Effects of maltodextrin concentration and inlet temperature on the physicochemical properties of spray-dried kuini powder

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Received 23rd October 2019 / Accepted 23rd November 2020

Abstract. Kuini (*Mangifera odorata*) is known for its intense flavour, attractive colour, rich fibre content and antioxidant properties. However, its short shelf life (bruise within a week) limits the availability of this fruit. Hence, spray drying was proposed to transform this fruit into powder to increase its application. The maltodextrin concentration of 5–20% (w/w) and inlet temperatures of 140–180°C were applied to produce kuini powders. The effect of maltodextrin concentrations at constant inlet temperature (160°C) showed that a higher amount of maltodextrin (20% w/w) produced powder with a low water activity (0.16 ± 0.01 Aw), moisture content ($2.16 \pm 0.60\%$) and hygroscopicity (20.45 ± 0.60 g/100g) but the orange colour of the powder turned pale. The kuini powder was further spray dried at different inlet temperatures at constant optimal maltodextrin concentration (20% w/w). The kuini powder that was spray dried at 160°C had the optimal properties: low water activity (0.17 ± 0.01 Aw) and hygroscopicity (22.12 ± 0.09 g/100g) with high water solubility index, WSI ($79.90 \pm 1.85\%$) and wettability (279 ± 8 s), indicating the powder can be applied as a food ingredient with high solubility. The optimal spray-drying condition for the production of kuini powder was 20% (w/w) maltodextrin concentration at 160°C inlet temperature to have the highest yield of $43.08 \pm 2.77\%$. Eventhough the reconstituted kuini powder had lower viscosity, colour and β -carotene content than kuini juice, this study showed the feasibility of production of kuini powder using spray drying operation which may broaden its application in the food industry.

Keywords: β -carotene, inlet temperature, kuini, maltodextrin, solubility, spray-drying

INTRODUCTION

Fruits, having a high content of moisture, are perishable and difficult to be sold as fresh produce, causing estimated post-harvest losses of over 20–30% (Cano-Chauca *et al.*, 2005). To prolong the shelf life of fruits, a few processing and preservation methods such as drying (Gallali *et al.*, 2000), chemical treatment (Oms-Oliu *et al.*, 2010) and packaging (Kader *et al.*, 2009) can be applied. Dehydration by spray-drying is one of the common preservation methods used in the food

industry (Chew *et al.*, 2019) to produce the dried powder. Spray-drying involves the transformation of a liquid state feed into a dry particulate. The feed in the form of fluid is atomised and the liquid droplets are dried when in contact with hot air stream in the drying chamber (Angel *et al.*, 2009). This results in products with a reduction of total volume and prolonged shelf life, reducing the space for transport and wastage of these fruits is also decreased (Singh *et al.*, 2013).

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However, spray-drying of food that is rich in sugar, such as fruit juices, may result in unfavourable powder that is sticky, hygroscopic and hard to solubilise. This is due to the high content of low molecular weight sugars such as sucrose, fructose and glucose, and acids such as citric acid which have a low glass transition temperature (Jaya & Das, 2004). This leads to reduced product yield and the caking of powders. Drying agent such as maltodextrin is often added into the spray-drying of fruit juices to facilitate the drying process (Adhikari *et al.*, 2004). These drying agents work by increasing the glass transition temperature of the powder, reducing its stickiness (Chang *et al.*, 2018a; Truong *et al.*, 2005).

There have been many studies on the production of powder through spray-drying, such as watermelon (Quek *et al.*, 2007), pineapple (Wong *et al.*, 2015), eggplant (Chang *et al.*, 2020a), *cempedak* (Pui *et al.*, 2020a; Gopinathan *et al.*, 2020) and papaya (Chang *et al.*, 2020b). To the best of the authors knowledge, there are limited reports available on spray drying of kuini fruit. Kuini (*Mangifera odorata*) is a species of mango that is native to South East Asia, which is one of the underutilised *Mangifera* species discovered in Malaysia (Lasano *et al.*, 2019). The fruit is orange-yellow in colour, fibrous, juicy, with a strong turpentine-like flavour and its flesh is sweeter than that of a common mango (Lim, 2012). There are that studies reported the potent antioxidant activities (Loo & Pui, 2020) and antibacterial activities (Adnan *et al.*, 2018) of kuini fruit. In addition, the storage stability of kuini powder through packaging (Loo & Pui, 2020) and incorporation of microencapsulated probiotics in kuini juice (Lai *et al.*, 2020) have been reported recently. Even though kuini has been available locally, this precious fruit is still not known by many and is often underutilised (Kozai *et al.*, 2005). The short shelf life (bruise within a week) of this fruit also brings about much wastage. Furthermore, the seasonal postharvest behaviour of kuini also reduces the availability of the fruit.

Hence, this research was conducted to produce kuini powder by spray-drying the kuini juice. The production of kuini powder would enhance the potential applications in various food industries i.e. as a functional ingredient in beverages, bakery, or healthy food products. The effects of different inlet temperatures and

maltodextrin concentrations on the physicochemical properties of the spray-dried kuini powder were studied and the properties between fresh kuini fruit and optimised spray-dried reconstituted kuini powder were compared. Inlet temperature and maltodextrin concentration were selected as the factors because these two parameters have been reported as important factors in the production of shelf-stable spray-dried powder (Ferrari *et al.*, 2012; Gallo *et al.*, 2011; Shavakhi *et al.*, 2012), besides feed flow rate.

MATERIALS AND METHODS

Materials

Fresh kuini fruits (*Mangifera odorata*) were collected and purchased from a local wholesale wet market in Selangor, Seri Kembangan, Selangor. The fruits at the commercial maturity stage (0.6 ± 0.1 kg), uniform in size and green skin with no presence of external injury were selected. Maltodextrin (DE 10) used for spray drying was procured from Bronson and Jacobs Sdn. Bhd., Malaysia. All analytical grade chemicals used for analysis were purchased from Sigma-Aldrich (Dorset, United Kingdom) unless otherwise stated.

Preparation of spray-drying feed

The kuini pulps were homogenised separately using a blender (MX-SM1031, Panasonic, Malaysia) at high speed (12000 rpm) until it became smooth. The blended kuini pulps were diluted in distilled water to standardise the juice to a total soluble solid (TSS) content of 12°Brix, measured using a digital refractometer MA 871 (0–85°Brix) (Milwakee, Romania). The juices were then filtered using a filter cloth before spray-drying. A known amount of maltodextrin was added into 200 g of filtered juice and the mixture was filtered again in order to ensure smooth consistency (i.e., free from the solid matter) (Chang *et al.*, 2018a).

The effects of inlet temperature and maltodextrin concentration on the spray-drying of kuini

The spray-drying experiments were carried out based on the One-Factor-At-A-Time (OFAT) approach with four different maltodextrin

concentrations (5–15% w/w) and five different inlet temperatures (140–180°C). The spray-drying of kuini powder was performed using a mini spray-dryer (Büchi Model B-290, Büchi Labortechnik AG, Switzerland). Prior to drying, the spray dryer was set at an aspirator rate of 100% and the inlet temperature of 160°C, which is the middle parameter of the inlet temperature factor. The pump setting at 20% was activated once the desired inlet temperature was reached, nozzle speed was set at 5 and the compressed air flow rate was set at 40 mm (600 L/h) (Chang *et al.*, 2020a). The spray-dryer was allowed to pump distilled water for the first 15 minutes in order to achieve internal equilibrium. After that, the spray drying feed with the addition of different maltodextrin concentrations (5, 10, 15 and 20% w/w) and known TSS (measured before spray drying) was pumped into the spray dryer and the powder was collected from the cyclone. Physicochemical analyses of the powders produced with different maltodextrin concentrations were performed for the determination of the optimised maltodextrin concentration for the production of kuini fruit powder.

In the second part of the experiment, the spray-drying of kuini juice was repeated at 140, 150, 160, 170 and 180°C. Selection of inlet temperature was based on observations made during preliminary work on spray-dried kuini powder, in which the powder that was spray-dried at a temperature below 140°C appeared sticky and wet while at a temperature above 180°C was yellowish due to burning. Meanwhile, the maltodextrin concentration was kept constant at 20% (w/w) (the optimised concentration from the first part of the study). Physicochemical analyses were conducted to determine the optimised inlet temperature condition. The optimised powder obtained from the spray drying was reconstituted and its properties were compared with the fresh kuini juice.

