OPINION PAPER

COLOR CHANGE KINETICS AND TOTAL CAROTENOID CONTENT OF PUMPKIN AS AFFECTED BY DRYING TEMPERATURE

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ABSTRACT

The color changes kinetics of pumpkin slices during convective hot air drying was investigated at drying temperatures of 50, 60, 70 and 80°C. The hunter lab L* a* and b* color coordinates were used as assessment indicators. The total color change ΔE, Chroma value, hue angle and brownness index (BI) of the pumpkin slices where also determined. To determine the most suitable kinetics model for the prediction of the color changes of pumpkin, the zero-order, first-order, and fractional conversion models were fitted to the experimental data, using linear regression analysis. The activation energy of the color change parameters (L*, a*, b* and ΔE) was estimated and found to be 41.59, 16.287 63.856 and 73.390 kJ/mol respectively. The fresh pumpkin samples contained a mean total carotenoid content of 25 μ-g/g, while the total carotenoid content of samples dried at 50, 60, 70 and 80°C were 146, 56.4, 37.9 and 102.5 μ-g/g, respectively. Further, the results of ANOVA showed there was significant difference between the total carotenoid content of the fresh pumpkin samples and those dried by convective hot air dryer at 5% ($p<0.05$) significant level.

Keywords: thin layer drying, color kinetics, color measurement, carotenoid, pumpkin

1. INTRODUCTION

Pumpkins are very good sources of carotenoid which are used either in small or large quantities for industrial utilization such as the production of food products, supplements, pharmaceutical, health care and cosmetic products (SEO *et al*., 2005; LEE and LIM, 2011; DURANTE *et al*., 2014). However, carotenoid content in pumpkins are highly degradable and must be preserved properly in order to increase shelf life and enhance their availability. Drying is one of the oldest methods of agricultural and food preservation (ALONGE and ONWUDE, 2013). It is also an operation unit in food processing that can result in longer shelf life, high retention of nutritional properties and a reduction in the bulk of products, thereby reducing the storage space required. Convective hot air drying is the most common method of industrial drying. This drying process has been reported to be largely influenced by factors such as drying temperature, material thickness, drying air velocity and relative humidity (KROKIDA *et al*., 2003; MISHA *et al*., 2013). These factors could adversely affect important product properties, such as moisture content, texture, color and total carotenoid content. The color properties and the total carotenoid content have been reported to be the most affected properties during drying of highly perishable fruits as a result of high processing temperature and longer drying time (KOCA *et al*., 2007; DEMIRHAN and ÖZBEK, 2009).

During drying, color changes occur due to the degradation of carotenoid and non-enzymatic reactions. Carotenoids constitute a large group of over 650 structures, which are responsible for most red, orange and yellow coloring in fruits. They are organic pigments and bioactive compounds synthesized from plants, fruits, vegetables and other photosynthetic plants (CRUPI *et al*., 2012). They are richly colored molecules and serve as a major source of vitamin A and its precursors, which include: α-carotene, β-carotene, lycopene and lutein (SEO *et al*., 2005; DURANTE *et al*., 2014). According to JOHNSON (2002), carotenoids are thought to be very beneficial due to their role as antioxidants. However, they have other health benefits such as anti-cancer, enhancement of human response and reduction in the risk of degenerative cardiovascular diseases (MOLDOVAN and RABA, 2010; DJUIKWO *et al*., 2011; NORSHAZILA *et al*., 2012). Carotenoids undergo degradation during drying due to factors such as a long processing time, high processing temperature and seasonal variations (AKANBI and OLUDEMI 2004; NOR, 2013). Degradation of carotenoids not only affects the attractive color of foods but also their nutritive value and flavor (PESEK and WARTHESEN, 1990). Thus, engineering processes that will optimize carotenoid retention become very essential.

Most often the optical (color) parameters used in the classification of fruits and vegetables are the linear color parameters, RGB (red, green and blue) and the nonlinear color parameters of HSI (hue, saturation and intensity) and L*a*b* (lightness, redness and yellowness) (HASHIM *et al*., 2012). RGB is difficult to measure due to the non-uniform scaling (CHENG *et al*., 2001). Thus, it is necessary to overcome this problem by modelling the color change kinetics using the L*a*b* color measurement parameters.

Regardless of the drying method, the optical properties and total carotenoid content (TCC) of most fruits decreases with longer drying time and higher drying temperature (NAWIRSKA, *et al*., 2009). Reducing drying time and temperature, and the time lag between material preparation and processing improve color quality and TCC retention significantly (RODRIGUEZ-AMAYA, 2003). High processing temperature and short time drying have also been reported to be a good alternative (RODRIGUEZ-AMAYA 2002, 2003). Modelling this processes can help in selecting the appropriate or optimum drying conditions, so that the drying process of pumpkin can be optimized as a means to maintain the product's optical properties, reducing carotenoid losses and improving product quality. Thus, color kinetic modelling approach such as the reaction order, rate constant and activation energy are indispensable in predicting the quality of foods with regards to color changes due to the degradation of carotenoid. Its application is therefore essential for a wide range of technologies, including online monitoring of the drying process of fruits and vegetables (NADIAN *et al.*, 2015).

Few studies on the color kinetics of food materials have been reported in the scientific literature. GAMLI (2011) studied the color changes of tomato puree and the kinetic modelling of the color changes of some fruits, such as kiwifruits (MOHAMMADI *et al.*, 2008), apple, banana and carrots (KROKIDA *et al.*, 2007) have also been investigated. More so, studies on the effect of process storage conditions and packaging on the color properties and carotenoid compositions of some fruits have been reported (BECHOFF *et al.*, 2011; GUINÉ *et al.*, 2011; BECHOFF *et al.*, 2015). However, no study has been reported on the color change kinetics and total carotenoid content of pumpkin during convective drying process, with particular emphasis on the selection of a suitable kinetic model in predicting the color stability and optimum drying conditions. Therefore, the objective of this study is to investigate the color change kinetics and the enhancement of the optical properties of pumpkin slices, under different drying conditions during the forced air conventional drying.

