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Effect of air-drying temperature on physico-chemical, powder properties and sorption characteristics of pumpkin powders

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Abstract

This study examined the use of hot-air drying in the preparation of pumpkin powder. The drying temperature was varied (50, 60 and 70°C) to determine the effect of temperature on physico-chemical properties, powder properties and sorption characteristics of pumpkin powders. The results showed that a drying temperature of 70°C removes moisture from pumpkin slices faster than the lower drying temperatures of 50 and 60°C. The moisture content and water activity values of the pumpkin powder dried at 60 and 70°C were within acceptable limits for safe storage. Pumpkin powder dried at 70°C exhibited the darkest yellow color, while pumpkin powders dried at 50 and 60°C were lighter. Moreover, pumpkin powder dried at 70°C showed the highest percent decrease in carotenoid content (56%) compared to those dried at 50 and 60°C (18% and 33%, respectively). The results also showed that increases in drying temperature are accompanied by decreases in the water solubility, water and oil adsorption capacities of the resulting pumpkin powders. Pumpkin powders dried at 50 and 60°C had water solubilities of more than 50% and higher water adsorption and oil adsorption capacities than those dried temperature at 70°C. Overall, a good quality pumpkin powder can be produced by hot-air drying at a temperature of 60°C in terms of moisture content, water activity, color characteristics, total carotenoid content, bulk density, water solubility, water adsorption, and oil adsorption capacities. When drying at a temperature of 50°C, the moisture content and water activity of pumpkin powder was higher than the acceptable limit of that standard and the dark yellow color of the powder was observed when subjected at a drying temperature of 70°C. Working sorption isotherms of dried pumpkin powder were found to be Type II of all the sorption curves.

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Introduction

Pumpkins belong to the family *Cucurbitaceae* and the genus *Cucurbita. Cucurbita moschata* Duchesne cultivars grown for direct human consumption is generally referred to as “squash.” Kabocha squash, which is commonly called “Buttercup pumpkin” in New Zealand or “Japanese squash” in Thailand and other parts of Southeast Asia, is one of the most popular varieties of pumpkin. It has a sweet and creamy yellow-orange flesh and is much sweeter than other pumpkin varieties (Loy, 2004). Pumpkins are stable for about 1 to 3 months after harvest. However, after peeling, they are susceptible to moisture loss, softening, color changes and microbial spoilage. In order to prolong shelf life, some drying and powdering techniques have been suitably recommended (Dirim and Caliskan, 2012). Powders are currently the main processed products of pumpkin. This is due to the fact that they can be easily stored for a long time. If processed in this way, it can be used as an ingredient in manufacturing food such as in bakery products, soups, spices, sauces and instant noodles, and as a natural coloring agent in pasta and flour mixes (Cumarasamy *et al*., 2002). Adding powdered pumpkin to the products not only enhances the content of various nutrients, but also improves the flavor of the manufactured food (Que *et al.*, 2008).

Production of fruit and vegetable powders by drying techniques such as hot-air drying (Dirim and Caliskan, 2012), freeze drying (Que *et al*., 2008), spray drying (Shavakhi *et al*., 2012), vacuum drying (Arévalo-Pinedo and Murr, 2006) and microwave vacuum drying (Rakcejeva *et al.*, 2011) have been studied. Specifically, the hot-air drying method could result in a quality product that is characterized by uniform, hygienic, and attractive color of dried fruit and vegetable powder. However, if the process is done in a rapid manner it usually results to an inferior product quality (Dirim and Caliskan, 2012).

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On the other hand, spray drying has been reported to produce a good quality product and high process yield, but the stickiness was noticeable in the fruit powder (Tran *et al*., 2008). These advantages are, however, not without financial and preparation constraints (Shavakhi *et al*., 2012). Freeze drying and spray drying are known to be expensive and require complicated preparation processes; hence, they are not suitable when considering to commit production with a limited budget (Que *et al*., 2008). In this case, hot air drying may be a more suitable technique for the processing and production of pumpkin powder, particularly for local companies.

Drying process can cause changes in food surface characteristics which lead to color changes. Changes attributed to carotenoids and other pigments can also be caused by heat and oxidation during drying. In particular, higher drying temperatures and longer drying times were seen to facilitate greater pigment losses (Noor Aziah and Komathi, 2009). The properties of food powders such as bulk density, wettability, solubility, and particle size are useful for product quality control (Dirim and Caliskan, 2012). Dried agricultural products, is hygroscopic, hence, its shelf life is affected by environmental conditions such as temperature and relative humidity (Alakali and Satimehin, 2009). The moisture sorption characteristics can be used to predict the shelf life of packaged moisture-sensitive products (Mayor *et al*., 2005). However, the literature available on pumpkin powder produced through hot-air drying and their powder qualities are very scarce. Therefore, the aim of this research is to respond to the literature gap. Furthermore, this study aims to understand the effect of air-drying temperature on physico-chemical properties, powder properties and sorption characteristics of pumpkin powders after the drying process.