Characterisation of physicochemical properties of spray-dried kuini powder

Process yield

The process yield of the spray-dried kuini powder was calculated using the following formula (Pui *et al.*, 2020b):

$$\text{Process yield (\%)} = \frac{\text{Mass of spray-dried powder (g)}}{\text{Dry mass of kuini juice (g)} + \text{Mass of maltodextrin (g)}} \times 100\% \quad (\text{Equation 1})$$

Colour

The HunterLab's ColorFlex Ez Colorimeter (Hunterlab, US), equipped with EasyMatch QV-ER software, was used to determine the colour of the samples. The colorimeter was standardised against a black tile followed by a white tile before analysis. Kuini juice or spray-dried kuini powder was placed in a sample cup and placed on a sample

port before analysis. The data was expressed in terms of L^* , a^* and b^* values, representing degree of lightness or darkness, degree of redness or greenness and degree of yellowness or blueness, respectively (Pui *et al.*, 2018). The colour difference was calculated by the following equation (Chang *et al.*, 2018b).

$$\text{Difference in colour} = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (\text{Equation 2})$$

where L_0^* , a_0^* and b_0^* are the lightness, redness and yellowness values of the fresh juice, and L^* , a^* and b^* are the lightness, redness and yellowness values of the reconstituted powders.

Water activity

Water activity was measured using water activity meter (AquaLab Pre, METER Group, US) (Pui *et al.*, 2020). The device was switched one hour before to warm up. Two grams of spray-dried kuini powder were weighed into a container and

placed in the sample port of the water activity meter and read at room temperature.

Moisture content

The moisture content of the spray-dried kuini powder was determined in accordance with Quek

et al. (2007) with some modification. Two grams of powder were weighed in an aluminium cup and dried in an oven at 105°C for 24 hours. The

moisture content of the powders was calculated using the equation below.

$$\text{Moisture content (\%)} = \left(M_i - \frac{M_0}{M_i} \right) \times 100\% \quad (\text{Equation 3})$$

where M_0 is defined as the initial mass of the powder and M_i is defined as the final mass of the powder.

Hygroscopicity. The hygroscopicity measurement was modified from Cai & Corke (2000). Two grams of spray-dried kuini powder was placed in a pre-weighed 100 mL beaker. The powder was then placed into a glass desiccator maintained at a relative humidity of $81 \pm 2\%$ by

filling the bottom part of the desiccator with saturated ammonium sulphate solution. The powder was weighed after a week and the hygroscopicity was expressed as g of moisture per 100 g of dry solids.

$$\text{Hygroscopicity (g/100g)} = \frac{\text{Final weight of sample (g)} - \text{Initial weight of sample (g)}}{\text{Initial weight of sample (g)}} \quad (\text{Equation 4})$$

Bulk density

The method described by Mishra *et al.* (2013) was used to measure the bulk density of the powder samples. Five grams of spray-dried kuini powder was added to a 10 mL graduated measuring cylinder. The measuring cylinder was tapped 3 times and the volume occupied by the powder was recorded. The bulk density was expressed as the ratio of the mass of powder to the volume occupied by the powder.

Phytoremediation is a commercially viable and promising technology that helps to accumulate heavy metals from contaminated land and water bodies. This solar-driven technique does not lead to the production of sludge; it doesn't lead to environmental disturbance and is cost-effective, making it an attractive technology to use. Although phytoremediation has lots of advantages and it helps to reduce soil pollution

caused by metalloids. However, the *in-situ* effectiveness of phytoremediation is heavily dependent on several factors like (i) climate of the region (ii) soil type (iii) plant capability to utilise metals. Therefore field trials are required to improve the accuracy of predictive models. Naturally occurring plants have very limited maintenance requirements and a low-cost process. In conclusion, it needs to be stressed that non-edible plants should be used to avoid bioaccumulation and biomagnification. Phytomining process can be implemented for the recovery of the heavy metals by incinerating the metal accumulator crops. Large scale application of various phytoremediation techniques such as phytotransformation, phytoextraction, phytovolatilisation, and phytovolatilisation, etc. will be an excellent sustainable method for recycling and reusing of heavy metals to keep the environment safe, green, and resourceful for future generations.

$$\text{Bulk density (BD)} = \frac{\text{Weight of powder (g)}}{\text{Volume of powder (mL)}} \quad (\text{Equation 5})$$

Water solubility index (WSI)

To determine the water solubility index (WSI) of the spray-dried kuini powder, 1 g of powder was added with 10 mL of water and mixed vigorously in a 50 mL Falcon tube. The mixture was then incubated in a water bath at $37 \pm 1^\circ\text{C}$ for 30

minutes to allow the powder to completely dissolve (Phoungchandang & Sertwasana, 2010). The solution was centrifuged at $6454 \times g$ (Model 4200, Kubota, Tokyo, Japan) for 10 minutes. The supernatant was collected in a pre-weighed aluminium cup and immediately oven dried at 105

$\pm 1^{\circ}\text{C}$ for 5 hours. The weight of the remaining residue on the aluminium cup was recorded after

drying. The solubility of the powder was calculated by the following equation:

$$\text{Water solubility index (\%)} = \frac{\text{Weight of dried powder (g)}}{\text{Weight of original powder (g)}} \times 100\% \quad (\text{Equation 6})$$

Wettability

The wettability of the spray-dried kuini powder was assessed according to the method reported by Marques *et al.* (2014). One gram of the powder was added to 100 mL of distilled water in a 250 mL beaker at $25 \pm 1^{\circ}\text{C}$. The time required to completely dissolve the sample was recorded and indicated as wettability of the powder.

Preparation of optimised reconstituted powder

The reconstitution of the optimised kuini powder was performed as suggested by Grabowski *et al.* (2008) with some modifications. The powder was reconstituted to the initial TSS contents of the spray-drying feed. Around 5.5 g of spray-dried kuini powders were added into 50 mL warm water. The mixture was stirred to solubilise the powder and the TSS content was examined using a digital refractometer (MA887, Milwaukee Instruments, Inc., North Carolina, USA) ($0\text{--}85^{\circ}\text{Brix}$). The powder was added continuously until the TSS achieved the initial TSS (before inserted into the spray drying system). Then, the viscosity, pH, colour and β -Carotene content of the reconstituted powder were measured.

Analysis of the reconstituted powder

Viscosity

A Brookfield viscometer (model DV-II+ Pro, Brookfield, US) equipped with Rheocalc software was used to measure the viscosity of the reconstituted powder. An LV-3 spindle was selected to measure the viscosities of the fresh kuini juice as well as the reconstituted powders (Chang *et al.*, 2020).

pH value

The pH value of the samples was measured using a digital pH meter (Jenway, UK). The calibration of the pH meter was done using a pH buffer 7.0 followed by a pH buffer 4.0. The probe of the pH meter was inserted into the sample and read at room temperature ($25 \pm 1^{\circ}\text{C}$) (Chang *et al.*, 2020b).

Colour

The colour of fresh kuini juice and the reconstituted powder was analysed as described above.

β -carotene content

The β -carotene extraction of fresh kuini juice and reconstituted powder was performed as described by Carvalho *et al.* (2012) with some modifications. Three grams of sample were weighed and added with 10 mL of distilled water with continuous stirring using a spatula until fully dissolved. In the process of β -carotene extraction, successive addition of 20 mL acetone was made into the sample-water mixture. The solution was transferred into a funnel with a 250 mL Buchner flask, where the solution was filtered under a vacuum. This procedure was repeated thrice. One-third of the extract obtained was then transferred into a separatory funnel (500 mL) which contains petroleum ether (20 mL). Distilled water (300 mL) was added slowly into the solution and the aqueous phase was discarded. This procedure was repeated thrice with the addition of 200 mL water at the second and third extraction. After that, the extract was transferred through a funnel which contains anhydrous sodium sulphate (15 g) to a 50 mL round bottom flask. The petroleum ether was removed in a rotary evaporator at $35 \pm 1^{\circ}\text{C}$. Finally, the volume of the dried extract was made up to 1.5 mL using acetone and the samples were read at 450 nm using a UV-VIS spectrophotometer (Hach DR 6000, Germany). A standard curve was generated using β -carotene solution ($5\text{--}25\text{ }\mu\text{g/g}$) for the determination of the β -carotene content.

