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QUALITY CHANGES OF 'CEMPEDAK' (*Artocarpus integer*) FRUIT POWDER PACKAGED IN ALUMINUM-LAMINATED POLYETHYLENE POUCHES

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ABSTRACT

'Cempedak' powder was produced by spray-drying of juice produced from Celluclast® 1.5 L-treated 'cempedak' fruit puree, to which 15% (w/w) maltodextrin DE 10 and 0.66% (w/w) calcium phosphate have been added. Spray-drying took place at an inlet air temperature of 160 °C. The powder was packed in aluminum-laminated polyethylene pouches and subjected to accelerated storage at a temperature of 38±1 °C and 90% relative humidity (RH) for 49 days. Spray-dried 'cempedak' fruit powder was found to have a more pronounced hygroscopicity and caking tendency with the increase of storage time-apart from becoming darker, more reddish but less yellowish. The kinetics of most quality parameters monitored was of zero-order, indicating that the 'cempedak' fruit powder degradation was constant: while hygroscopicity and water solubility index was of the first order. Under accelerated storage conditions, the shelf-life was extrapolated to be 60.43 days, based on the Guggenheim-Anderson-de Boer (GAB) model for water activity-moisture content.

1. Introduction

Protection of powder in packaging with a good barrier is essential, as, during storage and distribution, the product may be exposed to high temperature, light, oxygen and humid environment that leads to food degradation (Henríquez *et al.*, 2013). The selection of storage conditions is also important as it influences the food quality and shelf life (Yu *et al.*, 2015). A film such as laminated metalized films that are made from polyethylene and aluminum foils are commonly applied in the packaging of snacks and high-value food, as it has good protection to dried foods (Zorić *et al.*, 2016). Besides, aluminum-laminated polyethylene has low permeability to water vapor, thus prolonging the shelf-life of the product stored in the packaging pouch (Dak *et al.*, 2014).

Aluminum-laminated polyethylene has been applied in the packaging of aloe vera powder, coconut milk powder and also mango soy fortified yogurt powder (Ramachandra and Rao, 2013; Kumar and Mishra, 2004). In these studies, aluminum-laminated polyethylene was reported to be more superior compared to high-density polypropylene (HDPP), biaxially oriented polypropylene (BOPP) and polypropylene (PP), in retaining powder qualities and having longer product shelf-life (Ramachandra and Rao, 2013; Kumar and Mishra, 2004). Recent study from Loo and Pui (2020) concluded that aluminum-laminated polyethylene (ALP) is better compared to polyethylene terephthalate (PET) in retaining the properties of spray-dried Kuini mango powder, where the powder in ALP has lower water activity, moisture content, hygroscopocity and caking.

The shelf-life of a food product is the maximum time it can be stored without any deterioration in acceptability and quality, where the prediction of shelf life of a package-product was performed in the area of water transmission rate and water uptake that (Jena and Das, 2012). On the other hand, there are other definitions of shelf-life where it is considered as the time where the food reaches critical moisture content, thus causing caking to start (Labuza, 1982; Robertson, 2010). Shelf-life testing is performed where samples were subjected to conditions that mimic conditions prone to be encountered before consumption (Brown and Williams, 2003). The application of accelerated storage methods should be used to develop moisture ingress and storage time relationship quickly (Pua *et al.*, 2008). It involves the application of high humidity 90% relative humidity (RH) and temperatures at 38 °C.

Accelerated storage study has been incorporated in the work of on storage stability of apple peel powder, coconut milk powder and pomegranate arils, respectively (Henríquez *et al.*, 2013; Dak *et al.*, 2014; Jena and Das, 2012). Apple peel powder packaged in metalized films of the high barrier under conventional and accelerated condition was reported to have had shelf-life of 298 and 120 days, respectively, indicating a reduction of 2.5-fold of shelf-life with the application of accelerated storage study (Henríquez *et al.*, 2013). Based on accelerated storage tests, previous studies predicted aloe vera powder and mango soy fortified yogurt powder packaged in aluminum-laminated polyethylene to be 51.05 and 54 days, respectively (Dak *et al.*, 2014; Ramachandra and Rao, 2013).

Kinetic modeling is used to predict the changes against time (Ramachandra and Rao, 2013; Van Bockel, 1996). The deterioration of kinetics is measured under either environmental or accelerated conditions (Hough *et al.*, 2006). It can be determined according to equations that involve the rate of reaction against time. Common changes such as in food color either follow zero or first-order degradation reaction kinetics (Singh, 2000; Kumar and Mishra, 2004). The zero-order rate normally described the effect of reaction that is caused by enzymatic degradation or non-enzymatic browning and lipid oxidation (Singh, 2000). Food deterioration reactions involving vitamin, protein loss and microbial growth showed the first-order loss.