Materials and Methods

Sample preparation

Buttercup pumpkin or Kabocha squash (*Cucurbita maxima* Duch.) samples used for this research were procured from the local market in Palmerston North, New Zealand. The total soluble solids (TSS) for the fresh fruits varied from 10 to 12^{o}Brix. After cleaning and peeling, the pumpkin flesh was chopped into uniform strips with 2.54 cm. Similarly, the seeds were scraped off. The pumpkin strips were then cut into uniform slabs with a thickness of 5 mm, a length 40 mm and a width of 20 mm (Workneh *et al*., 2012). Subsequently, 300 g of pumpkin slices were weighed and subjected to water blanching by immersing it in hot water at 95°C for 5 minutes. The samples were then cooled to room temperature (Arévalo-Pinedo and Xidieh Murr, 2007).

Powder preparation

Hot-air drying was carried out in a cross-flow-cabinet hot-air tray dryer (Taylor and Andrews Ltd., Palmerston North, New Zealand) fitted with an electronic balance to record weight changes during the drying period. Drying of pumpkin slices was performed at temperatures varied at 50, 60 and 70°C. Air velocity was controlled to 2 m/s at the exit of the fan throughout the experiments. The system was allowed to run for about half an hour without samples in order to reach steady state. The samples were then arranged in a single thin layer on a stainless steel tray. The bottom surfaces of the samples, which were in contact with the tray, were exposed to hot air.

Afterwards, the weight of the samples were recorded throughout the study and the data was used to calculate the moisture content which changed during of time (MC_{db}, % db) from Eq. (1). The equilibrium moisture content (MCe) was then evaluated and used to calculate the moisture ratio (MR) from Eq. (2). Each experiment was repeated to ensure reproducibility of the data. (Nguyen and Price, 2007). The dried slices were ground in a blender and sieved through a 150-mesh screen with aperture size of 104 µm (Electromagnetic Sieve Shaker, Model EMS-8, Electrolab, Mumbai, India) to obtain pumpkin powders with a moisture content (expressed as a percentage on a dry basis, or %db) of 11.38% at 50°C, 8.07% at 60°C and 5.78% at 70°C. The pumpkin powders were sealed in aluminum foil bags and stored at 4°C for further analysis (Ahmed *et al*., 2014; Que *et al.,* 2008).

$$MC_{db}\ (\%db) = [(W_0 - W_f) / W_f] \times 100 \qquad (1)$$

Where, W_0 = initial weight; W_f = final weight; MC_{db} = moisture content dry basis (%db)

Moisture content, TSS and water activity (a_w)

The moisture contents of pumpkin flesh and pumpkin powder were determined using the method of AOAC (2005), with six replicates performed for each sample where the average was calculated. Moisture content (%db) was determined for each sample as the percentage ratio of the weight loss to the initial weight of the sample as in Eq. (1) above. TSS of pumpkin flesh was also determined using a digital refractometer (Model PAR-1, Atago, Tokyo, Japan) at room temperature. Water activity (a_w) of pumpkin flesh and pumpkin powder were measured using a water activity analyzer (Decagon, Aqualab 4TE – Decagon Devices Inc., Pullman, WA, USA). Three replicate measurements of TSS and water activity were performed for each sample (AOAC, 2005).

Color measurement

A Minolta Chroma Meter, (CR-200, Osaka, Japan) was used for the determination of color parameters. Zero calibration and white calibration were carried out with a zero calibration tile and a white calibration tile, respectively, on the target mask for a petri dish. Powder samples of 0.5 g were placed evenly on the petri dish for color measurement. L^*, chroma (c^*), and hue angle (h) values were recorded for triplicate lots of each powder sample (McGuire, 1992).