Statistical analysis

The data collected was expressed in terms of mean $\pm$ standard deviations. All the statistical analysis of the data collected from the experiment was analyzed using Minitab v.18 LLC (USA). One-way ANOVA was performed to determine the significant differences between the means of

data collected ($p \leq 0.05$) using Tukey's Honest Significant Difference (HSD) test. A paired T-test was used to compare the mean of two independent samples.

RESULTS AND DISCUSSION

Table 1. Physicochemical properties of fresh kuini juice (spray drying feed) ($n=3$).

Physicochemical properties	Values
pH	4.52 ± 0.06
Viscosity (cP)	3661.20 ± 118.90
Colour measurement	
L* value	54.94 ± 0.87
a* value	15.43 ± 1.51
b* value	68.61 ± 1.99
β -carotene content ($\mu\text{g/g}$)	14.12 ± 1.37

Notes: Data are presented as mean $\pm$ standard deviation of triplicate determination. Abbreviations: cP = centipoise, L* = degree of lightness or darkness, a* = degree of redness or greenness and b* = degree of yellowness or blueness, $\mu\text{g/g}$ = microgram per gram.

Physicochemical properties of fresh kuini juice

Table 1 shows the physicochemical properties of the fresh kuini juice used for the spray-drying process. The kuini juice used for spray drying was moderate acidic with high viscosity. To the best of the authors knowledge, there have been limited reports on the physical properties of kuini. Barbosa Gámez *et al.* (2017) reported that the titratable acidity of kuini fruit was 28.30 ± 6.35 g/kg dry weight, which was lower than *Mangifera indica* (41.23 g/kg) but higher than *Mangifera zeylanica* (21.93 g/kg), indicating kuini fruit has moderate acidity level. *M. indica* was reported to have lightness (L*), redness (a*), and yellowness (b*) values of 54.9–61.3, 11.5–14.4 and 39.6–48.3, respectively (Ribeiro *et al.*, 2007). These values were closed to the colour of kuini, except the b* value that was 68.61 ± 1.99 , indicating kuini juice exhibited more yellowish and reddish as compared to mango. Overall, the kuini juice has a bright orange-yellowish colour. The β -carotene content of kuini juice was measured to be 14.12 ± 1.37 $\mu\text{g/g}$. Kuini peel was reported to contain 1.008 ± 0.002 mg/g of β -carotene (Lasano *et al.*, 2019). A lower value of β -carotene obtained in this study probably due to the addition of maltodextrin which diluted the β -carotene

content in the juice. Meanwhile, Ndawula *et al.* (2004) reported that mango fruit had a β -carotene content of 59 $\mu\text{g/g}$, which was higher than kuini in this study.

Effects of maltodextrin concentration on process yield, outlet temperature, feed flow rate and powder condition

Table 2 presents the process yield, outlet temperature, feed flow rate and powder conditions of the spray-dried kuini powders produced with maltodextrin concentrations of 5–20% (w/w) under an inlet temperature of 160°C. From Table 2, the outlet temperatures of the powders were 103–106°C. All the outlet temperatures fall within the range of 90–110 °C as recommended by Caparino *et al.* (2012).

There were no significant differences ($p > 0.05$) in the process yield of the kuini powder, with the addition of different maltodextrin concentrations in the spray-dryer feed (Table 2). The process yield ranges from $24.61 \pm 0.65\%$ to $29.27 \pm 3.64\%$. According to Fang & Bhandari (2012), the increase in maltodextrin concentration increases powder recovery. This is because maltodextrin increases the total solid content present in the feed. This in turn reduces its moisture content and further reduces the surface stickiness of low molecular weight sugars found abundantly in fruits. Hence, it increases the process yield as less powder would stick to the drying chamber (Quek *et al.*, 2007). However, a contrast result was obtained in this study, probably due to the amount of maltodextrin used was lower than the study by Fang & Bhandari (2012), which is 40%.

Table 2 also shows that the feed flow rate of the spray drying process was not significantly affected ($p > 0.05$) with the addition of different maltodextrin concentrations. The feed flow rate ranged from 5.02 ± 0.36 g/min to 5.45 ± 0.63 g/min. This might be due to the spray drying feed has a similar smooth consistency and the feed flow rate did not significantly different. The kuini powder formed with the addition of 5% (w/w) maltodextrin appeared sticky and coarse. However, when the maltodextrin concentration used was more than 10% w/w, the powders formed were non-sticky and appeared fine and soft. Phisut (2012) reported that powders formed with a low concentration of drying agent turned

out to be sticky. Meanwhile, powders formed at 5–10% (w/w) maltodextrin had a brighter yellow colour. When maltodextrin concentration level was increased to 15% (w/w) or more, the colour of the powders formed was pale yellow. Quek *et*

al. (2007) also reported that when the addition of maltodextrin was more than 10% (w/w), the watermelon powder produced would lose its attractive colour.

Table 2. The outlet temperature, process yield, feed flow rate, and powder conditions of kuini powder spray-dried with different concentrations of maltodextrin and constant inlet temperature (160°C) (n=3).

Maltodextrin Concentration (%)	Outlet Temperature (°C)	Process Yield (%)	Feed Flow Rate (g/min)	Powder Conditions
5	103–105	24.61 ± 0.65	5.02 ± 0.36	Sticky and coarse powder with yellow colour
10	104–105	26.90 ± 2.29	5.30 ± 0.35	Fine and soft powder with yellow colour
15	104–106	27.75 ± 2.66	5.29 ± 0.41	Fine and soft powder with pale yellow colour
20	104–106	29.27 ± 3.64	5.32 ± 0.70	Fine and soft powder with pale yellow colour

Data are presented as mean ± standard deviation of triplicate determination.

Abbreviations: % = percent, °C = degree Celsius, g/min = grams per minute.

Effects of maltodextrin concentration on colour of spray-dried kuini powder

Table 3 shows the colour measurements of the spray-dried kuini powder produced with the addition of different maltodextrin concentrations (5–20% w/w). The powders had high lightness (L^*), low redness (a^*) and moderate yellowness (b^*) value. The L^* values of the powders were closer to 100, which indicates that the powders formed were light in colour. The positive a^* value and b^* value indicate that the powders produced were more reddish than greenness and more yellowish than blueness in colour, respectively.

The powder produced with the addition of 5% (w/w) maltodextrin had the lowest L^* values. This was followed by powders produced with 10% (w/w) maltodextrin concentration. Powders produced with maltodextrin concentration of more than 15% (w/w) had lighter colours. This result was in accordance with the findings of Kha *et al.* (2010) and Mishra *et al.* (2013), where the lightness of the gac and amla powders were positively affected by the concentration of maltodextrin. Caparino *et al.* (2012) found that the lighter colour in spray-dried mango powder was due to the addition of white colour maltodextrin that contributed to the increase in lightness. The a^* value of the powders decreased significantly by up to 58% from 4.63 ± 0.35 at 5% (w/w) maltodextrin to 1.95 ± 0.22 at 20% (w/w)

maltodextrin. On the other hand, the b^* value of the powders decreased significantly by up to 23% from 38.32 ± 2.06 at 5% (w/w) maltodextrin to 29.59 ± 0.48 at 20% (w/w) maltodextrin. In the production of sweet potato and gac powders, there were also found that reduction of redness (a^* value) and yellowness (b^* value) when the maltodextrin concentrations increased (Grabowski *et al.*, 2006; Kha *et al.*, 2010). Based on the colour profile, the powder produced with 5% (w/w) maltodextrin was the most favourable because as it has the most resemblance to the colour of the fresh kuini juice. Up to date, there is a limited report on the production of spray-dried kuini powder.