'Cempedak', also known as *Artocarpus integer*, is a smaller fruit that is similar to jackfruit (*Artocarpus heterophyllus*) (Subhadrabandhu, 2001). It has green, yellow or brown skin that is either round or spiky, while its pulp is soft and golden yellow to orange in color (Chong *et al.*, 2008). 'Cempedak' pulp can either be consumed fresh, processed into a refreshing juice or creamed to make jams and cakes (Janick and Paull, 2008; Subhadrabandhu, 2001). To increase product availability, 'cempedak' juice can be spray-dried into powder, as powder form can serve as an ingredient to the various food product while reducing transport cost, as compared to fresh fruits (Chew *et al.*, 2019). As 'cempedak' fruit is high in sugar, the encapsulation of the fruit puree with maltodextrin is essential to produce a powder that is non sticky and free-flowing. In our previous work, optimization of spray-drying of 'cempedak' powder were carried out, with the recommended condition of inlet air temperature and maltodextrin concentration of

160 °C and 15% (w/w), respectively (Pui *et al*., 2020a). Among different anti-caking agents (calcium silicate, silicon dioxide and calcium phosfate), Pui *et al.* (2020b) reported that Calcium phosfate (0.66 % w/w) yielded powder with the best properties: lowest moisture content, water activity, hygroscopicity and change in cake height ratio.

This research aimed to study the storage stability of spray-dried 'cempedak' fruit powder that has been packed in aluminum-laminated polyethylene pouches. The 'cempedak' fruit powder was kept under accelerated temperature conditions, namely 90% relative humidity (RH) and 38 °C, and the moisture content, water activity, hygroscopicity, color, degree of caking, water solubility index and total carotenoid content of the powder were monitored over time of storage.

2. Materials and methods

2.1. Materials

'Cempedak' variety CH28 was procured in 3 different batches (n = 3), with ten fruits per batch from the Department of Agriculture, Serdang, Selangor, Malaysia. Ripe 'cempedak' fruit was cut into half, pulp separated from the seeds and then vacuum-packed in transparent polyethylene bags (200 g per bag) and stored at -20 °C in the dark. Frozen 'cempedak' pulp was thawed at room temperature before the experiment and homogenized to puree form using a commercial blender at low speed (Pui *et al*., 2018).

The 'cempedak' puree was then diluted with water at 1:2 ratio and treated with Celluclast® 1.5 L (1.2% v/w) at 45 °C for 1 hour. After filtration through a piece of muslin cloth, the filtrate ('cempedak' juice) was spray-dried using a Büchi B-290 mini spray-dryer (Büchi Labortechnik AG, Flawil, Switzerland) with the addition of 15% (w/w) maltodextrin and 0.66% (w/w) calcium phosphate (Pui *et al*., 2020b). Spray-drying was conducted at an inlet air temperature of 160 °C, with flow rate, dryer aspirator rate and pump rate of 900 m^3/min air, 100% and 10%, respectively. Outlet air temperatures used ranged from 85-95 °C, with a feed flow rate of 5 mL/min (Pui *et al*., 2020a). The resultant powder was then used to study the effect of accelerated storage.

2.2. *Packaging of spray-dried 'cempedak' fruit powder*

'Cempedak' fruit powder (25±0.5 g per package) was sealed in aluminum-laminated polyethylene pouches (155×135 mm, Infra Plastic Sdn. Bhd. Selangor) by heat sealing using a vacuum packager (DZQ400/500, YuSheng, China), avoiding any air pockets. The pouches were then placed in a desiccator (maintained at 90±1% relative humidity by using saturated potassium nitrate solution), and the desiccator was placed in a convection oven (UFB 500, Memmert GmbH & Co. KG., Schwabach, Germany) at 38±2 °C temperature for 49 days. The pouches were properly arranged to avoid overlapping of the pouches (Kumar and Mishra, 2004). Physicochemical analyses were carried out on the stored powder after spray-drying and at 7 days intervals, in a total of 49 days (Ramachandra and Rao, 2013). The analyses carried out were water activity, moisture content, hygroscopicity, color, caking, water solubility index and total carotenoid content.

2.3. *Assessment of spray-dried 'cempedak' fruit powder quality during storage*

2.3.1 Water activity and moisture content

The measurement of water activity was carried out using a water activity meter (PRE 00207, AquaLab Pre, Decagon Devices, Inc., Pullman, USA). AOAC (2000) method was applied to determine the moisture content of stored 'cempedak' fruit powders (Chang *et al*., 2020). Calibration was conducted before sample measurement, in which potassium sulfate (K_2SO_4) and potassium chloride (KCl) solution were used for calibration.

2.3.2. Hygroscopicity

Hygroscopicity of the 'cempedak' fruit powder was determined by placing 'cempedak' fruit powder (2 g) (placed in a pre-weighed petri dish) in an airtight desiccator containing 500 mL of a saturated solution of Na_2SO_4, for one week at room temperature (Cai and Corke, 2000). Hygroscopicity of the powder was then calculated by weight difference, expressed as grams of adsorbed moisture per 100 g dry solids.

2.3.3. Color

A Hunter Lab ColorFlez Ultra-Scan spectrophotometer (Hunter Associate Laboratory Inc., Reston, USA) was used to determine the color values of stored 'cempedak' fruit powder (Wong *et al.*, 2015). The instrument was calibrated against a white tile and black tile before sample measurement. Color value readings were expressed in L* (lightness-darkness), a* (greenness-redness) and b* value (blueness-yellowness).

2.3.4. Caking properties

The caking test was performed using a powder rheometer, TA.HD Plus Powder Flow Analyzer (Stable Micro Systems, Godalming, UK) based on the method described by Janjatović *et al.* (2012). 'Cempedak' fruit powder (40 g) was added to the apparatus power column, and the rheometer's blade first leveled the top of the powder column to measure column height, and then move down at a speed of 20 mms^{-1} to compact the powder to 200 g force. After that, the blade was moved downwards at 10 mms^{-1} to slice through the powder. The compaction was performed in five cycles. From the software, the cake strength, mean cake strength and change in cake height ratio were obtained.