Total carotenoid content

To determine the amount of total carotenoids, approximately 2.5 g of pumpkin flesh or 0.5 g of pumpkin powder were weighed in a mortar on a digital balance. For the carotenoid extraction, successive additions of 25 mL of acetone were made to obtain a paste. This derived paste was, then, transferred into a sintered funnel (5 µm) coupled to a 250 mL Buchner flask and filtered under vacuum. This procedure was repeated three times or until the sample became colorless. The extract obtained was transferred to a 500 mL separatory funnel containing 40 mL of petroleum ether. The acetone was removed through the slow addition of pure water to prevent emulsion formation. The aqueous phase was discarded thereafter. This procedure was repeated four times until no residual acetone remained. Afterwards, the extract was transferred through a funnel to a 50 mL volumetric flask containing 15 g of anhydrous sodium sulfate. The volume was made using petroleum ether, and the absorbances of the samples were determined at 450 nm. The total carotenoid content was calculated using the following formula as Eq. (2) (de Carvalho *et al*., 2012):

$$\text{Total carotenoid content } (\mu g\ g^{-1} \text{ sample}) = \frac{A \times V(mL) \times 10^4}{A_{1cm}^{1\%} \times P(g)} \qquad (2)$$

Where, A = absorbance; V = total extract volume; P = sample weight; $A_{1cm}^{1\%}$ = 2592 (β-carotene Extinction Coefficient in petroleum ether).

Bulk density

Bulk density (g/mL) was measured in a graduated cylinder by gently adding 2 g of pumpkin powder into an empty 10 mL graduated cylinder and holding the cylinder on a vortex vibrator for 1 min. The volume was read recorded. The measurements were made in triplicate. The ratio of the mass of the powder to the volume occupied in the cylinder determines the bulk density value in g/ml using Eq. (3) (Goula *et al*., 2004).

$$\text{Bulk density } (g\ mL^{-1}) = W/V_1 \qquad (3)$$

Where, W = grams of pumpkin powder; V = measuring volume

Water solubility and water absorption

Water solubility and water absorption were determined following the method of Anderson and Kha (Anderson *et al*., 1970; Kha *et al*., 2010), with slight modifications. Firstly, the weight of cleaned centrifuge tubes was measured. Afterwards, 1 g of sample was dispersed in 10 ml of distilled water and poured into the centrifuge tubes, which were then placed in a water bath at 60°C. The tubes were held in the water bath for 20 min, followed by centrifugation for 10 min at 8000 rpm. The supernatant was collected in a pre-weighed beaker, and the residue was weighed after the water was evaporated at 105°C. The percentage of residue, with respect to the amount of pumpkin flour used in the test, was taken as water solubility, with the formula: Water solubility = (weight of residue / weight of pumpkin flour) x 100. Triplicate determinations were performed in this process (Que *et al*., 2008). On the other hand, the weight ratio of centrifuged precipitate to the amount of dried pumpkin powder used in the test was taken as the water absorption: Water absorption = weight of centrifuged precipitate / weight of dried pumpkin powder.

Oil absorption capacity

Oil absorption capacity was determined using the method of Que *et al.* (2008) with slight modifications. Specifically, it was done by mixing pumpkin powder (1 g) and 6 mL of corn oil in a centrifuge tube and stirring it for 30 s using a vortex mixer, followed by centrifugation in a bench top centrifuge at 8000 rpm for 10 min. The volume of supernatant was recorded and an average was calculated from triplicate determinations. The oil absorption capacity = (mL of supernatant)/grams of pumpkin powder.

Determination of the sorption isotherm

Experimental equilibrium moisture contents of the dried pumpkin powders, represented as MCe (%db), were determined using a gravimetric technique, specifically, the static equilibrium method (Mayor *et al*., 2005; Wolf *et al*., 1985). All measurements were performed in triplicate using 3 g of sample at 20°C. Saturated solutions of the recommended salts (Wolf *et al*., 1985) were used to generate relative humidity of 12.5% to 93%, obtained using eight salts: LiCl, $MgCl_2$, K_2CO_3, $Mg(NO_3)_2$, KI, NaCl, KCl and KNO_3.

Equilibrium moisture content was achieved when three consecutive weight measurements showed a difference of less than 0.002 g (approximately four weeks after). After equilibration, the moisture contents of the samples were estimated using Eq. (1) (Yan *et al*., 2008). The relationship between water activity and the equilibrium relative humidity (ERH) is calculated as: ERH (100%) = a_w x 100 (Lahsasni *et al*., 2004). In this study, the sorption isotherm of pumpkin powder at 20°C was experimentally determined and compared with bibliographic data for similar dried products.

Statistical analysis

The experiments were carried out in triplicate and the results were presented as mean values. Different mean values were analyzed by analysis of variance (ANOVA) and least significant difference (LSD) using SPSS software version 17.0. Graphs of the mean values with error bars were created using Microsoft Excel 2013. The level of significant difference was determined using $^*P \leq 0.05$ for all comparisons.

Results and Discussion

Drying characteristic curves of pumpkin slices

Figure 1 shows typical characteristic drying curves (moisture ratio versus time) for pumpkin slices using hot-air drying at temperatures of 50, 60 and 70°C, with drying air velocity of 2 m/s over 12 hr. The final moisture contents represent moisture equilibrium between the sample and the drying air under the conditions in the dryer, beyond which no further changes in the mass of sample could occur. The moisture content data was plotted as moisture content (%db) versus drying time.