Effects of maltodextrin concentration on water activity and moisture content of spray-dried kuini powder

Table 3 shows the water activity level of the powders produced with maltodextrin concentration of 5–20% (w/w). From Table 3, it can be observed that the water activities of the powders were relatively low (< 0.24 Aw). At 15–20% (w/w) maltodextrin concentration, the water activity levels of the powders were the lowest. Meanwhile, the water activity levels of the powders were the highest at 5–10% (w/w) maltodextrin. This result was in agreement with the findings of Kha *et al.* (2010) and Quek *et al.*

(2007), in which the water activities of the spray-dried gac and watermelon powders decreased with the increased concentration of maltodextrins. As the water activity falls below 0.6 A_w , the growth of microorganisms is inhibited (Cauvain & Young, 2008). Hence, the kuini powders produced with different maltodextrin concentrations were considered microbiologically stable as they all had a much lesser water activity level than 0.6 A_w . Powders with 15–20% (w/w) maltodextrin were the most favourable in terms of water activity level. The water activity of kuini juice was > 0.90, probably due to the presence of water that contributed to high water activity.

Table 3 shows the moisture content of kuini powders produced under different maltodextrin concentration (5–20% w/w). Powders with 5% (w/w) maltodextrin had the highest moisture content while powders with 20% (w/w) maltodextrin had the lowest moisture content. The moisture content of powders with 15–20% (w/w) maltodextrin showed no significant difference ($p > 0.05$). The moisture content of the

kuini powder decreased as maltodextrin concentration increased. Similar results were obtained in the studies of spray-dried pineapple powder by Abadio *et al.* (2004) and Jittanit *et al.* (2010) where the moisture content of the powders decreased with the increased maltodextrin concentrations by 15% w/w and 40% w/w, respectively. Quek *et al.* (2007) also reported that the increase in maltodextrin concentration decreased the moisture content of watermelon powder. These studies suggested that adding more maltodextrin (up to 40% w/w) increases the total solid content in the feed, which in turn reduces the amount of water for evaporation.

Powders with high moisture content tend to be stickier, lose their free-flowing capacity, and have low stability and bulk density (Hui *et al.*, 2008). Hence, powder with low moisture content is essential for stability and storage (Phisut, 2012). Thus, kuini powders produced with 20% (w/w) addition of maltodextrin can be considered as the most favourable in terms of moisture content.

Table 3. Physicochemical analyses of spray-dried kuini powder under different maltodextrin concentrations and constant inlet temperature (160°C) (n=3).

Analyses	Maltodextrin Concentration (%)			
	5	10	15	20
Colour (L*)	85.87 ± 0.41 ^c	87.66 ± 1.28 ^b	89.40 ± 0.10 ^a	90.16 ± 0.19 ^a
Colour (a*)	4.63 ± 0.35 ^a	3.43 ± 0.70 ^b	2.20 ± 0.21 ^c	1.95 ± 0.22 ^c
Colour (b*)	38.32 ± 2.06 ^a	34.83 ± 2.28 ^{ab}	31.24 ± 0.88 ^b	29.59 ± 0.48 ^b
Water Activity (A_w)	0.23 ± 0.03 ^{ab}	0.24 ± 0.02 ^a	0.18 ± 0.01 ^c	0.16 ± 0.01 ^c
Moisture Content (%)	5.11 ± 0.58 ^a	3.81 ± 0.20 ^b	3.07 ± 0.22 ^{bc}	2.16 ± 0.60 ^c
Bulk Density (g/mL)	0.30 ± 0.01 ^a	0.44 ± 0.01 ^a	0.47 ± 0.02 ^a	0.49 ± 0.02 ^a
WSI (%)	58.79 ± 12.50 ^a	63.59 ± 8.71 ^a	64.75 ± 7.64 ^a	70.86 ± 6.92 ^a
Wettability (s)	220.33 ± 30.83 ^c	236.67 ± 34.03 ^{bc}	278.33 ± 16.07 ^{bc}	299.33 ± 11.59 ^b
Hygroscopicity (g/100g)	24.90 ± 0.61 ^a	23.08 ± 0.99 ^{ab}	21.25 ± 0.55 ^{bc}	20.45 ± 0.60 ^{cd}

Data are presented as mean ± standard deviation of triplicate determination. Within the same row, different superscripts are significantly different at $p \leq 0.05$, as measured by the Tukey's HSD Test. Abbreviations: % = percent, °C = degree Celsius, L* = degree of lightness and darkness, a* = degree of redness or greenness, b* = degree of yellowness or blueness, A_w = water activity, g/mL = gram per millilitre, WSI = Water Solubility Index, s = second, g/100g = gram per 100 grams.

Effects of maltodextrin concentration on bulk density of spray-dried kuini powder

The bulk density of powder spray-dried with maltodextrin concentrations of 5–20% (w/w) can

be observed in Table 3. From the results obtained, maltodextrin concentration does not influence the bulk density. The bulk density of the powders ranged from 0.30 ± 0.01 to 0.49 ± 0.02 g/mL. All

the powders obtained in this study fall within the range reported by Hui *et al.* (2008), in which the bulk density of spray-dried powder varied from 0.3–0.7 g/mL. Spray-dried amla and gac powders also showed no significant difference in their bulk density when added with different concentrations of maltodextrins (Kha *et al.*, 2010; Mishra *et al.*, 2013). In contrast, Goula & Adamopoulos (2010) found out that spray-dried orange powders of lower bulk density were produced at a higher concentration of maltodextrin. The effect was due to the properties of maltodextrin, which minimises thermoplastic particles from sticking.

Effects of maltodextrin concentration on water solubility index and wettability of spray-dried kuini powder

The WSI of kuini powder increased with an increased concentration of maltodextrin. The highest WSI was obtained when 20% (w/w) maltodextrin was added to the feed before the spray drying process. A similar trend was observed by Vidović *et al.* (2014) where there was an increase of WSI when the maltodextrin concentration was increased during the spray drying of *Satureja montana* extract. According to El-Samahy *et al.* (2007), a higher WSI value showed a higher water dissolving ability of powder constituents. Hence, high values of WSI are favourable to give the powder a desired property. Meanwhile, the wettability of kuini powder was found to be increased when higher maltodextrin concentration (up to 20 % w/w) was used. A similar trend was observed by Chang *et al.* (2020a) in spray drying of “Terung Asam” powder. In addition, increased maltodextrin concentration resulted in a partial reduction in the powder wettability, although it increased powder moisture content. Furthermore, caking is more easily to occur in powders with higher moisture content, and this may contribute to their wetting ability because the liquid penetrates the pores more easily.

Effects of maltodextrin concentration on hygroscopicity of spray-dried kuini powder

Table 3 describes the hygroscopicity of powders produced using different maltodextrin concentrations (5–20% w/w). From Table 3, increasing the maltodextrin concentration from 5 to 20 % (w/w) reduced the hygroscopicity by up

to 18%, indicating the powder produced was less hygroscopic. This result is in agreement with Tonon *et al.* (2008) whereby at an inlet temperature of 160°C, an increase in maltodextrin concentration from 10 to 30% w/w caused a reduction in hygroscopicity of acai powder. This is because maltodextrin is a material with low hygroscopicity. A similar pattern was also observed in the spray drying of cactus pear juice and betacyanin pigments by Rodriguez-Hernandez *et al.* (2005) and Cai & Corke (2000), respectively. High hygroscopic powders indicate that the powders have a higher tendency to absorb the moisture from the surrounding air. This leads to the powder becoming sticky and prone to caking. Thus, the storage stability of highly hygroscopic powders is relatively low (Sarabandi *et al.*, 2014). Table 3 clearly shows that powders produced with maltodextrin concentration of 20% (w/w) had the significantly lowest hygroscopicity value which is more preferable.