2. MATERIALS AND METHODS

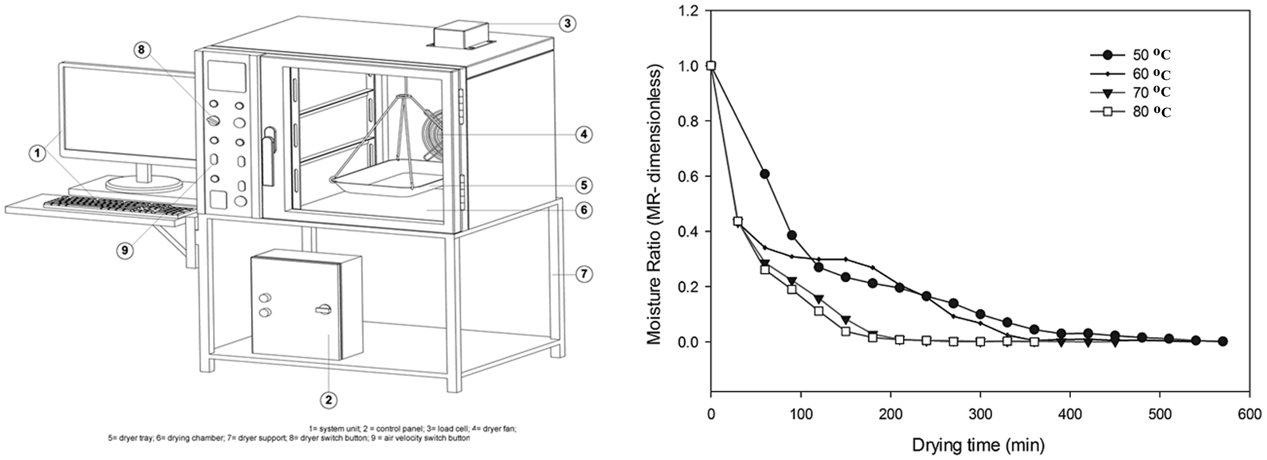
2.1. Materials

Freshly harvested pumpkin fruits of the *Cucurbita moschata* variety were purchased locally in Malaysia. The samples were stored at 11°C before the drying experiments, in order to slow down respiration, physiological and chemical changes. The homogenous samples were sorted visually for color (maturity) and size with no evidence of physical damage. Before each drying experiment, the selected samples were hand peeled, washed in running water and the pulp was sliced into 5 mm thickness using the Nemco slicer (55200AN, USA). A total of 40 samples with three replications each were used to perform the experiments.

2.2. Drying experiments

Pumpkin samples were dried using an automated convective hot air dryer (Fig. 1a) designed and developed by the Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra, Malaysia. The dryer used was a NFC-3D Series Electric Convection Dryer at a voltage of 380/220 V, a power of 4.5 kW and a frequency of 50 Hz. Details of the dryer can be found in the work of ONWUDE *et al.* (2016). During the drying experiments, the actual velocity was measured from the center of the drying chamber using a vane anemometer (Extech, 451104) with an accuracy of ± 0.030 m/s.

The drying was conducted at temperatures of 50, 60, 70 and 80°C, respectively. The relative humidity ranged from 40 to 50% throughout the experiments and the drying air velocity was constant at 1.2 m/s. During each drying experiments, the sample weight was recorded after every 1 hour periodically. Each drying experiment was allowed to run until there was no further change in the masses of two consecutive measurements. A total of 12 experimental runs were carried out with three replications and the average values were used to estimate the loss in moisture during drying, expressed in the form of dimensionless moisture ratio. The initial moisture content analysis was performed using the oven dry method at 103 ± 2°C (ASAE, 2005). Triplicate samples were analyzed and the average moisture content was found to be 5.63 dry basis (d.b.).



(a) schematics diagram of a convective hot air dryer

(b) Effect of drying temperature on moisture ratio

Figure 1. Schematic diagram of the convective hot air oven and effect of temperature on moisture ration of pumpkin.

The experimental data obtained for different temperatures was further expressed in the form of the moisture ratio (MR) versus time as given in the equation (2) below:

$$\mathrm{MR}=\frac{M_t-M_e}{M_o-M_e} \qquad (1)$$

M_t is the moisture content at any time t, Mo is the initial moisture content of the pumpkin sample and M_e is the equilibrium moisture content.

2.3. Color measurement

Each pumpkin sample was measured before and during drying at 1-hour time intervals until equilibrium moisture content was obtained using a Chroma Meter colorimeter (CR-10, Konica Minolta Sensing Americas, Inc.). The colorimeter was calibrated against a standard black and white plate in order to accurately determine the color parameters of the Hunter L* a* b* values. For each of the samples and replicates, at least four measurements were performed at different sample positions and the average value was estimated. The measurements were represented by the L* a* b* color parameters which were used to describe the kinetics of the color changes of the convective hot air drying of the pumpkin. The L* represents the degree of brightness or lightness with a range from 0 (black) to 100 (white). The a* shows the degree of redness with color values ranging from – 60 (green) to + 60 (red), and the b* shows the degree of yellowness when positive, and blueness when negative with a range from – 60 (blue) to + 60 (yellow).

2.4. Estimation of color change kinetics

Being difficult to develop an adequate kinetic model for color change during drying, there is a need to combine more than one kinetic model.

Generally, the kinetics of the color change of most foods have been estimated by the zero, first order kinetic and fractional conversion models given as follows (XIAO *et al.*, 2014; NIAMNUY *et al.*, 2008; DADALı *et al.*, 2007; KROKIDA *et al.*, 2007):

$$\frac{dC}{dt} = -k(C)^n \quad (2)$$

where k is the rate constant, C is the value of the three color parameters varying with time (t), n is the order of the reaction and $\frac{dC}{dt}$ is the rate of change of C with time (HASHIM *et al.*, 2012).
For zero-order reactions, the three color parameters C, are not dependent on the rate of reaction as shown below:

$$-\frac{dC}{dt} = k \quad (3)$$

Integrating Eq. 3 results in:

$$C = C_0 - kt \quad (4)$$

Eq. 4 is known as the zero-order reaction rate model. In terms of color kinetics, the solution of first order reaction rate (Eq. 2), which is also dependent on the color parameter, can be expressed as:
Integrating Eq. 2 gives:

$$C = C_0 e^{-kt} \quad (5)$$

Now, the first-order kinetic model (Eq. 5) can further be represented by fractional conversion, taking into account the final color value. Thus, according to XIAO *et al.* (2014), the color parameter can be expressed as a fractional ratio as shown below:

$$\frac{C - C_f}{C_0 - C_f} = e^{-kt} \quad (6)$$

Where C_0 is the sample color value at time zero and C_f is the final color value of the sample.
Furthermore, the rate constant is temperature dependent and follows an Arrhenius relationship (LAU *et al.*, 2000). Thus, the relationship between the rate constant of the total color change, the L*, a* and b* color parameters of the pumpkin and the drying temperatures were determined as follows:

$$K = K_0 \exp\left[-\frac{E_a}{R}\left(\frac{1}{T+273.15} - \frac{1}{T_{ref} + 273.15}\right)\right] \quad (7)$$