Because the pumpkin samples were prepared at different times, the initial moisture contents were not the same for all runs. The moisture contents decreased with time until they reached equilibrium, which was also seen during drying. The drying characteristic curves of the pumpkin slices exhibited four distinct drying periods: one warming-up period, two falling rate periods and another constant drying period. The initial moisture content were 289.25%db at 50°C, 297.28%db at 60°C, and 261.35%db at 70°C. In the warming-up period, the moisture ratio were almost constant and lasted for a very short time, with the length depending on the drying temperature used at

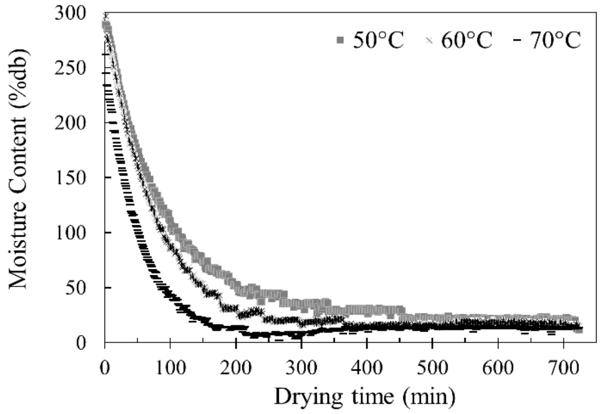

Figure 1. Moisture profile of pumpkin slices during drying at 50, 60 and 70°C

approximately 14 min at 50°C, 9 min at 60°C and 5 min at 70°C.

In the latter two drying periods, the moisture content decreased more rapidly. During the first falling rate period, the moisture content decreased in a linear manner until it reached an approximate moisture content of 40%db . After which, the second falling rate period started. The drying rates in the second falling rate period decreased slower than in the first falling rate period, which took place in a non-linear fashion. This continued until the constant drying period. During the first falling rate period, the moisture decrease was faster at 70°C than at 50 and 60°C as shown in Figure 1. The change from linear to non-linear decrease was found to occur after the moisture content had decreased by approximately 60%db after 180 min (61.54%db) at 50°C, 130 min (60.09%db) at 60°C, and 75 min (60.84%db) at 70°C. The higher capability of removing moisture at high temperatures can possibly be explained by the acceleration produced through the movement of water molecules at higher temperatures which took part in a more rapid decrease of the moisture content (Prachayawarakorn *et al*., 2008). The moisture contents of the pumpkin slices appeared to remain constant after 400 min of drying at 50, 60 and 70°C, however, this value is still considered high. Hence, drying was continued until the 720 min was attained, which was done to ensure that the moisture contents would be close to the expected values. As indicated in the literature, dried fruit and vegetable products with moisture contents higher than 14% may experience growth of bacteria, yeasts and moulds, which can affect their shelf lives (Noor Aziah and Komathi, 2009).

Some previous researches relevant to fruit drying have also reported the same change of drying periods with warming-up period, falling rate periods and constant drying period; although the sample

Table 1. Mean values for moisture content, water activity and total carotenoid content of dried pumpkin powders prepared by hot air-drying at different temperatures

Temperature (°C)	MC_{db} of fresh pumpkin	MC_{db} of dried pumpkin powder	a_w of fresh pumpkin	a_w of dried pumpkin powder
50	82.10	10.21^a	0.98	0.65^a
60	82.58	7.46^b	0.95	0.42^b
70	84.09	5.47^c	0.97	0.30^c
			ns	

Data are expressed as mean values. Mean values with different superscripts in the same column differ significantly at $P \leq 0.05$. The symbol ns means that the mean values are not significantly different.

and drying conditions employed were different. Prachayawarakorn *et al*. (2008) observed two falling rate periods when drying banana slices in a tray dryer. In their work, the critical moisture content at which the drying rate changed from linear to non-linear was found at a moisture content around 80% dry basis. This showed a relatively high content compared with what has been observed in the present study (approximately 60% dry basis). The different values of the critical moisture content may be due to the differences on moisture gradients and surface moistures produced by different drying conditions (Prachayawarakorn *et al*., 2008).

Physico-chemical properties of dried pumpkin powders

Moisture content and water activity

Table 1 shows the initial moisture content, water activity of fresh pumpkin, final moisture content, and water activity of dried pumpkin powder. The differences between the initial and final moisture contents were about 70-78% as seen from the data. Also, the results for the moisture contents and water activities of pumpkin powders produced at different drying temperatures showed significant difference ($P \leq 0.05$). The average initial moisture content of fresh pumpkin was found to be about 82.10-84.09% (wet basis, wb) and the initial water activity about 0.95-0.98%. The dried pumpkin powder produced at 70°C showed the lowest moisture content and water activity level compared to those produced at drying temperatures of 50 and 60°C.