Optimum maltodextrin concentration

Based on Table 3, the powder produced with the addition of 20% (w/w) maltodextrin concentration had the lowest moisture content ($2.16 \pm 0.60\%$) and water activity (0.16 ± 0.01 Aw). It was also one of the least hygroscopic powders with a hygroscopicity value of 20.45 ± 0.60 g/100g. The process yield of the powder was $29.27 \pm 3.64\%$ with a feed flow rate of 5.32 ± 0.70 g/min (Table 2). The powder formed was fine and soft, non-sticky and appeared to be pale yellow. Other than that, it had L^* value of 90.16 ± 0.19 , a^* value of 1.95 ± 0.22 and b^* value of 29.59 ± 0.48 . Besides, the powder also had a bulk density of 0.49 ± 0.02 g/mL, WSI of $70.86 \pm 6.92\%$ and wettability value of 299.33 ± 11.59 s. The powder is considered to be of good wettability (≤ 300 s). Therefore, the powder produced at 20% (w/w) maltodextrin concentration was optimal.

Effects of inlet temperature on process yield, outlet temperature, feed flow rate, and powder condition

Table 4 shows the process yield, outlet temperature, feed flow rate and powder conditions formed under different inlet temperatures of 140–180°C at the constant maltodextrin concentration of 20% (w/w). The outlet temperatures were ranged from 90–120°C

and were increased with the increase of inlet temperature. At 160–170°C of inlet temperature, the outlet temperature falls within the range of 100–110°C to achieve powders with the lowest moisture and high quality (Caparino *et al.*, 2012). The outlet temperature is mainly affected by the inlet temperature of the spray-dryer (Hui *et al.*, 2008) and it is an important parameter as the outlet temperature affects the particle morphology and interparticle interactions between the sample and carrier (Maas *et al.*, 2011).

The process yield of the kuini powder was the highest at 160–170°C and the lowest at 140–150°C. Nevertheless, the average yield (29.85–34.21%) of powders produced in the second part of the experiment (different inlet temperatures) was slightly higher than the average yield (21.66%–28.57%) of powders produced in the first part of the experiment (different maltodextrin concentrations) by up to 17%, indicating the inlet temperature affecting the yield of powder. The feed flow rate for the spray-drying of kuini fruit showed no significant difference among all inlet temperatures tested ($p > 0.05$), probably because the feeds had consistent smoothness. Other than that, the powder produced at 140 and 180°C were coarse and sticky

while the powder produced at 150–170°C was fine and soft. At a high temperature of 180°C, the powder yield was lower, probably due to the high temperature that causes the sugar in the sample to undergo caramelisation and sticky to the drying chamber, led to lower yield and sticky appearance (Fitzpatrick *et al.*, 2007). All powders produced appeared to be pale yellow.

Effects of inlet temperature concentration on colour of spray-dried kuini powder

The colour measurements which involved L^* , a^* and b^* of the spray-dried kuini powder produced under different inlet temperatures can be observed from Table 5. There were no significant differences ($p > 0.05$) in the colour (in terms of L^* , a^* and b^* values) of the powders spray-dried at all the different temperatures were observed. All L^* values were close to 100, indicating all the spray-dried powders were light in colour as the positive L^* value indicated lightness while the negative L^* value indicated darkness. The a^* values and b^* values obtained were all positive values, signifying the powders produced were more reddish than greenish and more yellowish than bluish, respectively.

Table 4. The outlet temperature, process yield, feed flow rate, and powder conditions of kuini powder spray-dried at different drying inlet temperature and constant maltodextrin level (20 % w/w) ($n=3$).

Inlet temperature (°C)	Outlet Temperature (°C)	Process Yield (%)	Feed Flow Rate (g/min)	Powder Conditions
140	90–91	29.85 ± 1.18^c	5.57 ± 0.37^a	Sticky and coarse powder with pale yellow colour
150	94–99	33.61 ± 1.06^{bc}	5.46 ± 0.12^a	Fine and soft powder with pale yellow colour
160	99–104	43.08 ± 2.77^a	5.23 ± 0.19^a	Fine and soft powder with pale yellow colour
170	105–110	40.74 ± 0.83^a	5.68 ± 0.28^a	Fine and soft powder with pale yellow colour
180	113–120	34.21 ± 1.41^b	5.23 ± 0.35^a	Sticky and coarse powder with pale yellow colour

Data are presented as mean $\pm$ standard deviation of triplicate determination. Within the same column, different superscripts are significantly different at $p \leq 0.05$, as measured by the Tukey's HSD Test. Abbreviations: % = percent, °C = degree Celsius, g/min = grams per minute.

Effects of inlet temperature concentration on water activity and moisture content of spray-dried kuini powder

Table 5 shows the water activity of the powders produced at different inlet temperatures (140–

180°C). The water activity of the powders decreased significantly from 0.23 ± 0.01 Aw (140°C) to 0.16 ± 0.01 Aw (170°C). It was then increased to 0.18 ± 0.01 Aw at 180°C. Masniza *et al.* (2013) reported that the water activity of grape

powder decreased when inlet temperature increased. At higher inlet temperatures, the temperature gradient between the atomised feed and the drying air is greater, leading to the production of powder that has a lower moisture content (Tonon *et al.*, 2008). Hence, the low moisture content was correlated to low water activity, indicating less free water is available. All the kuini powders produced under different inlet temperatures were considered microbiologically stable as the water activity level was lower than 0.6 (Cauvain & Young, 2008). In terms of water activity level, powders produced at 160–170°C were the most favourable. Meanwhile, the moisture contents of the powders produced at inlet temperatures of 140–180°C are presented in Table 5. It ranged from $2.38 \pm 0.79\%$ to $4.31 \pm 1.20\%$ with no significant difference ($p > 0.05$).

Effects of inlet temperature concentration on bulk density of spray-dried kuini powder

Table 5 displays the bulk density of the spray-dried kuini powder under different inlet temperatures (140–180°C). From the results obtained, the bulk density of the powders was within the range (0.3–0.7 g/mL) of the usual bulk density level of spray-dried powder (Hui *et al.* 2008). Bulk density of powders formed was the highest at an inlet temperature of 160 °C and the lowest at 180°C ($p \leq 0.05$). The bulk density of powder increased as inlet temperature increased from 140°C to 160°C, but then dropped when the inlet temperature was further increased to 170°C and 180°C.

As reported by Tonon *et al.* (2008), powders spray-dried under lower inlet temperature tend to have higher moisture content. Higher moisture content that is present in the powder causes the powder to stick together, leaving more interspaces between the particles, leading to larger bulk volume and lower bulk density (Phisut, 2012). Then again, excessive inlet temperature can cause lower bulk densities as rapid evaporation of the liquids can cause the dried particle droplets to expand rapidly, forming porous and hollow particles (Neikov *et al.*, 2009; Sarabandi *et al.*, 2014). These explained the pattern of the bulk density of the powders formed. Higher bulk density products are preferred because they occupy less space, have lower oxidation possibilities and better storage stability (Oliveira *et*

al., 2010). Hence, the powder produced at 160°C is the most favourable in terms of bulk density.

Effects of inlet temperature concentration on water solubility index and wettability of spray-dried kuini powder

The WSI of spray-dried kuini powder at different inlet temperatures (140–180°C) is shown in Table 5. The WSI of the powder produced from the different inlet temperatures ranges from $77.56 \pm 1.10\%$ to $80.55 \pm 1.64\%$ with no significant difference at $p > 0.05$. Phisut (2012) noted that maltodextrin has superior water solubility. This is possibly the reason for this observation. The WSI of the kuini powders produced in this section was lower when compared to 81.56% in pineapple juice powder (Abadio *et al.*, 2004) that was added with 15% (w/w) maltodextrin.

The wettability of powders obtained from different spray drying temperatures (140–180°C) can be observed in Table 5. Based on Table 5, the wettability time of powder is significantly lowest at 140°C. Powders produced at 170°C and 180°C have the highest wettability time. The wettability time increased with increase inlet temperature, which indicates that a longer time is needed for the particles to be penetrated by water (Marques *et al.*, 2014). Hence, powders with lower wettability value were more favourable. The result obtained was similar to the production of green corn extract powder by Marques *et al.* (2014) where the powder produced at 140°C was the most favourable in terms of wettability time. A wettability value of < 300 s was a good parameter in fruit juices (Lannes & Medeiros, 2003). Therefore, the powders produced at an inlet temperature of 150–170°C can be classified to have good wettability property.