2.3.5. Water Solubility Index (WSI)

The method described by Grabowski *et al.* (2006) was employed to determine the water solubility index (WSI) of spray-dried 'cempedak' fruit powder. 'Cempedak' powder (1 g) was mixed vigorously (30 seconds) with 10 mL water in a 15 mL centrifuge tube, and the powder suspension was incubated in a 37 ºC water bath for 30 minutes. It is then centrifuged at 2000 *x g* for 10 minutes at room temperature (Beckman J2-21M/E, Beckman Coulter, Inc., California, USA). The supernatant was placed in an aluminum tray (1 cm height x 3.5 cm diameter) and was dried overnight in an oven (UFB 500, Memmert GmbH & Co. KG., Schwabach, Germany) at 105 °C. WSI was expressed as the percentage of the total dry solids over the original weight of 'cempedak' fruit powder used in the analysis.

The calculation of WSI was shown in Eq. (1):

$$WSI = \frac{\text{Weight of residue}}{\text{Weight of 'cempedak' fruit powder}} \times 100 \quad (1)$$

2.3.6. Carotenoid content

'Cempedak' fruit powder (1 g) mixed with distilled water (10 mL) was subjected to incubation at room temperature for 30 minutes, following which 20 mL of cold acetone was added and mixed. The mixture was left to stand for 15 minutes before filtration with suction through a Whatman No. 1 filter paper, and filtrate collected. The residue was then placed in a mortar, and 15 mL cold acetone was added. A pestle was used to grind the residue to form a suspension, which was then filtered. All the filtrate was pooled, and 1/3 of the total volume was added with 20 mL petroleum ether into a 500 mL separation funnel, followed by 300 mL of distilled water. After mixing and separation of phase, the bottom colorless aqueous layer was discarded. Another 1/3 of the filtrate was added to the separation funnel, and the process of extraction was again repeated as described above. After the third extraction, the yellow-colored organic phase (upper layer carotenoid extract) was collected. The organic phase was evaporated to dryness at 35 °C, and the 10 mL acetone was added to dissolve the carotenoids. The absorbance of the solution was then read at 450 nm (Rodriguez-Amaya and Kimuram, 2004). A standard curve was constructed using different concentrations of the standard solution (0 to 6 mg/mL).

2.3.7. Kinetics of property changes during accelerated storage

The degradation constant (K) of 'cempedak' fruit powder was determined based on the moisture content, hygroscopicity, color change, caking (change in cake height ratio), water solubility index and carotenoid content while considering zero-order or first-order kinetics for these aspects according to Ramachandra and Rao (2013). The zero and first-order kinetics were determined using the Eq. 2 and 3 below:

$$[A]t = -kt + [A]0 \quad (2)$$

$$\text{In } [A]t = -kt + \text{In}[A]0 \quad (3)$$

Where [A]t = Concentration of the chemical of interest at a particular time (t), and [A]0 = Initial concentration, with the k = Order rate constant.

2.3.8. Measurement of permeability of packaging material

The water vapor permeability rate, k ($kg.m^{-2}$ day^{-1} Pa^{-1}), was calculated using Eq. 4 (Labuza, 1984).

$$k = \frac{dw/d\theta p}{Ap\ P^*} \quad (4)$$

In which dw/dθp = the slope of the straight-line plot between the time θp (day) and weight (kg) of the silica gel, Ap = Surface area of the packaging material (m^2), and P* = Saturation vapor pressure of water.

2.3.9. Assessment of shelf-life of spray-dried 'cempedak' fruit powder

The shelf-life of the powder was calculated according to the equation below (Eq. 5) (Crank, 1999).

$$\int d\theta = \frac{W_s}{P^* k A_p}\left(\int_{X_i}^{X_o} \frac{dX}{RH - a_w}\right) \quad (5)$$

where θ = Shelf-life (days), Ws = Weight of the dry solids (g), P* = Saturated vapor pressure of water at ambient temperature (Pa), k = Permeability of packaging material ($kg.m^{-2}day^{-1}Pa^{-1}$), Ap = Surface area of the packaging material (m^2), RH = Relative humidity of the environment in which the package is placed (%), aw = Water activity of the product, Xi = Initial moisture content (%, d.b.) and Xc = Critical moisture content (% d.b.).

2.4. *Statistical Analysis*

The statistical program used was Minitab 17 software (Minitab Inc., Pennsylvania, USA) was used to analyze the data obtained from this study using one-way ANOVA and significant differences ($p \leq 0.05$) using Tukey's test. All measurements were conducted in triplicates. The results were expressed as mean ± standard deviation.

3. Results and discussions

Table 1 presents the effects of accelerated storage (38 °C, 90% RH) on several properties of 'cempedak' fruit powder packed in aluminum-laminated polyethylene (ALP) and stored at accelerated condition (90% RH and 38±2 °C). The properties assessed included water activity, hygroscopicity, color, degree of caking and water solubility index

3.1. Water activity and moisture content of stored 'cempedak' powder

Water activity is an important index for spray-dried powder, as it can greatly affect its shelf-life (Thankitsunthorn *et al.*, 2009). It can be concluded that the increase of water activity (to 0.25) was negligible as the range of powder was in the range of 0.2-0.3, where the powder is considered as stable (Yu *et al*., 2015).