The result supports the notion that increasing the temperature of the drying process decrease the moisture content and water activity of the powder produced in this manner (Saeleaw and Gerhard, 2011). In particular, air-dried pumpkin powders produced at 60°C had moisture contents of about 8.77-9.46% wb (Noor Aziah and Komathi, 2009). The moisture contents and water activities of air-dried pumpkin powder produced in this study were lower than those of freeze-dried pumpkin puree powders, which were about 3.99% wb and 0.19, respectively (Dirim and Caliskan, 2012). In powders and flour, moisture contents higher than 14% will affect storage quality because mold growth, insect infestation, and agglomeration could occur in this condition (Noor Aziah and Komathi, 2009). Pumpkin industries such as that in Thailand are strict about this property and have established official quality and identity standards in the pumpkin powder production. In here, a moisture content of ≤7% and water activity of ≤0.6% for pumpkin powder products are required to maintain quality (TISI, 2014). In addition, pumpkin powders should be prepared at drying temperatures of 60 or 70°C to be considered within the acceptable limits of that standard.

Water plays a crucial role in food quality characteristics (Noor Aziah and Komathi, 2009) in relation to moisture content. The moisture levels of food products have a bearing on their dry matter content. Moisture content and water activity have a great effect on the food products in terms of storage stability, microbial stability, non-enzymatic browning, lipid oxidation, and enzymatic reactions during storage (Prachayawarakorn *et al*., 2008). The low moisture content and water activity levels of dried pumpkin powders produced at 60 and 70°C suggests a better keeping quality than those produced at 50°C. This is because most of the unfavorable changes in food during storage such as enzymatic reactions, non-enzymatic browning, lipid oxidation, and microbial growth are almost completely hindered when the water activity level drops below 0.4 (Noor Aziah and Komathi, 2009).

Color

The results of the color measurements were shown to be significantly different ($P \leq 0.05$) in lightness (L^*), chroma (c^*), and hue angle (h) values for dried pumpkin powders produced at 50, 60 and 70°C in this study. L^* values represent the degree of lightness, whereby chroma values indicate color intensity. The units are in the form of degrees° (or angles), ranging from 0° (red) through 90° (yellow), 180° (green), 270° (blue) and back to 0° (McGuire, 1992). In this study, light yellowness of dried pumpkin powder is shown by 90-100° hue angle values, while dark yellowness is represented by 70-80° hue angle values.

Furthermore, fresh pumpkin was found to be significantly different ($P \leq 0.05$) in L^* value about 99.63 when compared to dried pumpkin powder. The dried pumpkin powder produced at 50°C has the highest L^* value about 96.55, indicating that it has the lightest color when compare with the dried pumpkin powders produced at 60°C about 94.94 and at 70°C about 92.90. This indicates that increase in the darkening of the powder is affected by the increase in the drying temperature.

The degree of color saturation is denoted by the chroma value. In this study, it was found that the chroma values for fresh pumpkin and dried pumpkin powders were significantly different ($P \leq 0.05$), with fresh pumpkin being the most saturated in color with 54.66 in chroma value. On the other hand, there were no significant differences ($P \leq 0.05$) in the chroma values of dried pumpkin powders produced at different temperatures with 45.08 for 50°C, 45.27 for 60°C and 45.46 for 70°C.

Hue angle values were found to be significantly different ($P \leq 0.05$) for both fresh pumpkin and dried pumpkin powders. This was also seen for powders produced at the different drying temperatures. Results obtained for the measurement of yellowness represented by hue angle values indicated that the hue angle of fresh pumpkin was 103.61 which significantly higher ($P \leq 0.05$) than the dried pumpkin powders. The results also showed that the dried pumpkin powder produced at 70°C had the lowest hue angle value of 79.11, indicating the darkest yellow color, when compared with the dried pumpkin powders produced at 50 and 60°C with 99.08 and 95.54, respectively. When considering the color quality of the sample powder produced at three different drying temperatures, it was found that drying temperatures of 50 and 60°C led to lighter color retention than 70°C.

The color of food is an important quality parameter as it may indicate changes in food quality due to processing, storage, and other factors (Noor Aziah and Komathi, 2009). The yellowish color of pumpkin powders is because of the carotenoid pigments naturally found in these vegetables (Que *et al*., 2008). Drying conditions, including high temperature, light and oxygen exposure, can cause changes in food surface characteristics that lead to color changes, and may also cause carotenoid degradation (Workneh *et al*., 2012). Changes in carotenoids and other pigments which affect the attractive color and nutritive value of the final products can also be caused by heat and oxidation during drying (Que *et al*., 2008). Similarly, higher drying temperatures and longer drying times produce greater pigment losses (Fellows, 1988).

