dB}$ | $42.77 \pm 0.70^{cA}$ | $45.94 \pm 0.03^{cB}$ | $0.16 \pm 0.03^{aA}$ | $0.13 \pm 0.01^{aA}$ |
| 4 | $32.07 \pm 0.37^{cA}$ | $33.45 \pm 0.10^{cA}$ | $32.56 \pm 0.92^{dA}$ | $57.37 \pm 1.53^{eB}$ | $43.93 \pm 0.71^{cA}$ | $54.72 \pm 0.02^{dB}$ | $0.16 \pm 0.02^{aA}$ | $0.12 \pm 0.02^{aA}$ |
| 5 | $34.58 \pm 0.08^{dA}$ | $36.94 \pm 0.08^{dB}$ | $36.76 \pm 1.51^{eA}$ | $68.97 \pm 1.46^{fB}$ | $46.58 \pm 1.08^{dA}$ | $56.37 \pm 0.52^{eB}$ | $0.13 \pm 0.03^{aA}$ | $0.10 \pm 0.03^{aA}$ |
| 6 | $36.48 \pm 0.39^{eA}$ | $38.56 \pm 0.63^{eB}$ | $39.51 \pm 0.82^{fA}$ | $77.22 \pm 0.93^{gB}$ | $49.54 \pm 0.42^{eA}$ | $59.94 \pm 0.14^{fB}$ | $0.13 \pm 0.06^{aA}$ | $0.08 \pm 0.05^{aA}$ |
| 7 | $39.84 \pm 0.45^{fA}$ | $42.44 \pm 1.73^{fB}$ | $43.69 \pm 0.07^{gA}$ | $84.51 \pm 0.08^{hB}$ | $54.37 \pm 0.47^{fA}$ | $63.31 \pm 1.39^{gB}$ | $0.10 \pm 0.05^{aA}$ | $0.08 \pm 0.04^{aA}$ |

Data are means ± standard deviations of triplicate analyses of the samples ($n = 3$). Means with different lowercase superscripts within a column are significantly different at $p < 0.05$. Means with different uppercase superscripts within a row are significantly different at $p < 0.05$.

### *Flowability*

Flowability is the ability of powder to flow freely. Based on Table 2, increasing the storage time significantly ($p < 0.05$) decreased the flowability of spray-dried honey jackfruit powders packaged in both ALP and PET. The angle of repose increased from an initial of 35.14 to 54.37° and 63.31° for powder packed in ALP and PET, respectively, at the end of storage. Similar observations were reported on spray-dried mango milk powder (Chauhan and Patil, 2013) and spray-dried papaya powder (Wong and Lim, 2016) during storage. According to Ramachandran *et al.* (2014), flowability of powder will reduce during storage as the degree of caking of powder increases. Flowability of a powder could also be correlated with the moisture absorption during storage, which increases the cohesiveness of powder (Chauhan and Patil, 2013). The reduction in flowability of fruit powders during storage could also be explained by the fact that the presence of low molecular weight sugar in fruits tends to have high molecular mobility, which would easily lose its free flowing (Jaya and Das, 2005).

### *β-Carotene content*

Carotenoids are yellow-red isoprenoid polyene pigments present in plants. There was no significant difference ($p < 0.05$) for β-carotene concentration of the spray-dried honey jackfruit powder pacakged in ALP and PET as shown in Table 2. Carotenoids are susceptible to heat, light, oxygen, and can suffer auto-oxidation as their structure contains a conjugated double bond system over the entire length of the polyene chain (Ghosh, 2012). However, Hymavathi and Khader (2005), Costa *et al.* (2013), and Wong and Lim (2016) reported the decreased in β-carotene for vacuum-dried mango milk powder, spray-dried passion fruit powder, and spray-dried papaya powder during storage.

### *Colour characteristics*

Colour is an important attribute because it is usually the first property that the consumer observes (Sáenz *et al.,* 1993). The total colour difference (ΔE) of the spray-dried honey jackfruit powder was significantly ($p < 0.05$) affected by the type of packaging material as well as the storage period (Table 3). After storage of seven weeks, there was a greater colour change (51.05) in spray-dried honey jackfruit powder stored under accelerated condition (38°C, 90% RH) in PET, as shown in Table 3. The colour changes were significantly ($p < 0.05$) lower in ALP packaged powder than the PET packaged powder, which was obviously due to the permeability of the packaging material to water vapour and oxygen. Moreover, residual air remaining in the package may cause oxidation that led to colour changes during storage.