Effects of inlet temperature concentration on hygroscopicity of spray-dried kuini powder

Table 5 presents the hygroscopicity of kuini powders obtained from different inlet temperatures (140–180°C). The hygroscopicity of powders produced at the different drying temperatures showed no significant difference ($p > 0.05$) and ranged from 21.64 ± 0.69 g/100g to 22.41 ± 0.73 g/100g. This indicates the inlet temperature did not affect the hygroscopicity of the powder.

Table 5. Physicochemical analyses of spray-dried kuini powder under different inlet temperatures and constant maltodextrin level (20 % w/w) (n=3).

Analyses	Inlet Temperature (°C)				
	140	150	160	170	180
Colour (L*)	90.26 ± 0.47 ^a	90.06 ± 0.27 ^a	90.37 ± 0.36 ^a	89.87 ± 0.52 ^a	90.72 ± 0.96 ^a
Colour (a*)	2.00 ± 0.35 ^a	2.18 ± 0.46 ^a	1.80 ± 0.17 ^a	1.98 ± 0.72 ^a	1.62 ± 0.39 ^a
Colour (b*)	29.01 ± 2.58 ^a	30.54 ± 1.30 ^a	29.69 ± 0.78 ^a	30.26 ± 0.72 ^a	28.25 ± 2.91 ^a
Water Activity (A _w)	0.23 ± 0.01 ^a	0.20 ± 0.01 ^b	0.17 ± 0.01 ^{cd}	0.16 ± 0.01 ^d	0.18 ± 0.01 ^{bc}
Moisture Content (%)	4.31 ± 1.20 ^a	3.55 ± 0.84 ^a	3.03 ± 0.53 ^a	2.77 ± 0.38 ^a	2.38 ± 0.79 ^a
Bulk Density (g/mL)	0.50 ± 0.01 ^c	0.52 ± 0.01 ^{bc}	0.55 ± 0.01 ^a	0.53 ± 0.01 ^b	0.47 ± 0.01 ^d
WSI (%)	77.90 ± 1.30 ^a	77.56 ± 1.10 ^a	79.70 ± 1.85 ^a	80.55 ± 1.64 ^a	80.54 ± 0.70 ^a
Wettability (s)	195.00 ± 13.23 ^c	253.67 ± 21.63 ^b	279.00 ± 7.90 ^{ab}	298.33 ± 18.23 ^a	313.00 ± 7.94 ^a
Hygroscopicity (g/100g)	21.64 ± 0.69 ^a	21.81 ± 0.64 ^a	22.12 ± 0.09 ^a	22.41 ± 0.73 ^a	22.38 ± 0.25 ^a

Data are presented as mean ± standard deviation of triplicate determination. Within the same row, different superscripts are significantly different at $p \leq 0.05$, as measured by the Tukey's HSD Test. Abbreviations: % = percent, °C = degree Celsius, L* = degree of lightness and darkness, a* = degree of redness or greenness, b* = degree of yellowness or blueness, A_w = water activity, g/mL = gram per millilitre, WSI = Water Solubility Index, s = second, g/100g = gram per 100 grams.

Table 6. Physicochemical analyses of fresh kuini juice and optimised reconstituted powder.

Analyses	Kuini juice	Optimised reconstituted powder
TSS (°Brix)	12.37 ± 0.46 ^a	12.56 ± 0.45 ^a
Viscosity (cP)	3661.20 ± 118.90 ^a	619.70 ± 16.50 ^b
pH	4.52 ± 0.06 ^a	4.51 ± 0.02 ^a
Colour (L*)	54.94 ± 0.87 ^a	48.44 ± 1.68 ^b
Colour (a*)	15.43 ± 1.51 ^a	8.17 ± 0.62 ^b
Colour (b*)	68.61 ± 1.99 ^a	56.17 ± 2.66 ^b
β-carotene content (µg/g)	14.12 ± 1.37 ^a	5.54 ± 0.82 ^b

Data are presented as mean ± standard deviation of triplicate determination. Within the same row, different superscripts are significantly different at $p \leq 0.05$ as measured by the paired sample T-test. Abbreviations: TSS = total soluble solid, °Brix = degree Brix, cP = centipoise, L* = degree of lightness or darkness, a* = degree of redness or greenness and b* = degree of yellowness or blueness, µg/g = microgram per gram.

Optimum inlet temperature at optimum maltodextrin concentration

At an optimum maltodextrin concentration of 20% (w/w), the optimum inlet temperature was found to be 160°C. The process yield of powder produced at this temperature was the highest at $43.08 \pm 2.77\%$. The powder had a soft and fine texture as well as non-sticky characteristics with pale yellow colour, whereby it had L* value of 90.37 ± 0.36 , a* value of 1.80 ± 0.17 and b* value of 29.69 ± 0.78 . The powder also had a low water activity level at 0.17 ± 0.01 A_w and the highest bulk density value of 0.55 ± 0.01 g/mL. The powder formed under the same inlet temperature had a moisture content of $3.03 \pm 0.53\%$, WSI of $79.70 \pm 1.85\%$, good wettability value of 279.00

± 7.90 s, and hygroscopicity value 22.12 ± 0.09 g/100g. This result was in accordance with the findings of Ersus and Yurdagel (2006), in which 160°C was selected as the optimal inlet temperature for the production of black carrot powder at 20% (w/w) maltodextrin concentration.

Reconstitution of optimised kuini powder

Table 6 describes the TSS, viscosity, pH, colour and β-carotene content of fresh kuini juice and optimised reconstituted powder. The properties of optimised reconstituted powder and kuini juice were compared (Table 6). The TSS and pH were not significantly affected by spray-drying. However, the viscosity, colour and β-carotene

content were affected by the spray-drying process. The viscosity of reconstituted kuini powder decreased from 3661.20 ± 118.90 cP to 619.70 ± 16.50 cP after spray-drying, indicating the solution produced had better consistency, which is favourable for industrial application. The heat treatment during the spray-drying process may attribute to this factor as the increase in inlet temperature would decrease the viscosity of the reconstituted powder. This is because the elevated temperature weakens the molecular interactions i.e. intermolecular hydrogen bonding that exhibited surface tension (Grabowski *et al.*, 2006).

Apart from that, the reconstituted powder was less light and less redness and yellowness than the fresh kuini juice. This was possibly due to the addition of maltodextrin that causes the production of powder with pale colour and loss in red-orange colour. The destruction of β -carotene may also add to the loss of colour (Quek *et al.*, 2007). The results were similar to the findings of Jittanit *et al.* (2010), whereby the powder showed less lightness compared to the juice. The overall difference in colour of fresh kuini juice and spray-dried kuini powder was calculated to be 15.85 ± 2.85 . The total colour difference was higher compared to gac powder which had colour difference of around 10 when spray-dried at 160°C with 20% (w/w) maltodextrin concentration (Kha *et al.*, 2010).

The β -carotene content of kuini was observed to be lower after spray-drying. The β -carotene content of the juice was 14.12 ± 1.37 $\mu\text{g/g}$ while the β -carotene content of the powder was 5.54 ± 0.82 $\mu\text{g/g}$. The recommended dietary intake of β -carotene is 3–6 mg β -carotene/day. Hence, with this guideline, the spray-dried kuini powder can be added as a supplementary source with other functional ingredients as one of the sources of β -carotene. The high temperature during the spray-drying process may contribute to this loss (Quek *et al.*, 2007). This is because carotenoids are highly sensitive to high temperatures. The properties of optimised reconstituted powder were significantly different from the fresh kuini juice.

