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Drying characteristics and quality evaluation of kiwi slices under hot air natural convective drying method

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Abstract

Dried kiwis are highly needed in food industries such as cereals, ice-cream, beverages and supplemental products. In this paper, drying characteristics and product quality of hot air dried kiwi slices were studied. Hot air drying of kiwi slices was investigated at drying temperature ranged from 40°C to 60°C and slice thickness of 0.3 cm and 0.6 cm. Results showed that drying of kiwi slices at higher drying temperature stimulates the drying rate, which leads to shorter total drying time required. The drying kinetics of kiwi slices was best fitted by approximation diffusion model. Increased in drying temperatures and slice thickness of kiwi enhanced the effective moisture diffusivity (D_{eff}). The highest D_{eff} of the kiwi slices was recorded as 1.5681 x 10^{-8} m^2/min at slice thickness of 0.6 cm. In terms of quality analysis, kiwi slices dried at temperature of 60°C with fastest drying rate retained most of the Total Phenolic Content (TPC) in the dried sample. However, drying of kiwi slices at high drying temperature deteriorated the vitamin C content of kiwi slices due to thermal degradation. Thinner kiwi slices could preserve higher amount of TPC and vitamin C during the drying process, yet the best hot air drying temperature for drying of kiwi slices could be relied on the consumers' preference based on the dried product quality as reported in the current work.

Introduction

Kiwifruit *(Actinidia deliciosa)* is a berry and it is from the family of climbing shrubs known as Actinidia. The genus *Actinidia* can only grow at certain geographic area that has a warm and gentle climate such as New Zealand, California, Chile, Italy and France (Deutch, 1994). It is a multi-nutritional berry due to its high contents of Vitamin C and total polyphenols, which range from 92 mg – 132 mg per 100 g of fresh weight (Park *et al*., 2006). Among of all kiwifruit producing countries, Italy and New Zealand produces up to 60% of world production and the exported crop exceeded local consumption since 1976 (Bano and Scrimgeour, 2011). Moreover, kiwifruit has very short shelf-life due to its highly perishable nature and it has to be preserved in order to increase its shelf-life and for storage purpose. One of the preservation alternatives is through drying. Drying reduces water activity through the reduction of water content as to minimize biochemical, chemical and microbiological deterioration (Doymaz and Pala, 2003). The main objective of drying agriculture crops is to reduce the crop losses. Also, cost of transportation and packaging will be reduced as the volume and weight of crops have been reduced.

However, drying is a time and energy consuming process. During drying, it will cause changes of the fruits, in terms of physical, chemical and nutritional value. A successful drying process has to meet the requirements such as short drying time, low energy consumption, high rate of water removal and lastly, maintaining the best quality of the dried products.

Drying process often leads to the quality degradation of drying materials due to high drying temperature and long drying time. Heat sensitive bioactive ingredients such as total phenolic content (TPC) vitamin C content in the fruits will be degraded upon drying process. Thus, it is vital to preserve the quality of the dried fruits with maximum retention of bioactive ingredients upon drying process. There are several methods for drying of fruits, which are using open-air sun drying, infra-red drying, spray drying, fluidized bed drying, vacuum drying, microwave drying and others. Different drying methods and conditions will produce different quality of dried fruits. As example, fluidized bed drying required shorter drying time and it was found to produce superb quality of dried mushrooms as compared to microwave drying (Walde *et al*., 2006). Vacuum drying is also considered as a good alternative as this method could retain the quality of fruits

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although longer drying time is required as compared to microwave drying. Microwave drying produced unsatisfactory result although the drying time is shorter than the previous two approaches.

There is lack of studies on drying of kiwifruit. Kiwifruits dried by open-air sun often produce unsatisfactory quality products due to higher humidity, insect disturbance, dust and microbial contamination and others (Jain and Tiwari, 2000; Yahya *et al*., 2001). It caused difficulty in fulfilling the requirements of consumers. Also, there is scarcity of research done on the effect of drying on TPC and vitamin C of dried kiwifruits. Thus, in this research, detail studies should be carried out to investigate the drying kinetics of kiwifruits and the quality of dried kiwifruits in terms of TPC and vitamin C, in order to produce high quality of dried kiwifruits.