Figure 1 shows that the moisture content of 'cempedak' fruit powder packaged in aluminum-laminated polyethylene pouches showed a 50% increase at the end of the storage period (Week 7), as compared with the moisture content of initial 'cempedak' fruit powder (0 day storage time). This value (7.0%) was lower than the maximum moisture content of 10% for food powders to remain stable (Tze *et al.*, 2012).

Also, moisture content increase in 'cempedak' fruit powder followed zero-order kinetics (Table 2), indicating a constant rate in the uptakes of water by the powder during the storage period. A similar pattern was also observed by Kumar and Mishra (2004) in the mango/soy yogurt powder, where it is dependent on the packaging material as well (Kumar and Mishra, 2004). Hence, to keep the quality of powder during storage, utilizing the packaging material with a good moisture barrier property is essential (Rao *et al.*, 2011). Temperature and RH also significantly affected the moisture gain was also reported in jackfruit powder (Pua *et al.*, 2008).

3.2. Hygroscopicity of stored 'cempedak' powder

Hygroscopicity measures the material's ability to absorb moisture from its environment (Vidović *et al.*, 2014). Table 1 shows the effects of accelerated storage on the hygroscopicity of the packaged 'cempedak' fruit powder. It can be concluded that increasing the storage time led to the hygroscopicity of 'cempedak' fruit powder to increase 1.3-fold at Week 7 as compared to Week 0. The moisture uptake depends on the water vapor permeability of the packaging material (Dak *et al.*, 2014). Besides, the rate of hygroscopicity increase followed first-order reaction kinetics (Table 2), suggesting the degradation of powder compounds (Singh, 2000). However, it is hard to predict the time when the powder deteriorates enough to be unacceptable to the consumers, as there were no guidelines on the maximum hygroscopic range.

The increment of moisture content decreases the water retention capacity, thus deteriorating its physical, chemical and technological properties. The hygroscopicity of mango powder was also reported to increase with storage time (Jaya and Das, 2005). From Figure 1 and Table 1, it can be observed that moisture content increase also leads to an increase of hygroscopicity in 'cempedak' powder.

3.3. Color of stored 'cempedak' powder

Color is an important quality indicator of food, and it is used to determine its acceptance, while the quality of deterioration was indicated by retention of color (Shin and Bowmik, 1995).

From Table 1, it is observed with increased storage time, the L*and b* values of 'cempedak' fruit powder decreases (reduction of 21% and 13%), while a* values increases (14%). This indicates that as the storage time increased, the stored 'cempedak' fruit powder becomes darker, more reddish and also yellowish. The decreasing of L* values and increasing of a* value indicates browning (Pua *et al.*, 2008). Sornsomboonsuk *et al.* (2019) suggested that the elevated storage temperature increases the rate of oxidation, which in turn causes the rise a* and lowering L* of the bael powder stored.

Figure 2 shows the total color change across the storage period, where an increase of 16.0 was noted. However, there was no limit in which range a product should be rejected, although the changes should be as the minimum possible. Total color changes (ΔE) increased with the increase of storage time, while storage temperature did not have much effect (Yu *et al.*, 2015; Idham *et al.*, 2012). The increase in yellowness indicates the powder's tendency to become brown. At a water activity level of 0.3-0.7, Maillard, or non-enzymatic, the browning reaction takes place (Yu *et al.*, 2015). From Table 1, it can be observed that the increase of water activity also leads to the changes in color (increase in darkness and redness, while the decrease in yellowness), probably due to browning.

Table 1. Effects of accelerated storage (38 °C, 90% RH) on properties of 'cempedak' fruit powder packaged in aluminum-laminated polyethylene pouches

Powder property	Storage time (week)							
	0	1	2	3	4	5	6	7
Water activity	0.19± 0.01[a]	0.19± 0.01[ab]	0.20± 0.01[ab]	0.21± 0.01[ab]	0.22± 0.00[ab]	0.23± 0.00[ab]	0.24± 0.00[b]	0.25± 0.02[b]
Hygroscopicity (g/100 g)	20.7± 0.6[a]	22.3± 1.2[ab]	22.0± 1.0[ab]	22.7± 1.3[b]	23.0± 1.0[bc]	24.7± 1.2[bc]	25.0± 1.0[c]	23± 0.6[d]
Color								
*L**	73.42± 0.99[a]	69.55± 1.02[b]	66.56± 1.20[c]	64.72± 1.34[c]	64.27 ± 1.49[cd]	61.67± 1.35[d]	59.91± 0.63[de]	58.00± 1.90[c]
*a**	8.61± 0.36[a]	5.56± 0.34[ab]	8.77± 0.34[ab]	8.84± 0.10[ab]	9.01± 0.49[ab]	9.10± 0.55[ab]	9.20± 0.56[ab]	9.82± 0.69[b]
*b**	34.49± 1.02[a]	32.01± 1.71[ab]	31.85± 1.27[a]	31.55± 0.17[ab]	31.45± 1.83[ab]	31.49± 1.25[ab]	30.42± 1.59[b]	29.97 ± 1.07[b]
Cake strength	840± 129[a]	2175± 272[b]	2547± 263[b]	2444± 292[ab]	1164± 137[b]	3702± 364[c]	5895± 842[d]	12990± 1293[e]
Mean cake strength	159.04± 38.50[a]	198.42± 30.57[ab]	195.97± 59.40[ab]	151.78± 27.81[ab]	132.22± 149[a]	159.47± 22.61[ab]	212.24± 8.27[c]	232.40± 18.27[d]
Water Solubility Index (WSI)	89.74± 0.35[a]	86.05± 0.5[b]	85.85± 1.03[ab]	85.72± 1.06[ab]	83.88± 0.49[ab]	83.53± 0.75[bc]	81.27± 1.30[bc]	78.64± 2.16[c]