CONCLUSION

This work aimed to study the effects of maltodextrin concentration and inlet temperature

on the properties of spray-dried kuini powder. The addition of 20% (w/w) maltodextrin was optimal for the spray-drying of kuini, in which the kuini powder had considerable low moisture content ($2.16 \pm 0.60\%$), water activity level (0.16 ± 0.01 Aw) and hygroscopicity value (20.45 ± 0.60 g/100g). It also had a good wettability of 299.33 ± 11.59 s. With the increase of maltodextrin concentration from 5 to 20% (w/w), the lightness of the powders increased while their redness and yellowness decreased. In the second part of the experiment, it was found out that the optimum inlet temperature was at 160°C . The powder obtained at this temperature has the highest yield of $43.08 \pm 2.77\%$, the highest bulk density at 0.55 ± 0.01 g/mL and the lowest water activity level (0.17 ± 0.01 Aw). The wettability value was classified as good at 279.00 ± 7.90 s. In conclusion, the kuini powders formed at a spray-drying temperature of 160°C with the addition of 20% (w/w) maltodextrin had the optimum properties. The reconstitution of optimised spray-dried kuini powder had a lower viscosity, colour (L^* , a^* and b^* values), and β -carotene content as compared to fresh kuini juice. A future study can be conducted to use different drying aids (Arabic gum, cellulose, starch) to encapsulate the kuini powder in order to prevent loss of pigment during the spray drying process.

REFERENCES

- Abadio, F. D. B., Domingues, A. M., Borges, S. V., & Oliveira, V. M. 2004. Physical properties of powdered pineapple (*Ananas comosus*) juice – effect of malt dextrin concentration and atomization speed. *Journal of Food Engineering* 64: 285–287.
- Adhikari, B., Howes, T., Bhandhari, B. R., & Troung, V. 2004. Effect of addition of maltodextrin on drying kinetics and stickiness of sugar and acid-rich foods during convective drying: experiments and modelling. *Journal of Food Engineering* 62(1): 53–68.
- Adnan, H., Mat Ali, M. S., Hassan, H., Abdul Manan, M., Ghazali, M. N., & Ramli, N. S. N. 2018. Bioassay-guided of fresh and fermented kuini (*Mangifera odorata*) extracts against bacterial activity. *International Journal of Agriculture, Forestry and Plantation*, 7: 27–32.
- Angel, R. C. M., Espinosa-Munoz, L. C., Aviles-Aviles, C., Gonzalez-Garcia, R., Moscote-Santillan, M., Grajales-Lagunes, A., & Abud-Archil, M. 2009. Spray-drying of passion fruit juice using lactose-maltodextrin blends as the support material. *Brazilian Archives of Biology and Technology* 52(4): 1011–1018.
- Barbosa Gámez, I., Caballero Montoya, K. P., Ledesma, N., Sáyago Ayerdi, S. G., García Magaña, M. de L., Bishop von

- Wettberg, E. J., & Montalvo-González, E. 2017. Changes in the nutritional quality of five *Mangifera* species harvested at two maturity stages. *Journal of the Science of Food and Agriculture* 97(14): 4987–4994.
- Cai, Y. Z. & Corke, H. 2000. Production and properties of spray-dried *Amaranthus* betacyanin pigments. *Journal of Food Science* 65(6): 1248–1252.
- Cano-Chauca, M., Stringheta, P. C., Ramon, A. M., & Cal-Vidal, J. 2005. Effects of the carriers on the microstructure of mango powder obtained by spray drying and its functional characterization. *Innovative Food Science and Emerging Technologies* 6: 420–428.
- Caparino, O. A., Tang, J., Nindo, C. I., Sablani, S. S., Powers, J. R., & Fellman, J. K. 2012. Effect of drying methods on the physical properties and microstructures of mango (*Philippine 'Carabao' var.*) powder. *Journal of Food Engineering* 111: 135–148.
- Carvalho, L. M. J., Gomes, P. B., Godoy, R. L. O., Pacheco, S., Monte, P. H. F., Carvalho, J. L. V., Nutti, M. R., Neves, A. C. K., Vieira, A. C. R. A., & Ramos, S. R. R. 2012. Total carotenoid content, α -carotene and β -carotene, of landrace pumpkins (*Cucurbita moschata* Duch): A preliminary study. *Food Research International* 47: 337–340.
- Cauvain, S., & Young, L. 2008. *Bakery Food Manufacture and Quality* (pp. 178–188). Oxford: Blackwell Science.
- Chang, L. S., Eau Yong, S. M., & Pui, L. P. 2020a. Production of spray-dried “Terung asam” (*Solanum lasiocarpum* Dunal) powder. *Walailak Journal of Science and Technology* 18(1).
- Chang, L. S., Karim, R., Sabo Mohammed, A., & Mohd Ghazali, H. 2018a. Production and characterization of enzyme-treated spray-dried soursop (*Annona muricata* L.) powder. *Journal of Food Process Engineering* 41(e:12688). Blackwell Publishing Inc.
- Chang, L. S., Tan, Y. L., & Pui, L. P. 2020b. Production of spray-dried enzyme-liquefied papaya (*Carica papaya* L.) powder. *Brazilian Journal of Food Technology* 23: e2019181.
- Chang, L. S., Karim, R., Abdulkarim, S. M., Yusof, Y. A., & Ghazali, H. M. 2018b. Storage stability, color kinetics and morphology of spray-dried soursop (*Annona muricata* L.) powder: effect of anticaking agents. *International Journal of Food Properties* 21(1): 1937–1954. Taylor & Francis.
- Chew, S., Tan, C., Pui, L., Chong, P., Gunasekaran, B., & Nyam, K. 2019. Encapsulation technologies: A tool for functional foods development. *International Journal of Innovative Technology and Exploring Engineering* 8(5S): 154–160.
- El-Samahy, S. K., El-hady, E. A. A., Habiba, R. A., & Moussa-Ayoub, T. E. 2007. Some functional, chemical, and sensory characteristics of cactus pear rice-based extrudates. *Journal of the Professional Association for Cactus Development* Dec: 136–147.
- Ersus, S. & Yurdagel, U. 2006. Microencapsulation of anthocyanin pigments of black carrot (*Daucus carota* L.) by spray drier. *Journal of Food Engineering* 80: 805–812.
- Fang, Z. & Bhandari, B. 2012. Comparing the efficiency of protein and maltodextrin on spray drying of bayberry juice. *Food Research International* 48: 478–483.
- Ferrari, C. C., Germer, S. P. M., & de Aguirre, J. M. 2012. Effects of spray-drying conditions on the physicochemical properties of blackberry powder. *Drying Technology* 30(2): 154–163.
- Fitzpatrick, J. J., Hodnett, M., Twomey, M., Cerqueira, P. S. M., O’Flynn, J., & Roos, Y. H. 2007. Glass transition and the flowability and caking of powders containing amorphous lactose. *Powder Technology* 178(2): 119–128.
- Gallali, Y. M., Abujnah, Y. S., & Bannani, F. K. 2000. Preservation of fruits and vegetables using solar drier: a comparative study of natural and solar drying, III; chemical analysis and sensory evaluation data of the dried samples (grapes, figs, tomatoes and onions). *Renewable Energy* 19: 203–212.
- Gallo, L., Llabot, J. M., Allemandi, D., Bucalá, V., & Piña, J. 2011. Influence of spray-drying operating conditions on *Rhamnus purshiana* (*Cáscara sagrada*) extract powder physical properties. *Powder Technology* 208(1): 205–214. Elsevier B. V.
- Gopinathan, M., Yusof, Y. A., & Pui, L. P. 2020. Effects of different drying methods on the physicochemical and antioxidant content of ‘cempedak’ (*Artocarpus integer* L.) powder. *Journal of Food Processing and Preservation*: in press.
- Goula, A. M. & Adamopoulos, K. G. 2010. A new technique for spray drying orange juice concentrate. *Innovative Food Science and Emerging Technologies* 11: 342–351.
- Grabowski, J. A., Truong, V. D., & Daubert, C. R. 2008. Nutritional and rheological characterization of spray dried sweet potato powder. *LWT - Food Science and Technology* 41: 206–216.
- Grabowski, J. A., Truong, V. D., & Dubert, C. R. 2006. Spray-drying of amylase hydrolyzed sweet potato puree and physicochemical properties of powder. *Journal of Food Science* 71(5): 209–217.
- Hui, Y. H., Clary, C., Farid, M. M., Fasina, O. O., Noomhorm, A., & Welti-Chanes, J. 2008. *Food Drying Science and Technology: Microbiology, Chemistry, Applications*. DEStech Publications, Inc.
- Jaya, S. & Das, H. 2004. Effect of maltodextrin, glycerol monostearate and tricalcium phosphate on vacuum dried mango powder properties. *Journal of Food Engineering* 6: 125–134.
- Jittanit, W., Niti-Att, S., & Techanuntachaikul O. 2010. Study of spray drying of pineapple juice using maltodextrin as an adjunct. *Chiang Mai Journal of Science* 37(3): 498–506.
- Kader, A. A., Zagory, D., Kerbel, E. L., & Wang, C. Y., 2009. Modified atmosphere packaging of fruits and vegetables. *Critical Reviews in Food Science and Nutrition* 28(1): 1–30.
- Kha, T. C., Nguyen, M. H., & Roach, P. D. 2010. Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder. *Journal of Food Engineering* 98: 385–392.
- Kozai, N., Keizer, M., dela Cruz, F., Sajise, P. E., & Idris, S. 2005. The marketing channel of two underutilized fruit species of Malaysia: Pulasan (*Nephelium ramboutan-ake* (Labill.) Leech) and Kuini (*Mangifera odorata* Griff.).
- Lai, J. T., Lai, K. W., Zhu, L. Y., Nyam, K. L., & Pui, L. P. 2020. Microencapsulation of *Lactobacillus plantarum* 299v and its storage in kuini juice. *Malaysian Journal of Microbiology* 16(4): 235–244.
- Lannes, S. C. S. & Medeiros, M. L. 2003. Cupuassu chocolate drink powder processed by spray-dryer. *Brazilian Journal of Pharmaceutical Sciences* 39(1): 115–123.
- Lasano, N. F., Hamid, A. H., Karim, R., Dek, M. S. P., Shukri, R., & Ramli, N. S. 2019. Nutritional composition, anti-diabetic properties and identification of active compounds using UHPLC-ESI-orbitrap-MS/MS in *Mangifera odorata* L. peel and seed kernel. *Molecules* 24(2): 1–20.
- Lim, T. K. 2012. *Edible medicinal and non-medicinal plants* (Vol. 1, pp. 127–129). Dordrecht, The Netherlands: Springer.
- Loo, Y. Y. & Pui, L. P. 2020. Storage stability of kuini (*Mangifera odorata*) powder in aluminum laminated polyethylene and polyethylene terephthalate. *Malaysian Journal of Analytical Sciences*: in press.
- Maas, S. G., Schaldach, G., Littringer, E. M., Mescher, A., Griesser, U. J., Braun, D. E., Walzel, P. E., et al. 2011. The impact of spray drying outlet temperature on the particle morphology of mannitol. *Powder Technology* 213(1): 27–35.
- Marques, G. R., Borges, S. V., Mendonca, K. S., Fernandes, R. V. B., & Menezes, E. G. T. 2014. Application of maltodextrin