E_a is the activation energy in kJ/mol, R is the universal gas constant (R = 8.31451 x 10^{-3} kJmol−1 k−1), K_0 is the pre-exponential factor, T_{ref} is the reference temperature, which is the median of the drying temperatures (65°C) and T is the air temperature expressed in °C.

The Total color change (ΔE or TCD) of the pumpkin samples was calculated using following equation:

$$\Delta E = [(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2]^{1/2} \qquad (8)$$

The polar coordinate Chroma, which is an indication of how dull/vivid the product is (ranging from 0 to 60), was estimated from the a* and b* Cartesian co-ordinates as follows:

$$\text{Chroma} = \left(a^{*2} + b^{*2}\right)^{1/2} \qquad (9)$$

Another measure is the degree to which the appearance color of fruits and vegetables can be said to be similar to or different from the primary colors of red, green, blue, and yellow. An angle of 0° or 360° represents red hue, while angles of ≤ 90° indicates yellow, angle of ≤180° and ≤270° signifies green and blue hues, respectively. This parameter has been widely used in the determination of the color parameters in fruits and vegetables (PATHARE *et al.*, 2012) and is expressed as:

$$\text{Hue Angle} = \tan^{-1}(b^*/a^*) \qquad (10)$$

where L^* is the degree of lightness, L_0^* is the initial value of L^*, a^* is the degree of redness, a_0^* is the initial value of a^* while b^* signifies the degree of yellowness and b_0^* is the initial value of b^*.

The Browning index, which is defined as brown color purity (MOHAMMADI *et al.*, 2008; DADALI *et al.*, 2007) is associated with the browning of fruits during drying. This was estimated as:

$$BI = \frac{[10(x - 0.31) * 10^3]}{17} \qquad (11)$$

where

$$x = \frac{(a + 1.75L)}{(5.645L + a - 3.012b)} \qquad (12)$$

The order of reaction for the color parameters during convective hot air drying of the pumpkin was determined by using linear regression analysis on Eq. 4, Eq. 5 and Eq. 6. In each case, the best fit was selected and the kinetic rate constant for each processes was determined.

2.5. Extraction and separation

A method described by RAVELO-PEREZ *et al.* (2008) and RODRIGUEZ (2001) with some modifications was employed to extract the carotenoid content from pumpkin samples. Approximately 5 g of fresh and dry samples (for each drying temperature) were ground and weighed on a digital weigh balance (A and D GF-10k, USA) and transferred into a beaker. 20 mL of 0.05% (w/v) BHT in hexane, 20 mL of acetone and 10 mL of ethanol in the ratio of 2:2:1 (v/v/v) were added, stirred and filtered. The process was continued with the residue until it became colorless in order to obtain optimum extract. The crude extract was evaporated in a rotary evaporator (Eyela OSB – 2100, Japan) attached to a vacuum pump at a temperature of 35°C, using glass pearl for optimization of the recovery in the re-dissolving process (RODRIGUEZ-AMAYA, 2001; NORSHAZILA *et al.*, 2012). The process was performed under subdued light and analyzed within one day in order to minimize degradation of carotenoids.

2.6. Spectrophotometry analyses

The total amount of carotenoid was determined using a UV-spectrophotometer (1800 series, Shimadzu, Japan). Preliminary analysis of lutein and β-, α- carotenes in pumpkin samples tested resulted in absorbance peak values within the range of 431-475 nm (visible region spectrum), which is in agreement with the absorbance peak values reported by SCOTT (2001). However, the absorbance values used in determining the total carotenoid content were those read at 450 nm (absorbance peak for pumpkin's lutein and β-, α-carotene in hexane and ethanol solvent). All analyses were performed in triplicate.

The total carotenoid content (TCC) was calculated from modified Lambert-Beer law using the formula reported by DE CARVALHO *et al.* (2012) as follows:

$$\text{Total Carotenoid content } (\mu g/g) = \frac{A\ x\ V(ml)\ x\ 10^4}{A_{1cm}^{1\%}\ x\ w(g)} \qquad (13)$$

where A = absorbance; V = total extract volume; w = sample weight; $A_{1cm}^{1\%}$= 2500 (it represents the carotenoid extinction coefficient for hexane on pumpkin samples where majority of the carotenes are dominant) (RODRIGUEZ-AMAYA, 2001; SCOTT, 2001).

2.7. Statistical analysis

Experimental data for the different color parameters were fitted to the zero, first order and fractional conversion kinetic models and processed using SIGMA plot 12.0 software (Systat Software Inc., California, USA). The coefficient of determination (R^2) and the sum of square error (SSE), were used to evaluate the goodness of fit of the best drying conditions for the color parameters. For the total carotenoid content, all data were recorded as the mean ± standard deviation of triplicate determination. One way analysis of variance (ANOVA) was also used to compare means of TCC and absorbance of pumpkin samples at different drying temperatures (5% significant level). Post-hoc Tukey's tests were used as the indicators for means comparison. The Kolmogorov–Smirnov test was used to access the normality of the data.

3. RESULTS AND DISCUSSIONS

3.1. Color changes

The effect of drying temperatures and drying time on the moisture content of pumpkin (*Cucurbita moschata*) is shown in Fig. 1b. An increase in temperature resulted in a decrease in the drying time and a corresponding decrease in the moisture content of pumpkin, which is expressed in the form of a dimensionless moisture ratio. In particular, a safe moisture ratio under 0.05 was reached after 480 min at drying temperature of 50°C, 420 min at temperature of 60°C and 70°C and 300 min at drying temperature of 80°C. Consequently, a decrease in the drying time of about 38% was observed as the temperature increased from 50°C to 80°C.