Each value represents the mean of triplicate samples ± standard deviation. Values within the same row with different superscript (a-e) are significantly different at p≤0.05, as measured by Tukey's HSD test.

Table 2. Non-linear regression analysis of physicochemical property kinetics in 'cempedak' fruit powder

Powder property	Zero-order			First-order		
	K_0	$[A]_0$	*R*	K_1	$[A]_0$	*R*
Moisture content	0.340	4.659	0.991	0.057	4.786	0.977
Hygroscopicity	0.809	20.635	0.950	0.341	20.747	0.957
Total color change	2.096	1.444	0.992	0.185	4.707	0.956
Change in cake height ratio	0.028	-0.005	0.999	0.147	0.149	0.822
Water solubility index	-1.164	88.85	0.912	-0.014	88.29	0.953
Carotenoid content	-0.114	1.068	0.956	-0.235	1.296	0.863

Abbreviations: K0, Zero order rate constant; K1, the first-order rate constant; [A]0, initial concentration; R, the Regression coefficient of the reaction.

Table 2 shows the color change kinetics during accelerated storage. It can be observed that the degradation of 'cempedak' fruit powder color is followed by zero-order kinetics. Change in the total color difference that followed zero-order kinetics, indicating enzymatic degradation or non-enzymic browning, was also reported for mango soy fortified yogurt powder (Kumar and Mishra, 2004). A study on the kinetics of color change in dried aloe vera gel powder during storage for 49 days at 38±1 °C and 90±1% RH showed the color change of powder stored in ALP is 19.62 (Ramachandra and Rao, 2013). The kinetic parameter of color change was obtained from first-order kinetics. The value of the rate constant for AF pouches (k1) was −0.0444, in which the negative sign indicates it reduces with the increase in storage time. Aluminum foil above 17 microns in thickness is considered as a good barrier against moisture, gases and light (Emblem, 2000).

3.4. Caking of stored 'cempedak' powder

The caking properties in terms of cake strength and mean cake strength are also presented in Table 1, while the change in cake height ratio is presented in Figure 3. Results obtained that the cake strength, mean cake strength and change in cake height ratio increased about 15.5, 1.3 and 2.2-fold, respectively, after 7 weeks of storage. The increase in change in the cake height ratio shows that it is more prone to caking (Shah *et al.*, 2008). However, there was no range reported on the maximum limit of the cake height ratio in defining its caking properties.

Pua *et al.* (2008) reported that lumpiness in jackfruit powder increases with the increase of storage time due to an increase in moisture content. Mango and soy fortified yogurt powder showed caking at a moisture content between 6.8% and 2% (Kumar and Mishra, 2004). The caking is attributed to the migration of moisture from the environment, increasing the water activity that caused the plasticizing of compounds and collapse in structure (Lee *et al.*, 2013). Also, Durakova *et al.* (2019) attributed the change in granulometric composition in Lucuma powder to packaging permeability.

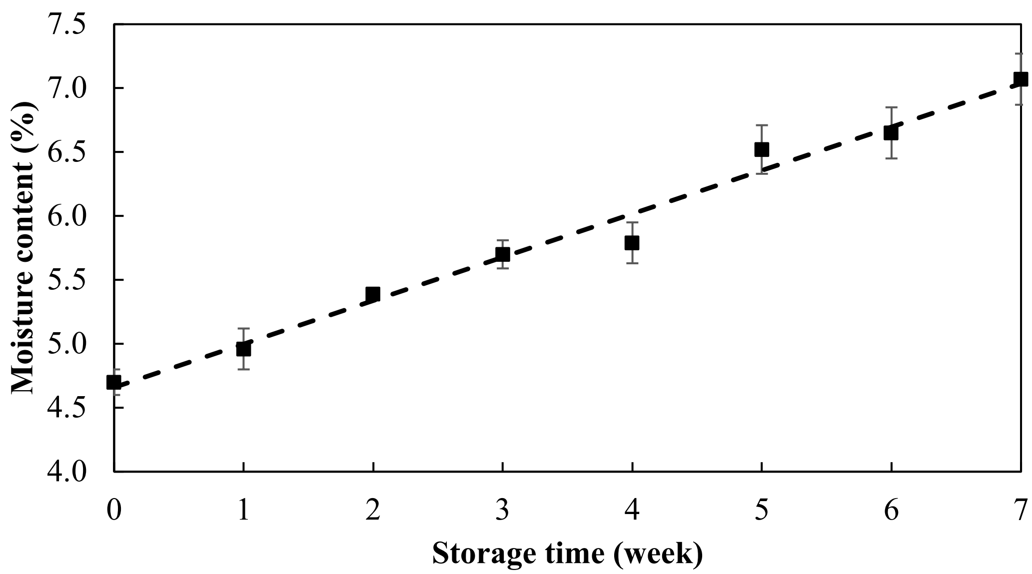

Figure 1. Effects of accelerated storage (38°C, 90% RH) on moisture content (%) of 'cempedak' fruit powder packaged in aluminum-laminated polyethylene pouches