Pre-drying treatments, such as blanching and dipping in salt solution can be used to improve quality of the product by preserving color and flavor, extend shelf life and reduce drying time for dried pumpkin products (Workneh *et al*., 2012). The main purpose of blanching is to improve food quality by inactivating enzymes such as polyphenoloxidases, peroxidase, catalase and phenolase. Inactivating these enzymes can reduce deterioration such as undesirable changes in the color, flavor or texture of the product (Arévalo-Pinedo and Xidieh Murr, 2007). Brightness and yellowness values were found to be quite high for freeze-dried samples compared with hot-air-dried pumpkin powders. This indicates that freeze-drying reduced the discoloration and produced pumpkin powders of high-quality color (Que *et al*., 2008).

Total carotenoid content

The results for total carotenoid content of fresh pumpkin and dried pumpkin powders are shown in Table 2. Carotenoid content is an important parameter for the determination of the final quality of dehydrated pumpkin as it is a determining factor in both color and nutritional quality of the product (Dirim and Caliskan, 2012). In this present study, the total carotenoid content of dried pumpkin powder produced at 70°C (about 17.66 μg/g dry weight) was found to be significantly lower ($P \leq 0.05$) when compared to powders produced at 50 and 60°C (about 25.99 and 16.42 μg/g dry weight, respectively). Moreover, the dried pumpkin powder produced at 70°C showed the highest percentage of decrease in carotenoid content compared to those produced at drying temperatures of 50 and 60°C. The carotenoid degradation observed in this study was greater than the 26% at 60 and 70°C observed by Dirim and Caliskan (2007) in freeze-dried pumpkin puree powder.

Pumpkin is a green-yellow vegetable and its flesh is an excellent source of β-carotene, which

Table 2. Mean values for total carotenoid contents of fresh pumpkin and dried pumpkin powders prepared by hot-air drying at different temperatures and decreases in total carotenoid content

Temperature (°C)	Fresh pumpkin (µg/g dry weight)	Dried pumpkin powder (µg/g dried powder)	Decrease in total carotenoid content (%)
50	252.48^{a}	207.34^{a}	18
60	163.34^{b}	109.96^{b}	33
70	185.48^{c}	82.28^{c}	56

Data are expressed as mean values. Mean values with different superscripts in the same column differ significantly at $P \leq 0.05$.

the body converts into antioxidant vitamin A important for bodily functions (Turksoy and Özkaya, 2011). Decrease in total carotenoid content can be attributed to degradation of β-carotene as well as other carotenoids. Generally, this is due to auto-oxidation (Hymavathi and Khader, 2005). The highly unsaturated chemical structure of carotenoids makes them very sensitive to thermal degradation and oxidation (Chavasit *et al*., 2002). Carotenoids are stable under an inert atmosphere, however, they rapidly lose their activity when heated in the presence of oxygen, especially at higher temperatures (Lešková *et al*., 2006). Carotenoid degradation in freeze-dried fruits is considerably lower when compared with the losses caused by high-temperature drying methods due to the low temperatures and to the use of vacuum in the process (Dirim and Caliskan, 2012). Changes in carotenoid content in pumpkin powders were also observed in samples that have been packed in paper/foil/polythene pouches and stored at room temperature and at 37°C for 6 months without vacuum or nitrogen flushing. After 6 months, freeze-dried samples stored at 37°C showed higher rates of carotenoid degradation than those stored at room temperature (about 92 and 90%, respectively). However, hot-air-dried samples showed comparatively less carotenoid oxidation at 37°C (Kumar *et al*., 2007).

Powder properties of dried pumpkin powder

The effects of bulk density, water solubility, water adsorption, and oil adsorption capacities are shown in Table 3.

Bulk density

In powders, a number of key textural characteristics influence bulk density and ease of rehydration (Akubor and Ike, 2012). The bulk density provides an indication of the packing and arrangement of the particles, as well as the compaction profile of a material (Mirhosseini and Amid, 2013). The different drying temperatures used in this study (50, 60 and 70°C) significantly ($P > 0.05$) affected the bulk densities of the dried pumpkin powders, as shown in Table 3. The bulk densities of the dried pumpkin powders ranged from 0.62-0.91 g/mL, depending on the drying temperature. In particular, dried pumpkin powders produced at higher temperatures exhibited slightly higher bulk densities than those produced at lower temperatures. Previous studies reported variations showing bulk densities of about 0.11 g/ml for freeze dried pumpkin puree powder (Dirim and Caliskan, 2012), 0.33 g/ml for freeze dried pumpkin powder (Que *et al*., 2008), and 0.402g/ml for kiwi fruit puree powder (Benlloch-Tinoco *et al*., 2012).