Figure 2 shows that temperature and time have a significant effect on the color properties of pumpkin during convective hot air drying. The L*, a*, b* and total color change (ΔE) values obtained during the drying experiments are presented in Fig. 2a-d. The L* value of the pumpkin slices decreased with an increase in drying time. Also, the L* value of pumpkin dried at a higher temperature (80°C) declined rapidly with an increase in the drying time. Furthermore, it can be seen that the L* value decreased from with increasing drying temperature. This decrease in the L* value is in line with the decrease in the moisture content at higher temperatures (BAL *et al.*, 2011; DEMIRHAN and ÖZBEK, 2011; DEMIRHAN and ÖZBEK, 2009; AVILA *et al.*, 1999). In addition, towards the end of the drying process the change rate of L* became slower similarly to the rate of moisture loss from pumpkin (Fig. 1b) (HASHIM *et al.*, 2014; DOYMAZ, 2007). Thus, it can be seen that the moisture loss is also a factor that affect the changes in the brightness of pumpkin slices during drying.

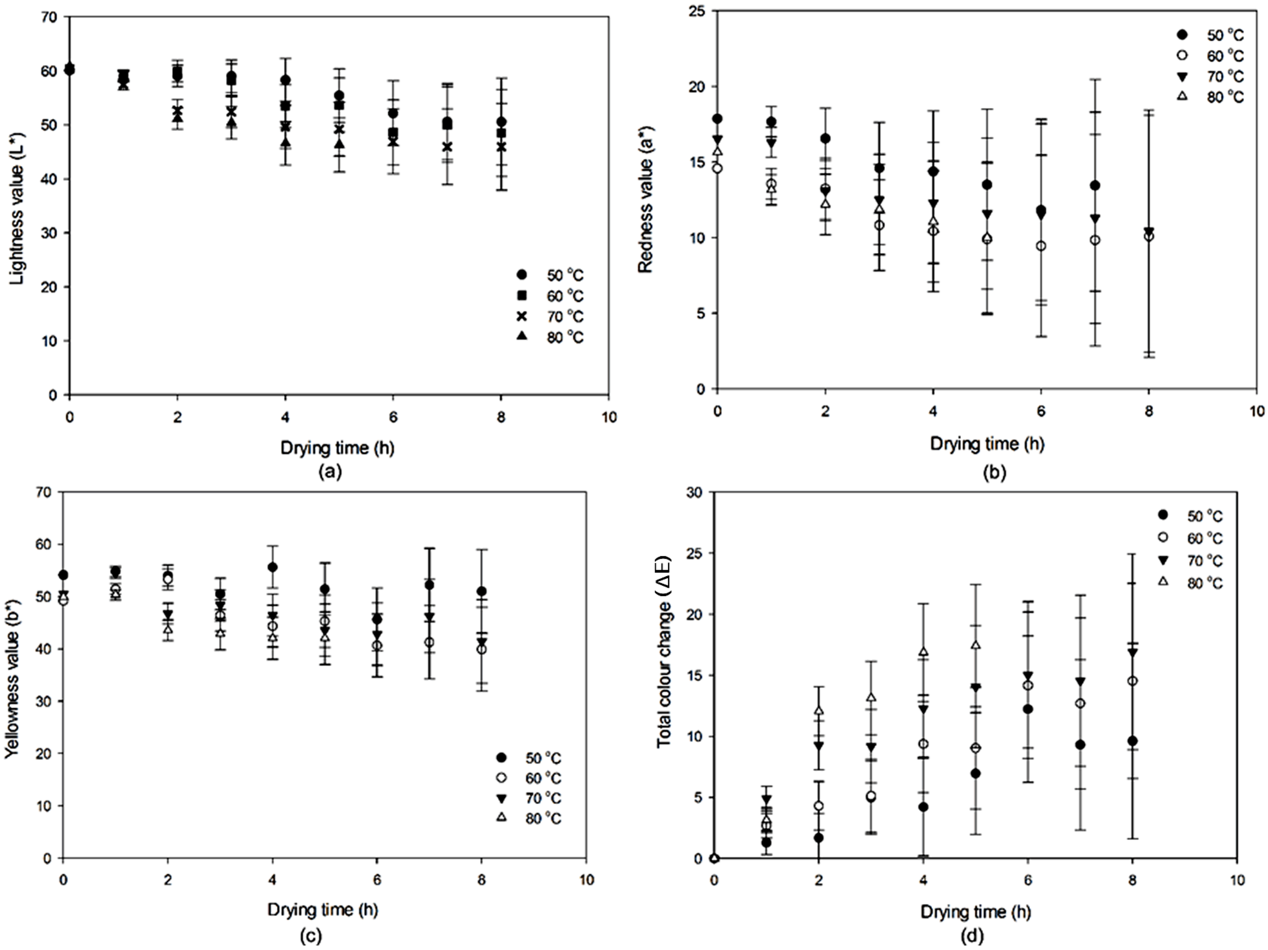


Figure 2. Pumpkin color degradation (L* a* b* and ΔE parameters) during convective hot air drying (bars represent standard error of the mean).

The variation of the redness values during drying is shown in Fig. 2b. From the figure, a decrease in the redness value with increase in drying time can be observed. Also, the final a* value decreased with an increase in the drying temperature. However, the standard deviation of the a* values of pumpkin increases as the drying time increases at temperatures (50, 60, and 70°C). This could be due to the prolong exposure to heat. Thus, there is no justification in prolonging drying of pumpkin, as this would adversely affect the a* value of pumpkin. However, at higher drying temperatures (70 to 80°C), there was a decrease in the a* value. This behavior can be attributed to the heat and mass transfer from within the pumpkin slices to the surface, which is faster at higher temperatures during drying. Furthermore, the decrease of the a* value during drying could be due to the autoxidation of carotenoids which gradually caused the redness color of the pumpkin to deteriorate at much higher temperatures and longer drying times. For this study, there was no significant difference in the a* value of pumpkin slices under all drying conditions. Similar results, on the reduction of a* during drying have been reported by VEGA-GÁLVEZ *et al*. (2008) concerning the convective dehydration of red bell pepper and KOCA *et al*. (2007) on the dehydrated carrots.