Materials and Methods

Sample preparation

"Hayward" kiwifruits were purchased from AEON, Wangsa Maju, Setapak, Kuala Lumpur to be used as drying samples. They were purchased from the same store for the consistency of data taken. The fruits were sliced into circular shape of two different thicknesses, which were 0.3 ± 0.05 cm and 0.6 ± 0.05 cm. The initial weight of the cut kiwifruits was measured as 8.0 ± 0.5 g and 14.0 ± 0.5 g for 0.3 cm and 0.6 cm slices thickness, respectively before drying.

Drying procedures

Drying kinetics of different thickness of kiwifruits were investigated at three drying temperatures which are 40°C, 50°C and 60°C, in hot air natural convection oven (Beschikung, Loading Modell 100-800, Memmert). Besides drying kinetics, the range of temperature was chosen to determine the effect of heat contact on the heat sensitive bioactive ingredients (e.g. vitamin C and TPC) during drying of kiwi slices. Drying at temperature of 40°C is considered as low temperature in oven with minimum heat contact with the samples whereas drying at 60°C is expected to significantly degrade the heat sensitive bioactive ingredients in the kiwi slices. Firstly, the oven was adjusted to a selected drying temperature for about half an hour prior to the beginning of experiment to achieve steady state conditions. Next, samples were put into the oven. For the first 30 minutes, the weight of the samples was recorded at 5 minutes interval, whereas for the next 60 minutes, the weight of the samples was recorded at 10 minutes interval and the rest of the hour, the weight of samples was recorded at 30 minutes interval. Readings for the following day will be recorded at 1 hour interval. The weight of the samples were measured until equilibrium moisture content (EMC) was reached, in which EMC indicates that there is no further changes of weight in dried samples. In the current experiment, EMC is considered achieved when constant weight of dried kiwi slices was recorded for three readings consecutively.

Physical analysis

Dry weight of samples was determined using oven drying at temperature of 105°C for 24 hours (AOAC, 1990).

Initial moisture content (Dry basis):

$$M_o \text{ (g } H_2O\text{/g dry sample)} = \frac{W_o - W_d}{W_d} \quad (1)$$

Equilibrium moisture content (EMC) (Dry basis):

$$M_{eq} \text{ (g } H_2O\text{/g dry sample)} = \frac{W_{eq} - W_d}{W_d} \quad (2)$$

Moisture ratio (MR): $$MR = \frac{M_t - M_{eq}}{M_o - M_{eq}} \quad (3)$$

Drying Rate (g H_2O/m^2.min): $$R = \frac{W_d}{A}\left(\frac{M_{n+1} - M_n}{t_{n+1} - t}\right) \quad (4)$$

Where W_o, W_d, and W_{eq} are initial, dry and equilibrium weight of the sample, respectively. M_t, M_n and A represent moisture content at time t, free moisture content and exposed surface area of the samples, respectively.

Mathematical modelling

A total of nine mathematical models were used to model the drying kinetics of kiwi slices. They were Newton model (O'Callaghan *et al*., 1971), Page model (Page, 1949), Modified Page model (Overhults *et al*., 1973), Henderson and Pabis model (Henderson and Pabis, 1961), Logarithmic model (Chandra and Singh, 1995), Two-term model (Henderson, 1974), Two-term exponential model (Henderson, 1974), Wang and Singh model (Wang and Singh, 1978) and Approximation of Diffusion model (Kassem, 1998). These models were selected to compare the different number of constant terms used in modelling i.e. single-constant k in Newton, two-constant k, n in Page, three-constant a, k, n in Logarithmic models and etc. Three parameters were used to evaluate the fitness of each thin layer model to the experimental data, which were coefficient of correlation (r), root mean square error (RMSE) and reduced chi-square (χ^2) (Togrul and Pehlivan, 2004). Generally, it is assumed that the model which has the highest

r, lowest RMSE and χ^2 is the best representing the drying kinetic of the drying materials. Formula for each parameter is shown as below:

$$r = \frac{N\sum_{i=1}^{N} MR_{pre,i}\, MR_{exp,i} - \sum_{i=1}^{N} MR_{pre,i} \sum_{i=1}^{N} MR_{exp,i}}{\sqrt{N\sum_{i=1}^{N}(MR_{pre,i})^2 - \sum_{i=1}^{N}(MR_{pre,i})^2} * \sqrt{N\sum_{i=1}^{N}(MR_{exp,i})^2 - \sum_{i=1}^{N}(MR_{exp,i})^2}} \quad (5)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{N}} \quad (6)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{N - N_c} \quad (7)$$

Where N, N_c, MR_{pre}, MR_{exp}, represent number of data, number of constant, predicted moisture ratio and moisture ratio from experimental data, respectively.