Water solubility

Table 3 reveals that rates of increase in drying temperatures are accompanied by decrease in the water solubility of pumpkin powders (about 55% at 50°C, 50% at 60°C and 43% at 70°C). Water solubility values of about 34.90% have been reported for pumpkin flours prepared by hot-air drying at 70°C, which were higher than those obtained by freeze drying at -50°C (30.71%) (Que *et al*., 2008).

Water adsorption capacity

As shown in Table 3, the water adsorption values for dried pumpkin powders produced at 50 and 60°C (3.50 g/g and 3.00 g/g, respectively) were higher than that for dried pumpkin power produced at 70°C (2.33 g/g). It was observed that the trend of reduction of water adsorption paralleled that of the increase in drying temperatures. As seen in previous studies, pumpkin flours prepared by hot-air drying at 70°C and freeze drying at -50°C showed water adsorption values of about 2.74 and 2.60 g water/g in dry pumpkin flour, respectively (Que *et al*., 2008). The same value for coarse powder dried at 70°C in

Table 3.Bulk density, water solubility, and water and oil adsorption capacities of dried pumpkin powders prepared by hot air-drying at different temperature

Temperature (°C)	Bulk density (g/mL)	Water solubility (%)	Water adsorption (g water / g dry sample)	Oil adsorption capacity (g oil /g dry sample)
50	0.62[c]	54[a]	3.50[a]	4.42[a]
60	0.86[b]	50[b]	3.00[b]	3.97[b]
70	0.91[a]	43[c]	2.33[c]	3.87[b]

Data are expressed as mean values. Mean values with different superscripts in the same column differ significantly at $P \leq 0.05$.

hot-air-drying oven at about 3.07 g water/g was seen in dry coarse powder (Zhang *et al*., 2009).

Oil adsorption capacity

The oil absorption capacities of dried pumpkin powders are reduced as drying temperatures increase as shown in Table 3. The oil adsorption capacities of the dried pumpkin powders were found to be 4.42 g/g at 50°C, 3.97 g/g at 60°C, and 3.87 g/g at 70°C. These values were higher than the 2.38 g oil/g sample dry previously reported for freeze-dried pumpkin flour and 1.08 g oil/g sample flour for hot-air-dried pumpkin flour (Que *et al*., 2008).

Powder properties such as bulk density, water solubility, water holding capacity, oil absorption capacity, oil holding capacity, dispersibility, wettability, and sinkability affect the functional properties of the powder and are critical parameters for controlling quality (Mirhosseini and Amid, 2013). Fruit and vegetable powders, which have high water absorption and oil adsorption capacities, can impart water-retention and fat-binding properties which are essential in bakery products and other select food applications (Traynham *et al*., 2007). Pumpkin powders have been observed to have high water and oil holding capacities, which could be an alternative emulsifying agent to be used in food formulations (Noor Aziah and Komathi, 2009). Accordingly, pumpkin powders with high water solubilities (at least 50%) are preferable (Noor Aziah and Komathi, 2009).

The results of this study show that increased drying temperatures are accompanied by decrease in the water solubility, water adsorption capacity, and oil adsorption capacity of pumpkin powders. Dried pumpkin powders produced at 50 and 60°C showed water solubilities of more than 50% and high water and oil adsorption capacities. According to these results, dried pumpkin powders produced at drying temperatures of 50 and 60°C may have more potential for baking purposes than those produced at a drying temperature of 70°C.

Bulk density is an important consideration in producing pumpkin powder as seen in various literature. This property is an indication of the porosity of a product and can be used in determining the required type of packaging material. Flours with low bulk densities require less dense packing materials (Akubor and Ike, 2012). The development of porosity and bulk density in foods, in general, depends on the initial moisture content, the composition, and the size (thickness and diameter) of the material. It is also affected by the type of drying (for example, air-drying versus freeze-drying) and the drying conditions (that is, temperature, air velocity and air humidity), particularly in air-drying (Marousis and Saravacos, 1990). The highly porous structure of dried foods is caused by the removal of water vapor from the product, while transport of liquid water causes shrinkage during air-drying (Diosady *et al*., 1985). In relation, increase in the porosity and bulk density of fruits and vegetables during drying follows a characteristic function for each food material as seen in another study (Marousis and Saravacos, 1990). Freeze drying and spray drying also decreased bulk density. In previous work on durian seed gum, among all drying techniques (freeze drying, oven drying, spray drying and vacuum oven drying), freeze-drying caused the highest reduction in bulk density (Mirhosseini and Amid, 2013).