Fig. 2c shows a decrease in the b* value with an increase in both temperature and time. The final reduction in the b* value varied from 51.00 at 50°C to 42.02 at 80°C. The loss in b* value indicates that the yellowness of pumpkin under convective hot air drying decreased with a corresponding increase in the drying temperature and time. According to PRAKASH *et al*. (2004), the high rate of β-carotene loss during the solar cabinet drying of carrot was caused by longer drying times and exposure to light, which leads to light induced oxidation of the β-carotene. In addition, reduction in β-carotene during drying at high temperatures has been attributed to the oxidation of its highly unsaturated chemical structure (OLIVEIRA *et al*., 2015). Thus, the reduction in the b* value of pumpkin slices in a convective hot air dryer was due to the oxidation of the dominant carotenes (β-carotene and lutein). Furthermore, the partial formation of brown pigments (quinones and melanins) could also be responsible for the reduction of b* at higher temperatures. Overall, the total color change (ΔE) of the pumpkin slices increased significantly with increase in the drying temperature and time during convective hot air drying, with a value ranging from 10.6 to 17.46 at a temperature range of 50°C to 80°C as shown in Fig. 2d.

Generally, slight differences in the color parameters were observed at time 0. This was as a result of samples variability used during the drying experiments. The decrease in L*, a* and b* values and the corresponding increase in ΔE values during the convective hot air drying of pumpkin could be attributed to the changes that occurs as a result of the oxidation of β-carotene, when drying at higher temperature and longer time. However, at temperature of 80°C, there was gradual stability in the reduction rate, due to shorter drying time.

Chroma, hue angle and browning index are also very important color parameters. These parameters were estimated from the experimental data by using Eq. (9) to Eq. (12) and the results are shown in Fig. 3a-c. The Chroma value decreased with a corresponding increase in temperature and drying time (Fig. 3a). The final Chroma value varied from 52.74 at 50°C to 43.19 at 80°C. The high Chroma value signifies that the dominant pumpkin colors of yellow and red are pure and intense. Conversely, the Hue angle increased with an increase in drying time (Fig. 3b). However, as the drying temperature was raised from 50 to 60°C, the Hue angle increased rapidly and began to stabilize at 77° after 4 to 5 hours. A further increase in the drying temperature showed a slight increase in the Hue angle and stabilized at 75° before further decrease as the drying continued. Generally, the results indicated a good hue angle as the hue angle for the pumpkin at different drying conditions ranged between 71° to 78° (< 90° for the yellow-orange-red HSB/HSL color). Fig. 3c shows the effect of temperature on the browning of pumpkin under convective hot air drying. The BI which was estimated from Eq. (11) and Eq. (12) and fitted to the experimental data, increased slightly with an increase in drying time. Similar results have been reported during the drying of coconut slices (YUN *et al*., 2015). Generally, in order to minimize the oxidation of carotenoid during drying, it is not recommended to dry at a temperature above 80°C.

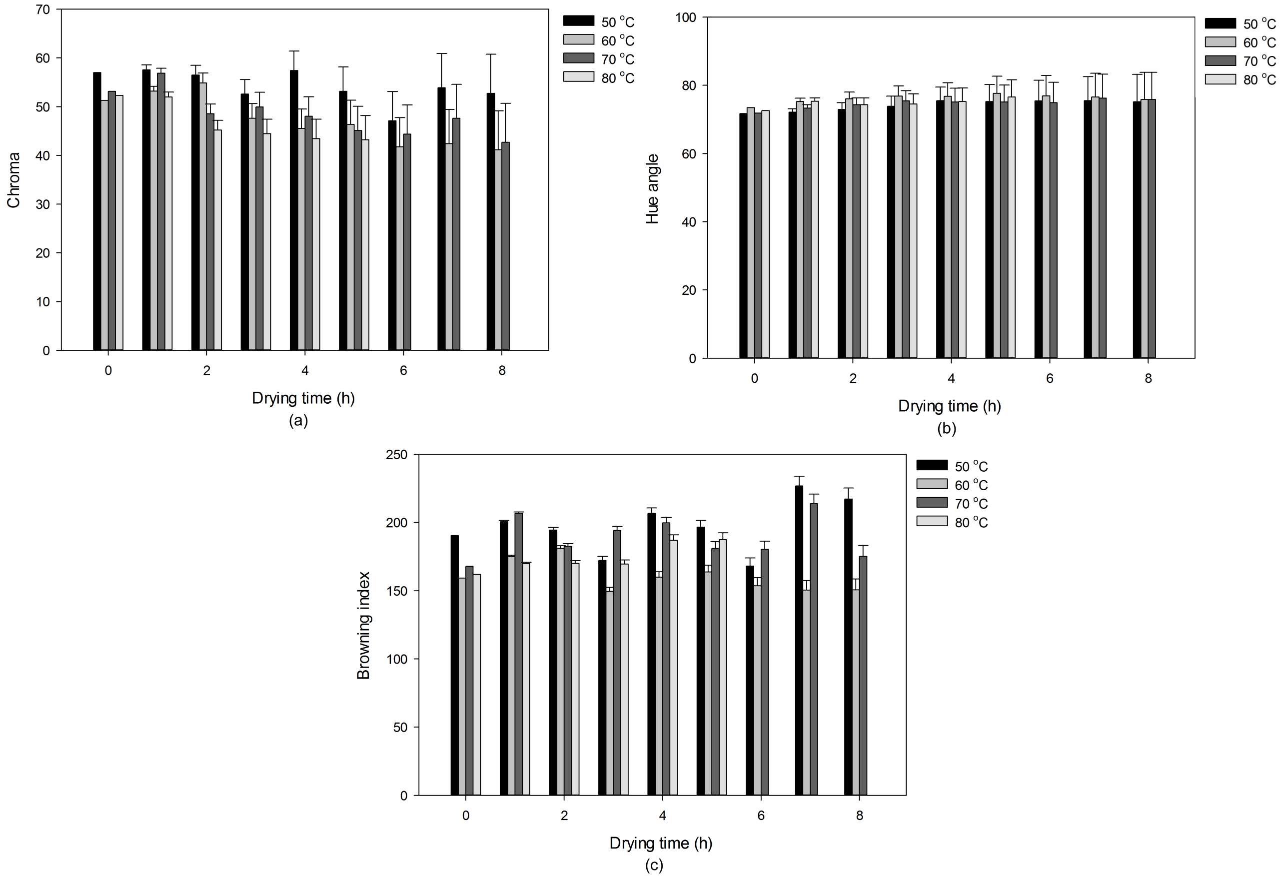


Figure 3. Effect of drying temperature on the (a) Chroma, (b) hue angle, and (c) browning index of pumpkin slices (bars represent standard error of the mean).