- in green corn extract powder production. *Powder Technology* 263: 89-95.
- Masniza, M., Hani Izzati, M. H., Farah Salina, H., & Rinani Shima, A. R. 2013. Maltodextrin encapsulation of *Garcinia atroviridis* Griff by spray drying technique. *International Journal of Scientific Engineering and Technology* 2(10): 1011-1012.
- Mishra, P., Mishra, S., & Mahanta, C. L. 2013. Effect of maltodextrin concentration and inlet temperature during spray drying on physicochemical and antioxidant properties of amla (*Embilica officinalis*) juice powder. *Food and Bioproducts Processing* 92(3): 1-7.
- Ndawula, J., Kabasa, J. D., & Byaruhanda, Y. B. 2004. Alterations in fruit and vegetable β -carotene and vitamin C content caused by open-sun drying, visqueen-covered and polyethylene-covered solar-dryers. *African Health Sciences* 4(2): 125-130.
- Neikov, O. D., Naboychenko, S. S., and Dowson, G., 2009. *Handbook of Non-Ferrous Metal Powders: Technologies and Applications*. Elsevier.
- Oliveira, W. P., Souza, C. R. F., Kurozawa, L. E., & Park, K. J. 2010. Spray drying of food and herbal products. In Woo, M.W., Mujumdar, A.S., and Daud, W.R.W (eds.). *Spray Drying Technology*, pp.113-154.
- Oms-Oliu, G., Rojas-Grau, M. A., Gonzalez, L. A., Varela, P., Soliva-Fortuny, R., Hernando, M. I. H., Munuera, I. P., Fiszman, S., & Marin-Belloso, O. 2010. Recent approaches using chemical treatments to preserve quality of fresh-cut fruit: A review. *Postharvest Biology and Technology* 57(3): 139-148.
- Phisut, N. 2012. Spray drying technique of fruit juice powder: some factors influencing the properties of product. *International Food Research Journal* 19(4): 1297-1306.
- Phoungchandang, S., & Sertwasana, A. 2010. Spray-drying of ginger juice and physicochemical properties of ginger powders. *Science Asia* 36(1): 40-45.
- Pui, L. P., Karim, R., Yusof, Y. A., Wong, C. W., & Ghazali, H. M. 2018. Physicochemical and sensory properties of selected 'cempedak' (*Artocarpus integer* L.) fruit varieties. *International Food Research Journal* 25(2): 861-869.
- Pui, L. P., Karim, R., Yusof, Y. A., Wong, C. W., & Ghazali, H. M. 2020a. Anti-caking agent effects on the properties of spray-dried 'cempedak' fruit powder. *Journal of Tropical Agricultural Science*: in press.
- Pui, L. P., Karim, R., Yusof, Y. A., Wong, C. W., & Ghazali, H. M. 2020b. Optimization of spray-drying parameters for the production of 'Cempedak' (*Artocarpus integer*) fruit powder. *Journal of Food Measurement and Characterization*: 1-12.
- Quek, S. Y., Chok, N. K., & Swedlund, P. 2007. The physicochemical properties of spray-dried watermelon powders. *Chemical Engineering and Processing* 46: 386-392.
- Ribeiro, S. M. R., Humberto de Queiroz, J., Ribeiro de Queiroz, M. E. L., Campos, F. M., & Sant'ana, H. M. P. 2007. Antioxidant in mango (*Mangifera indica* L.) pulp. *Plant Foods for Human Nutrition* 62: 13-17.
- Rodriguez-Hernandez, G. R., Gonzalez-Garcia, R., Grajales-Lagunes, A., & Ruiz-Cabrera, M. A. 2005. Spray-drying of cactus pear juice (*Opuntia streptacantha*): Effect on the physicochemical properties of powder and reconstituted product. *Drying Technology* 23(4): 955-973.
- Sarabandi, Peighambari, S. H., & Shirmohammadi, M. 2014. Physical properties of spray dried grape syrup as affected by drying temperature and drying aids. *International Journal of Agriculture and Crop Sciences* 7(12): 928-934.
- Shavakhi, F., Boo, H. C., Osman, A., & Ghazali, H. M. 2012. Effects of enzymatic liquefaction, maltodextrin concentration, and spray-dryer air inlet temperature on pumpkin powder characteristics. *Food and Bioprocess Technology* 5(7): 2837-2847.
- Singh, V. K., Mandhyan, B. L., Pandey, S., & Singh, R. B. 2013. Process development for spray drying of ber (*Ziziphus juube* L.) juice. *American Journal of Food Technology* 8(3): 183-191.
- Tonon, R. V., Brabet, C., & Hubinger, M. D. 2008. Influence of process conditions on the physicochemical properties of acai (*Euterpe oleracea* Mart.) powder produced by spray drying. *Journal of Food Engineering* 88: 411-418.
- Truong, V., Bhandari, B. R., & Howes, T. 2005. Optimization of co-current spray drying process of sugar-rich foods. Part I – Moisture and glass transition temperature profile during drying. *Journal of Food Engineering* 71(1): 55-65.
- Wong, C. W., Pui, L. P., & Ng, J. M. L. 2015. Production of spray-dried Sarawak pineapple (*Ananas comosus*) powder from enzyme liquefied puree. *International Food Research Journal* 22(4): 1631-1636.
- Vidović, S. S., Vladoić, J. Z., Vaštag, Ž. G., Zeković, Z. P., & Popović, L. M. 2014. Maltodextrin as a carrier of health benefit compounds in *Satureja montana* dry powder extract obtained by spray drying technique. *Powder Technology* 258: 209-215.