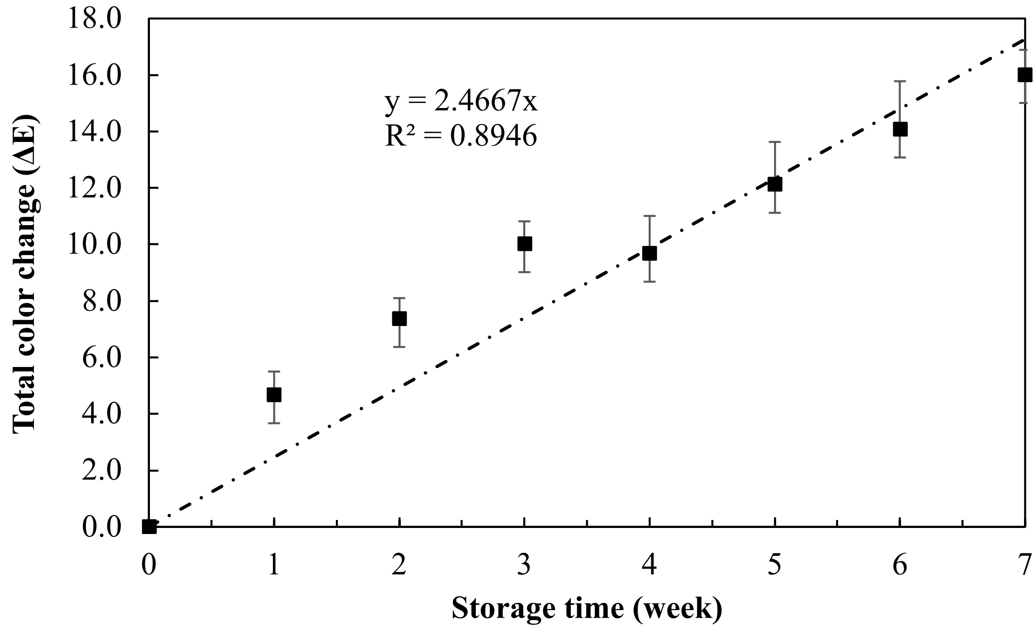

Figure 2. Effects of accelerated storage (38 °C, 90% RH) on total color change (ΔE) of 'cempedak' fruit powder packaged in aluminum-laminated polyethylene pouches

The kinetics of caking in terms of change in cake height ratio changes in stored 'cempedak' fruit powder is presented in Table 2. It can be concluded that the caking of stored powder followed by zero-order kinetics. This may be due to the continuous increase in moisture uptake during storage (Pua *et al.*, 2008).

3.5. Water solubility of stored 'cempedak' powder

The water solubility index of 'cempedak' fruit powder packaged and subjected to accelerated storage is shown in Table 1. It can be seen that the water solubility index of stored 'cempedak' fruit powder decreased following the increase of storage time. However, the reduction of 12% in the water solubility index after Week 7, indicates that the stored 'cempedak' fruit powder still retains its water-soluble properties. Gavarić *et al.* (2019) also observed a decrease in solubility of spray-dried basil extract with storage time, in which after 50 days of storage, dehydration time increased from 6-9.1s to 11.2 to 18.3 s.

The slight reduction of the water solubility index of stored 'cempedak' fruit powder may occur due to the caking or lump formation of powder (Laokuldilok and Kanha, 2015). The caking of powder from absorbed moisture as the time of storage increases was affected by its water vapor permeability of ALP pouch (Pua *et al.*, 2008). Besides, the first-order reaction kinetics shown in Table 2 indicates microbe or loss of powder component such as protein or vitamins (Singh, 2000).

3.6. Carotenoid content of stored 'cempedak' powder

Figure 4 provides information on the stability of the carotenoid content of packaged 'cempedak' fruit powder at accelerated storage. It can be observed that there is a decrease in carotenoid content with an increase in storage time, incurring a reduction of 63% and 88% after 6 and 7 weeks of storage, respectively. The loss in carotenoid content compromised the quality of the fruit powder. The storage of mango powder was packed in metalized polyester/ polyester poly packaging, where after 6 months of storage, the carotene amount was still in the acceptable and good range (50%

of pigment retention) (Hymavathi and Khader, 2005).

Table 2 shows the kinetics of changes in carotenoid content of the 'cempedak' fruit powder during accelerated storage. As can be observed, the degradation of carotenoids in the 'cempedak' fruit powder followed zero-order kinetics, indicating the degradation of carotenoid pigments (Singh, 2000). Although there is scarce information on the carotenoid degradation kinetics with storage of powder, anthocyanin retention and degradation in accelerated storage has been examined by a few researchers (de Oliveira *et al.*, 2009; Idham *et al.*, 2012; Tonon *et al.*, 2010). The kinetic degradation of anthocyanin in dried pomegranate arils was found to be following zero-order kinetics (Dak *et al.*, 2014).