3.2. Kinetic modelling

Kinetic modelling of the color changes of pumpkin slices during convective hot air drying was investigated using the zero-order, first-order and fractional conversion (Eq. 4 to Eq. 8) kinetic models respectively. These models were fitted to the experimental data of the color parameters, and the most suitable kinetic constant and model were selected based on the highest coefficient of determination (R^2) and least sum of square error (SSE) of linear regression analysis.

Tables 1 and 2 show the results of the kinetic modelling of the color change of pumpkin slices. From the results, the most suitable model for the color parameters (L*, a*, b*, ΔE, Chroma and Hue angle) was generally the fractional conversion model, even though the first order model gave the best correlation at a temperature of 80°C for a* and b*, respectively. The zero order kinetic model was not found to be suitable for the prediction of pumpkin color changes during convective hot air drying, this model gave the lowest R^2 statistical values for all but one of the color parameters (BI at 80°C) and temperature conditions.

Table 1. Estimated regression results of zero-order, first-order and fractional conversion models for L*, a*, b*, and ΔE at various drying temperatures.

		Zero-order model			First-order model			Fractional conversion model		
Temp. (°C)	Parameter	K	R^2	SSE	K	R^2	SSE	K	R^2	SSE
50	L*	0.954	0.876	1.133	0.0166	0.864	1.181	0.0013	0.971	0.0731
	a*	0.826	0.871	0.781	0.0536	0.883	0.741	0.0662	0.909	0.160
	b*	0.524	0.288	2.561	0.0100	0.288	2.560	7.1E-9	0.237	4.934
	ΔE	-1.404	0.8517	1.6294	0.1476	0.571	7.2762	0.0320	0.8777	0.1645
60	L*	1.3322	0.8843	1.4392	0.0237	0.8803	1.4642	0.0138	0.9460	0.1028
	a*	0.7592	0.7492	0.9625	0.0645	0.8265	0.8005	0.0891	0.9581	0.0935
	b*	1.0707	0.6884	2.6741	0.0232	0.6762	2.7261	0.0044	0.8156	0.2365
	ΔE	-1.958	0.9435	1.2458	0.1979	0.6157	9.9669	0.0960	0.9457	0.0898
70	L*	1.9717	0.7752	2.1610	0.0374	0.8234	1.9155	0.3076	0.9826	0.0500
	a*	0.8648	0.7951	0.9805	0.0645	0.8588	0.8140	0.2392	0.9368	0.0953
	b*	1.0316	0.6669	2.3349	0.0218	0.6657	2.3393	0.0533	0.6973	0.2608
	ΔE	-2.440	0.7818	2.5498	0.3820	0.3148	12.5844	0.3337	0.9765	0.0529
80	L*	3.3011	0.9123	1.8214	0.0617	0.9295	1.6334	0.2249	0.9678	0.0852
	a*	1.2229	0.8445	0.7673	0.0954	0.8989	0.6187	0.5793	0.5068	0.2709
	b*	1.8982	0.7853	1.8159	0.0416	0.7996	1.7547	1.216e-5	0.7828	0.01367
	ΔE	-4.023	0.9015	2.2730	0.4266	0.4919	13.5336	0.2717	0.9763	0.0716

The fractional conversion kinetic rate constant for L* increased from 0.0013 to 0.3076 min^{-1}, a* increased from 0.0662 to 0.2392 min^{-1}, b* increased from 0.0100 to 0.0533 min^{-1} and the total color change, ΔE, increased from 0.032 to 0.3337 min^{-1} as the drying temperature was raised from 50 to 70°C. This implies that the rate of color reduction as a result of carotenoid degradation was faster with an increase in the drying temperature due to the high energy transferred to the inside of the food material. However, the value of the kinetic rate constant reduced with a further rise in the drying temperature to 80°C. This may be attributed to a shorter drying time experienced at temperatures above 70°C. This shorter drying time results to lesser exposure of the pumpkin to light and heat, thus reducing the rate of carotenoid degradation at temperatures between 70°C to 80°C. Therefore, the fractional conversion model can be used to predict the color change kinetics of pumpkin during convective hot air drying.

Similarly, several authors from the literature have reported that the fractional conversion and first-order kinetic models can adequately predict the change of different color parameters of some agricultural food products during drying (XIAO *et al.*, 2014; HOSSEINPOUR *et al.*, 2013; AVILA *et al.*, 1999).

Table 2. Estimated regression results of zero-order, first-order and fractional conversion models for Chroma, Hue angle and Browning index at various drying temperatures.

		Zero-order model			First-order model			Fractional conversion model		
Temp (°C)	Parameter	K	R^2	SSE	K	R^2	SSE	K	R^2	SSE
50	Chroma	0.7130	0.3866	2.6415	0.01310	0.3882	2.6379	0.02790	0.4133	0.6528
	Hue Angle	-0.5858	0.7838	0.7248	8.6736E-019	0.2817	3.04560	0.05170	0.9699	0.08260
	BI	-1.9244	0.1278	17.825	1.7347E-018	0.1315	20.302	7.9442E-009	0.3510	0.6142
60	Chroma	1.2303	0.7404	2.5771	0.02580	0.7288	2.6340	0.007200	0.8483	0.2073
	Hue Angle	-0.5473	0.2117	1.3450	1.4229E-018	0.3288	3.07380	1.3734	0.4021	0.4335
	BI	0.5342	0.04690	10.971	0.003400	0.04630	10.975	51.414	0.8938	3.1117
70	Chroma	1.2335	0.7153	2.3657	0.02510	0.7167	2.3602	0.07080	0.7441	0.2290
	Hue Angle	-0.6247	0.5037	0.9581	1.5658E-018	0.4876	3.2966	0.5198	0.9125	0.1080
	BI	-3.9046	0.4954	18.824	3.2747E-018	0.1361	27.260	51.414	0.8938	3.1117
80	Chroma	2.1608	0.8220	1.7858	0.04550	0.8397	1.6948	0.03140	0.9816	0.07050
	Hue Angle	-0.7779	0.5157	0.9285	3.7663E-019	0.2240	2.7419	0.7182	0.7046	0.2019
	BI	-4.9892	0.8287	4.3260	1.6660E-018	0.6778	17.103	0.04430	0.7951	0.2076