Spray-dried honey jackfruit powder packaged in PET experienced a larger change in terms of L*, a* and b* values over seven weeks of storage (Table 3). The powder gradually became darker over time. This observation was also reflected by the increase in Hunter a* value and decrease in Hunter L* value. These results are in agreement with those reported by Kumar and Mishra (2004) and Wong and Lim (2016) for the mango soy fortified yogurt and spray-dried papaya powder during storage, respectively.

### *Total plate count*

Microbiological integrity of food is an

Table 3. Total colour change, L*, a*, and b* value of spray-dried honey jackfruit powder packaged in ALP and PET stored at 38 ± 2°C for seven weeks.

| Storage time (week) | Total colour change (ΔE) | | L* value | | a* value | | b* value | |
|---|---|---|---|---|---|---|---|---|
| | ALP | PET | ALP | PET | ALP | PET | ALP | PET |
| 0 | - | - | $95.09 \pm 0.01^{aA}$ | $95.09 \pm 0.01^{aA}$ | $0.40 \pm 0.13^{aA}$ | $0.40 \pm 0.13^{aA}$ | $12.15 \pm 0.17^{aA}$ | $12.15 \pm 0.17^{aA}$ |
| 1 | $1.51 \pm 0.01^{aA}$ | $7.14 \pm 0.02^{aB}$ | $94.85 \pm 0.01^{aA}$ | $94.43 \pm 0.04^{aA}$ | $0.44 \pm 0.17^{aA}$ | $0.49 \pm 0.08^{aA}$ | $13.64 \pm 0.04^{aA}$ | $19.26 \pm 0.01^{bB}$ |
| 2 | $2.48 \pm 0.03^{bA}$ | $12.68 \pm 0.02^{bB}$ | $94.44 \pm 0.05^{aA}$ | $93.23 \pm 0.08^{bA}$ | $0.63 \pm 0.00^{bA}$ | $1.05 \pm 0.07^{bB}$ | $14.54 \pm 0.02^{bA}$ | $24.67 \pm 0.02^{cB}$ |
| 3 | $3.24 \pm 0.11^{cA}$ | $17.84 \pm 0.04^{cB}$ | $93.82 \pm 0.03^{aA}$ | $91.97 \pm 0.05^{cB}$ | $1.28 \pm 0.02^{cA}$ | $5.05 \pm 0.03^{cB}$ | $15.00 \pm 0.01^{bA}$ | $29.09 \pm 0.04^{dB}$ |
| 4 | $4.18 \pm 0.13^{dA}$ | $24.28 \pm 0.04^{dB}$ | $93.44 \pm 0.02^{aA}$ | $89.81 \pm 0.04^{dB}$ | $1.55 \pm 0.23^{cA}$ | $8.10 \pm 0.01^{dB}$ | $15.82 \pm 0.09^{bA}$ | $34.56 \pm 0.01^{eB}$ |
| 5 | $5.73 \pm 0.16^{eA}$ | $35.02 \pm 0.00^{eB}$ | $91.58 \pm 0.03^{bA}$ | $83.96 \pm 0.05^{eB}$ | $2.05 \pm 0.07^{dA}$ | $11.37 \pm 0.07^{eB}$ | $16.37 \pm 0.07^{bA}$ | $43.49 \pm 0.02^{fB}$ |
| 6 | $6.79 \pm 0.04^{fA}$ | $43.61 \pm 0.15^{fB}$ | $90.79 \pm 0.08^{bA}$ | $75.61 \pm 0.02^{fB}$ | $2.38 \pm 0.08^{eA}$ | $13.94 \pm 0.05^{fB}$ | $17.01 \pm 0.03^{cA}$ | $48.75 \pm 0.05^{gB}$ |
| 7 | $11.83 \pm 0.04^{gA}$ | $51.05 \pm 0.16^{gB}$ | $84.93 \pm 0.02^{cA}$ | $64.32 \pm 0.09^{gB}$ | $2.60 \pm 0.01^{fA}$ | $14.16 \pm 0.00^{fB}$ | $17.79 \pm 0.15^{cA}$ | $50.49 \pm 0.14^{hB}$ |