On the other hand, Tonon *et al.* (2010), in their work on spray-dried acai powder, observed two first-order kinetics for the anthocyanin degradation, the highest rate at 45–60 days and lower degradation rate until 120 days. The first order of anthocyanin degradation was exhibited by the pomegranate aril (Dak *et al.*, 2014). Degradation of total carotenoid in jackfruit powder also followed a first-order reaction (Saxena *et al.*, 2012).

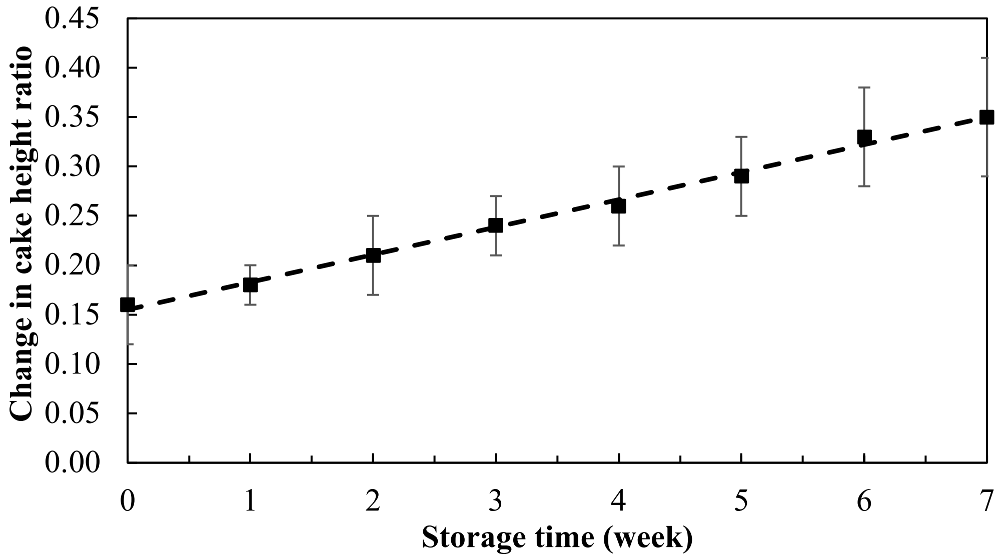

Figure 3. Effects of accelerated storage (38°C, 90% RH) on change in cake height ratio of 'cempedak' fruit powder packaged in aluminum-laminated polyethylene pouches.

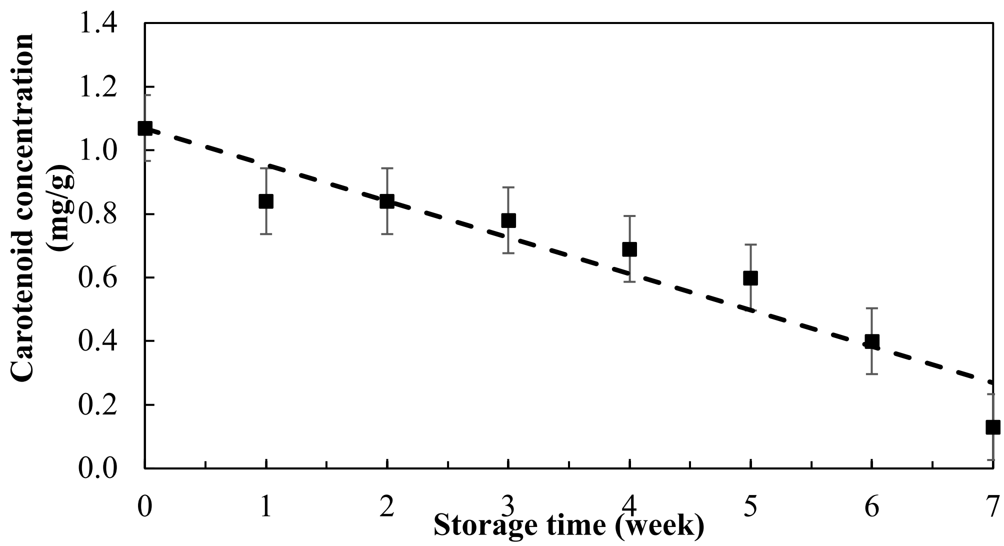

Figure 4. Effects of accelerated storage (38 °C, 90% RH) on carotenoid content (mg/g) of 'cempedak' fruit powder packed in aluminum-laminated polyethylene pouches

A higher degradation rate is caused by the presence of non-encapsulated material that has contact with oxygen or the presence of oxygen in the pores (Ferrari *et al.*, 2013; de Oliveira *et al.*, 2009).