In addition, Fig. 4 shows the relationship between the experimental color data and predicted color data, based on the fractional conversion model for L* color parameter. The values fitted close to a straight line with $R^2 > 0.9$. This validates the application of the fractional conversion model in predicting the color change kinetics of pumpkin during convective hot air drying.

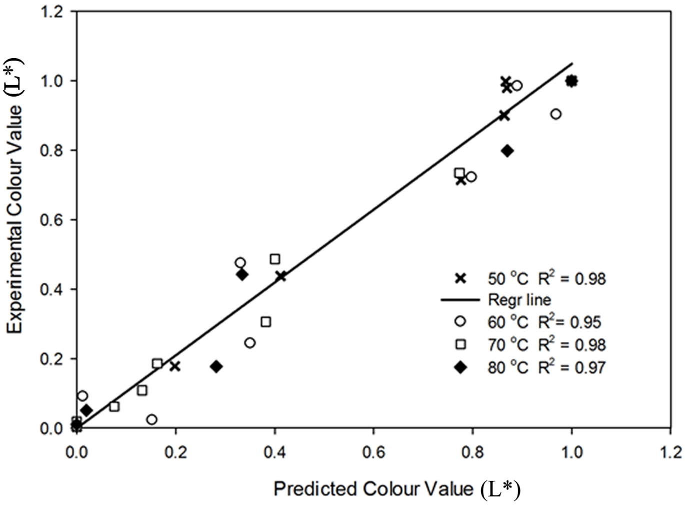


Figure 4. Validation of the fractional conversion model for the prediction of color change kinetics.

3.3. Estimation of activation energy

The activation energy of the color change can be estimated from a plot of the kinetic constant against the drying temperatures as shown in Fig. 5.

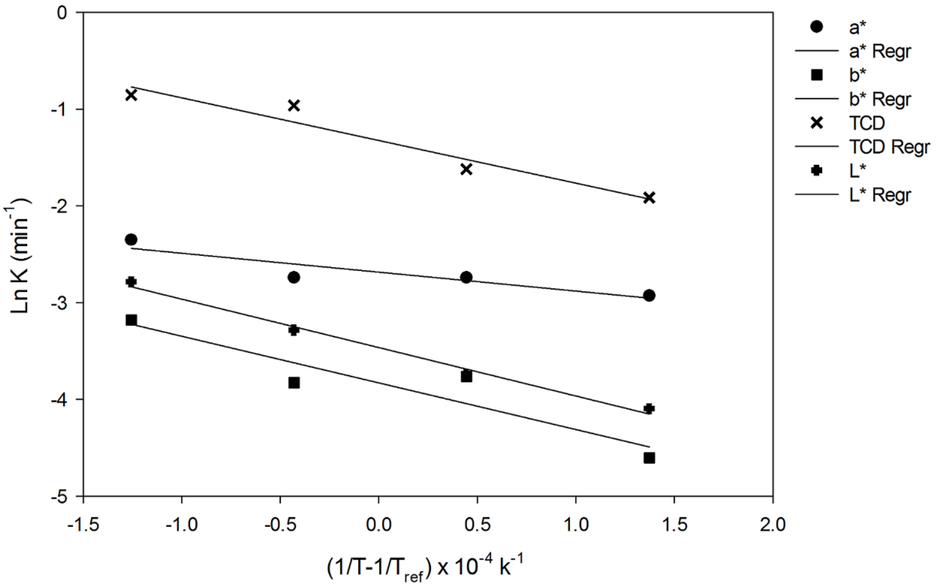


Figure 5. Estimation of activation energy.

Table 3 shows the linear models of the kinetic rate constant and temperature for different color parameters. The activation energy for the L*, a* and b* was estimated by linear regression using Eq. 7 and was found to be 41.59, 16.287 and 63.856 kJ/mol respectively. Higher values of L*, b* and ΔE indicates that higher energy is required in order to cause a significant change in the brightness and yellowness of pumpkin during convective drying, and therefore monitoring the color change during drying becomes more indispensable. Accordingly, a lower minimum energy is required to reduce the redness of pumpkin during the drying process due to its lowest activation energy. Overall, the minimum energy required to cause a significant total color change (ΔE) during the drying of pumpkin is 73.390 kJ/mol. In addition, the results of the activation energies for L∗, a∗, and b∗ color change kinetics were lower than those of peach puree (AVILA *et al.*, 1999), the L* , a* were lower than those of celery leaves (DEMıRHAN and ÖZBEK, 2011) and the a*, and b* were lower than those of American ginseng (XIAO *et al.*, 2014). Similarly, the activation energies for the L* a∗ b∗ and ΔE color change kinetics were higher than those of Okra (DADALI *et al.*, 2007) and carrot (KOCA *et al.*, 2007). Thus, the variation in the activation energies of the color parameters of pumpkin as compared to other fruits and vegetables may be due to the variations and compositions of different food products, including the method and drying process conditions.

Table 3. Activation energy for the color degradation of pumpkin for different major color kinetics parameter.