Data are means ± standard deviations of triplicate analyses of the samples ($n = 3$). Means with different lowercase superscripts within a column are significantly different at $p < 0.05$. Means with different uppercase superscripts within a row are significantly different at $p < 0.05$.

important part of food safety and quality as it is related to health aspects such as food infections and intoxications. The growth of microorganism also affects the food attributes such as appearance and flavour. Thus, microbiological tests are important to ensure that a food product is safe for consumption. Total plate count was carried out to detect the presence of any viable microorganism in spray-dried honey jackfruit powder during storage and it can provide a general indication of the microbiological quality of food. A high total plate count in food may indicate that the quality of food has deteriorated. As shown in Table 4, there was a significant ($p < 0.05$) increase of total plate count with storage time. The total plate count increased to log 2.58 CFU/g (ALP) and log 6.13 CFU/g (PET) from an initial of log 1.38 CFU/g. From Table 4, it is apparent that ALP could retain the log CFU within safe limits for over seven weeks, while PET only for six weeks. The log CFU/g of honey jackfruit powder packaged in ALP was lower than the $10^6$ CFU/g limit established by the NSW Food Authority (2009) guidelines for ready-to-eat food. Hence, it could be concluded that ALP exhibited more antimicrobial protection as compared to PET for storage of spray-dried honey jackfruit powder.

Table 4. Total plate count (log CFU/g) of spray-dried honey jackfruit powder packaged in ALP and PET stored at 38 ± 2°C for seven weeks.

| Storage time (week) | Total Plate Count (log CFU/g) | |
|---|---|---|
| | ALP | PET |
| 0 | $1.38 \pm 0.03^{aA}$ | $1.38 \pm 0.03^{aA}$ |
| 1 | $1.64 \pm 0.01^{bA}$ | $2.38 \pm 0.01^{bB}$ |
| 2 | $1.94 \pm 0.01^{cA}$ | $2.95 \pm 0.02^{cB}$ |
| 3 | $2.33 \pm 0.01^{dA}$ | $3.48 \pm 0.05^{dB}$ |
| 4 | $2.51 \pm 0.04^{eA}$ | $4.18 \pm 0.02^{eB}$ |
| 5 | $2.55 \pm 0.02^{eA}$ | $5.07 \pm 0.01^{fB}$ |
| 6 | $2.56 \pm 0.04^{eA}$ | $5.97 \pm 0.04^{gB}$ |
| 7 | $2.58 \pm 0.03^{eA}$ | $6.13 \pm 0.02^{hB}$ |

Data are means ± standard deviations of triplicate analyses of the samples ($n = 3$). Means with different lowercase superscripts within a column are significantly different at $p < 0.05$. Means with different uppercase superscripts within a row are significantly different at $p < 0.05$.

The total plate count colonies formed might also be correlated with the water activity of powders. According to Chauhan and Patil (2013), the lower water activity in product in combination with chemicals released due to degradation might lead to destruction of microbial cells. Thus, powder packaged in ALP with a lower water activity (0.29 $a_w$) at the end of the storage also showed a lower microbial count (log 2.58 CFU/g). Similar observations were reported by Chauhan and Patil (2013) and Yang (2014) in the storage study of convective dried mango milk powder and honey-dew melon juice, respectively.

## Conclusion

The results of the present work indicated that ALP was a better packaging material for keeping spray-dried honey jackfruit powder as compared to PET. Spray-dried honey jackfruit powder packaged in ALP showed significantly ($p < 0.05$) lower moisture content, water activity, hygroscopicity, and degree of caking upon storage, which would help to prolong the shelf-life of the powder. Meanwhile, the water solubility index for powder packaged in ALP was above 81% as compared to that of PET (60%). The increase in moisture content (12.32%) for powder packaged in PET over storage period resulted in higher lumpiness, therefore lowering the overall acceptability.

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