3.7. Shelf-life prediction of stored 'cempedak' powder

Figure 5 shows the weight gain or uptake by silica gel that is packed (aluminum-laminated polyethylene) that is stored in an environment maintained at 90±1% relative humidity and 38±1 °C temperature. It should be noted that aluminum-laminated polyethylene used in this study has a water vapor transmission rate (WVTR) of 8.64×10^{-6} kg.m^{-2} day^{-1} Pa^{-1}. The WVTR obtained for the aluminum-laminated polyethylene packaging for dried pomegranate arils and mango soy fortified yogurt powder has been reported to be 6.16×10^{-8} kg m^{-2} day^{-1} Pa^{-1} (Dak *et al.*, 2014; Kumar and Mishra, 2004), while those for jackfruit powder and bovine colostrum powder were 1.21×10-6 and 1.58×10^{-8} kg m^{-2} day^{-1} Pa^{-1}, respectively. The WVTR obtained in this study is still considered as a higher WVTR (Yu *et al.*, 2015; Pua *et al.*, 2008). This may be caused by thinner packaging material (40 µm), as compared to 90 µm utilized in the work of Jaya and Das (2005).

In this study, the values of Guggenheim-Anderson-de Boer (GAB) parameters, Mo (monolayer value of powder), Cg (GAB model constant) and Kg (GAB model constant) for aluminum laminated polyethylene were 0.0862, 0.226 and 21.848 (Jena and Das, 2012). The surface area (Ap) of the aluminum-laminated polyethylene pouches used in this study was 13.5×10^{-3} m^2, while the amount of the dry solids (Ws) was 0.020726 kg. From the calculation in Eq. 4, shelf-life (θs) of the spray-dried 'cempedak' fruit powder was determined to be 60.4 days base on the free-flowing properties as subjected to accelerated storage under 90% relative humidity (RH) at 38 °C.

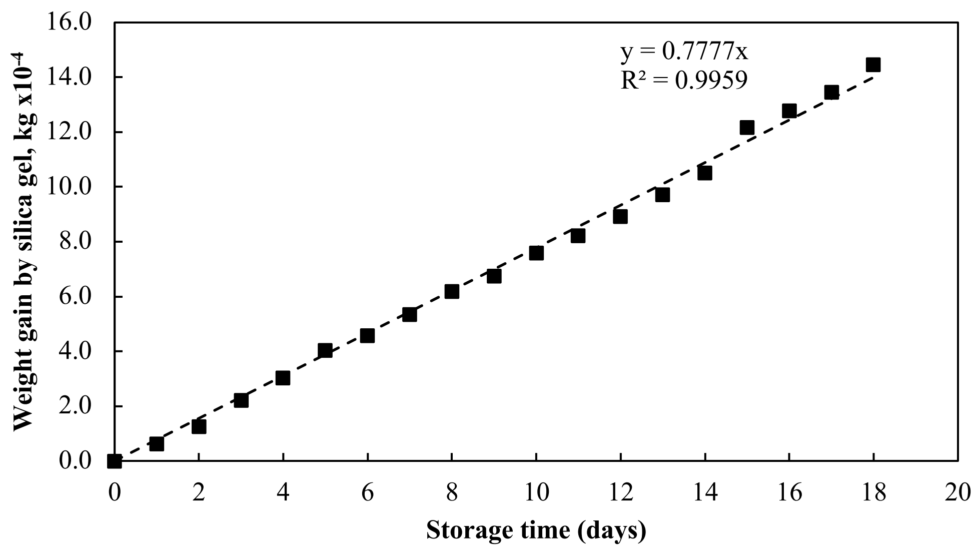

Figure 5. Permeability of aluminum-laminated polyethylene pouches

This result is in agreement with the shelf-life (based on free-flowness) of mango soy fortified yogurt and aloe vera gel powder, which has shelf lives of 54 and 51.05 days, respectively (Ramachandra and Rao, 2013; Kumar and Mishra, 2004). However, the shelf-life obtained in this study was shorter as compared to the 187 days shelf-life of pomegranate aril packed in aluminum-laminated polyethylene under accelerated storage (Dak *et al.*, 2014). This may be due to the different properties used in the determination of shelf-life, where the previous study adapted color change as the factor for shelf-life determination (Dak *et al.*, 2014).

4. Conclusions

This study demonstrated the accelerated storage of ‘cempedak’ fruit powder packaged in aluminum-laminated polyethylene pouches and subjected to 90% RH at 38 °C for 49 days. As the storage time increase, ‘cempedak’ fruit powder increased in its moisture content, water activity, hygroscopicity, total color change and caking (change in cake height ratio), while decreased in its water solubility index and carotenoid content. In general, it can be concluded that the accelerated storage resulted in spray-dried ‘cempedak’ fruit powder that is more hygroscopic and susceptible to caking. The powder is darker, more reddish, but less yellowish after storage. Moisture content, total color change, caking and degradation of carotenoid of ‘cempedak’ fruit powder during storage followed zero-order reaction kinetics. In contrast, its hygroscopicity and water solubility index followed first-order reaction kinetics. Permeability in terms of water vapor transmission (WVTR) of aluminum-laminated polyethylene was found to be 8.64 x 10^{-6} kg.m^{-2} day^{-1} Pa^{-1}. Besides, during storage under accelerated conditions (38±1 °C, 90% RH), the predicted shelf-life of spray-dried ‘cempedak’ fruit powder was found to be 60.43 days in aluminum-laminated polyethylene pouches based on free-flowness with the Guggenheim-Anderson-de Boer (GAB) model. ‘Cempedak’ fruit powder produced can be used as an ingredient for other food products, where sensory evaluation can be proposed to determine the acceptability of spray-dryer feed (enzyme-treated ‘cempedak’ juice), ‘cempedak’ fruit powder and its final products (representative food systems).

5.References

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