Color kinetics parameter	Linear modelled equation	R^2	E_a(kJ/mol)
L*	$Lnk = -3.4618 - 5002.1\left(\frac{1}{T_{abs}}\right)$	0.9898	41.592
a*	$Lnk = -2.6831 - 1958.9\left(\frac{1}{T_{abs}}\right)$	0.8335	16.287
b*	$Lnk = -4.01073 - 7680.1\left(\frac{1}{T_{abs}}\right)$	0.8687	63.856
ΔE	$Lnk = -2.01781 - 8826.7\left(\frac{1}{T_{abs}}\right)$	0.9411	73.390

3.4. Effect of drying conditions on total carotenoid content

From Table 4, the total carotenoid content (TCC) and absorbance values of pumpkin (*Cucurbita moschata*) can be observed. The results showed a mean total carotenoid content of 146 μg/g for samples dried at 50°C, 56.4 μ-g/g for samples dried at 60°C, 37.9 μ-g/g for samples dried at 70°C and 102.5 μ-g/g for samples dried at 80°C. These values are lower than those reported by de CARVALHO *et al.* (2012) in landrace pumpkin, with values ranging from 234.21 to 404.98 μ-g/g (wet matter). The lower TCC values may be attributed to the specie of pumpkin used in this study and also nature of materials used during extraction (dried pumpkin in this study and fresh pumpkin in the study of De CARVALHO *et al.* (2012). On the other hand, the TCC values of this present study are similar to those reported by ŞLEAGUN *et al.* (2007), with values ranging from 110.62 to 40.41 μ-g/g (dry matter). This similarity can be attributed to nature of material before extraction, and the drying method (thin layer hot air drying) used in both cases. Further, the TCC of the pumpkin (*Cucurbita moschata*) in this study are within the acceptable range of 20.3 μ-g/g to 158.56 μ-g/g for most pumpkin varieties (AZIZAH *et al.*, 2009; SAHABI *et al.*, 2012).

Further, the results show that convective hot air drying gives a significant effect on the TCC of pumpkin. From Table 4, it can be seen that there is significant statistical difference between the TCC of pumpkin samples at 5% ($p<0.05$) significant level and 95% confidence interval.

Table 4. Total carotenoid content and absorbance values of Pumpkin (*Cucurbita moschata*) as affected by drying conditions.

Samples	Total carotenoid content (μg/g x 10^3)
50°C	$0.146^{a}\pm0.083$
60°C	$0.0564^{b}\pm0.055$
70°C	$0.0379^{b}\pm0.018$
80°C	$0.1025^{a}\pm0.064$

Means ± Standard deviation of samples.

[a,b] Variations in the letters of samples in a column indicate significant difference at 5% ($p\leq0.05$) using Tukey's test.

As shown in Fig. 6, the TCC is highest in samples dried at 50°C. TCC values decreased when the drying temperature is 70°C. A further rise in the temperature to 80°C resulted in a higher TCC value. This high TCC value is due to the shorter drying time required to achieve a desired moisture content with a decrease in the drying time of about 38% as the temperature was raised from 50°-80°C as stated above. More so, the result showing that carotenoid contents are lower for samples which had been dried at temperatures between 50° and 70°C can be further explained by the fact that a longer drying time is needed at these lower drying temperatures. The increase in drying time at lower temperatures increases the exposure of pumpkin samples to light and heat. This further increases the rate of oxidation and carotenoid degradation. Similar results on different fruits have been reported by previous researchers (STAHL, 1992; PRAKASH *et al*., 2004; ALAM *et al*., 2013; MARIA *et al*., 2014). Therefore, from the results, it can be said that convective hot air drying at appropriate drying temperature can reduce the loss of carotenoid in pumpkin.

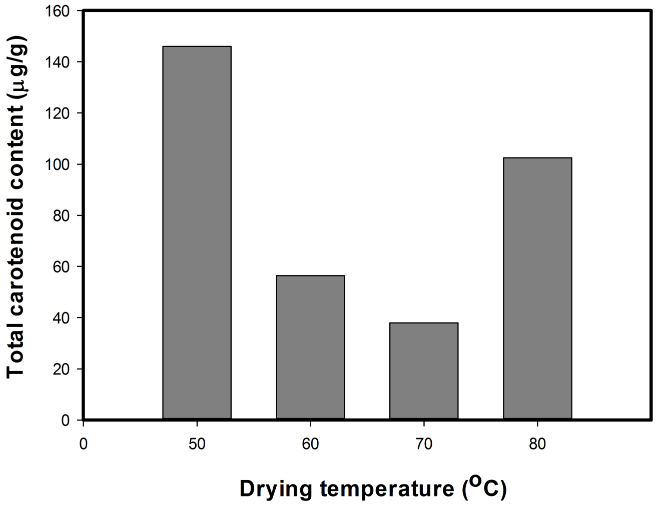


Figure 6. Effect of drying temperature on TCC.

4. CONCLUSIONS

This study showed that convective hot air drying affects the moisture content, color parameters and total carotenoid of pumpkin (*Cucurbita moschata*). Drying at a higher temperature resulted in a shorter drying time. The color parameters and total carotenoid content were significantly affected by drying temperatures and longer drying time. The final values of L *, a*, b*, total color change ΔE, Chroma, hue angle and browning index were also influenced by the drying temperature and time. The results of the total color change and the browning index further showed that drying at higher temperatures above 80°C will result in the darkening and significant pumpkin color change as compared to the fresh slices.

In order to make a better estimate of the color change kinetic parameters, a fractional conversion kinetic model was selected as the most appropriate model for predicting the color change kinetic of pumpkin. Also, the first order model sufficiently fitted the experimental data for certain drying conditions. Thus, can be used to predict the color changes of pumpkin during drying. In addition, the values of the activation energy were 41.59 kJ/mol for L*, 16.287 kJ/mol for a*, 63.856 kJ/mol for b*, and 73.390 kJ/mol for ΔE, respectively. From these values, it can be seen that a significant amount of energy is required to cause the change in the color of pumpkin during drying.

From the results of this study, it can be concluded that convective hot air drying can be used to enhance the shelf life of pumpkin, maintain the optical properties while enhancing the availability of carotenoid in pumpkin (*Cucurbita moschata*). Thus, in practice a drying temperature between 50°C to 80°C could be used in the convective drying and extraction of carotenoid from pumpkin, considering the combined effects on moisture content, optical parameters and total carotenoid content. However, for the optimization of the drying process, a drying time of less than 300 minutes at a drying temperature between 70 to 80°C can be used. This research can be useful in evaluating the color change kinetics models as a reliable tool for predicting, controlling and optimizing the effect of drying conditions on the color and carotenoid degradation of pumpkin. Finally, it is suggested that different kinetic models could be used for different drying levels in future research.

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