Many factors affect the water solubility of powdered products, including processing conditions, composition, particle size, density, pH and storage conditions (Mirhosseini and Amid, 2013). It has been found that increase in drying temperature are accompanied by increased protein denaturation, which decreases the water solubility of the powder (Fellows, 1988). It has also been found that hot-air drying reduced the oil and water absorption capacities and porosities of pumpkin powders, while it markedly increased their water solubility and bulk density (Que *et al.*, 2008). Higher water solubility was observed in hot-air-dried pumpkin powder when compared with freeze-dried, indicating that more starch had been decomposed during hot-air drying. This is due to the fact that water solubility reflects the extent of starch degradation in powders (Diosady *et al.*, 1985). A comparative study of pumpkin powder preparation methods found that there was no difference in water absorption and true density between powders prepared by freeze drying and hot-air drying. However, higher bulk density and lower porosity were obtained in pumpkin flours prepared by hot-air drying. Moreover, pumpkin powders prepared by freeze drying had a higher oil absorption capacity than flours prepared by hot air-drying (Que *et al.*, 2008). A higher water solubility was observed in hot-air-dried pumpkin flours when compared with freeze-dried flours (Que *et al*., 2008)., indicating that more starch are decomposed during hot air-drying (Diosady *et al*., 1985).

Characteristic of the moisture sorption isotherm of dried pumpkin powders

Figure 2 illustrates the experimental data obtained for sorption of dried pumpkin powder at 20°C, which was validated from 0.12 to 0.93 water activity. The dried pumpkin powder at 70°C showed the lowest equilibrium moisture content (MC_e) compared to the drying temperature at 50 and 60°C. As seen in the study, the MC_e of the dried pumpkin powder at 50, 60 and 70°C increased as the water activity increased at constant temperature. The isotherms seen from the data exhibited S-shapes described as type II in the isotherms classification (AL-Muhtaseb *et al.*, 2001; Brunauer *et al.*, 1940).

Similarly, the shape of sorption isotherms was in accordance with the work of dried banana in hot air oven at 35 and 45°C (Yan *et al.*, 2008) and dried ginger in an air convection electric oven at 85°C (Alakali and Satimehin, 2009). This S-shape type isotherm is common for many foods having rich soluble components (Lahsasni *et al*., 2004), which is probably due to the higher carbohydrate content seen in them (Bolin, 1980). This shape of the isotherm was also seen in dried pumpkin powder because of their high carbohydrate content, especially when the composition of the edible portion of buttercup pumpkin with 62-68% carbohydrate (52-53% starch and 10-15% sugar) and 5-8% protein (measured on a dry basis) are taken into account (Loy, 2014).

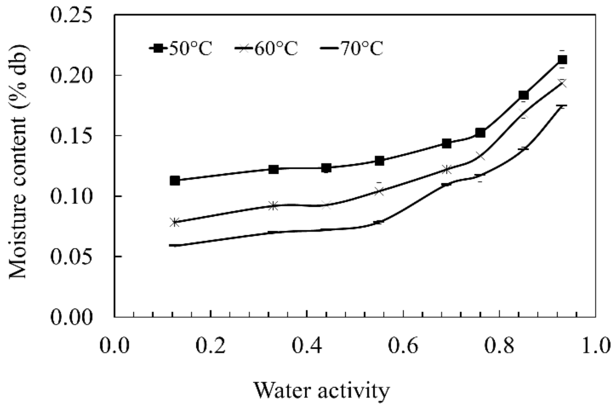

Figure 2. Moisture sorption isotherms of dried pumpkin powder at drying temperatures of 50, 60 and 70°C. Error bars represent standard deviation (SD)

Conclusion

The present work describes the possibility of producing pumpkin powders by hot-air drying. Water removal through drying of the pumpkin slices occured during the falling-rate periods. The effective transport of moisture during drying was seen to increase with the increase in temperature. The effect of hot-air drying temperature on the physico-chemical and powder properties of pumpkin powders was also investigated. Hot air-drying at 60°C was adequately effective in preserving color and total carotenoid content in pumpkin powder. On the other hand, the moisture content and water activity values were within acceptable limits for the safe storage of products. Moreover, dried pumpkin powder produced at 60°C had water solubility of more than 50% and high water adsorption and oil adsorption capacities, were seen to have a higher potential for use in baking. Hot-air drying can be suitably applied to the drying of pumpkin to obtain powders that can be used as an ingredient for the purposes of flavoring and improving nutritional values. Lastly, the shape of the sorption isotherms of pumpkin powders was found to be Type II (slight sigmoidal shape) at 20°C.

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