Effective moisture diffusivity, diffusivity constant and activation energy

Effective moisture diffusivity (D_{eff}) of the samples was determined by assuming the slices are of the shape of slab. They are determined by plotting graph of ln (MR) against t. Gradient of graph is determined and D_{eff} could be calculated using Equation (8).

$$\ln (MR) = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}\, t}{L^2} \text{ ; slope} = -\frac{\pi^2 D_{eff}}{L^2} \quad (8)$$

Where L is the thickness of the kiwi slices in meter.

Diffusivity constant (D_o) and activation energy (E_a) can be calculated by using Equation (9). Based on graph ln (D_{eff}) against 1/ (T + 273.15), Ea can be obtained from the gradient of graph while Do is determined from y-intercept of graph.

$$D_{eff} = D_o \exp\left[-\frac{E_a}{R\,(T+273.15)}\right] \quad (9)$$

Where R and T are gas constant ($KJ.mol^{-1}.K^{-1}$) and drying temperature (^oC), respectively.

Determination of total phenolic content

Hot air dried kiwifruit slices were extracted with 50 ml solvent which made up of acetone, water and hydrochloric acid in volume percentage of 75%, 22% and 3%, respectively. The extracted solution was kept in refrigerator for 24 hours. Next, 1 ml of extract was mixed well with 5 ml of 0.2 N Folin - Ciocalteau reagent and held for 3 minutes. Then, 4 ml of 7.5% sodium carbonate solution (Na_2CO_3) was added into the mixture and held for 30 minutes incubation in dark at room temperature to allow color development. This is followed by diluting the extract with 40 ml of distilled water and absorbance of the extract was measured at 765 nm in single beam spectrophotometer. Gallic acid (0.1 - 0.5 mg/ml) was used as standard solution to produce the calibration curve for the determination of TPC in the sample. TPC of the samples is expressed in mg of gallic acid / 100g dry weight.

Determination of vitamin C

The vitamin C content of kiwi slices was determined using 2,6 – Dichloroindophenol Titration Method as described in Official Method of Analysis, Method 967.21. Before the analysis, three reagents such as extracting solutions, ascorbic acid standard solution and indophenols standard solution must be prepared as below:

(i) Extracting solution, metaphosphoric acid-acetic acid (HPO_3-CH_3COOH):15 g of HPO_3 pellets or freshly pulverized stick HPO_3 was dissolved with shaking in 40 ml CH_3COOH and 200 ml H_2O; diluted to 500 ml. The solution was then filtered rapidly through fluted paper into glass-water bottle and store in refrigerator.

(ii) Ascorbic acid standard solution (1 mg/ml): 50 mg of ascorbic acid (USP Ascorbic Acid Reference Standard) was weighted and transferred to 50 ml volumetric flask. It was diluted to volume immediately before used with HPO_3-CH_3COOH solution.

(iii) Indophenol standard solution: 50 mg of 2,6 – dichloroindophenol sodium salt was dissolved in 50 ml of H_2O which had been added with 42 mg sodium bicarbonate ($NaHCO_3$). The mixed solution was shook vigorously until dye dissolved and consequently diluted to 200 ml with H_2O. The solution was then filtered through fluted paper into glass-water bottle. The bottle should not expose to direct sunlight and store in refrigerator.

Hot air dried kiwifruit slices were extracted with 50 ml extracting solution which contained 3% (w/v) metaphosphoric acid and 8% (w/v) acetic acid. The solutions were kept in refrigerator for 24 hours. After the solid kiwi slices were filtered from the supernatant, the supernatant was titrated into 5 ml of indophenol standard solution until the indophenol standard solution turns from blue to distinct colourless persists for 5 seconds. The amount of supernatant used was recorded. Ascorbic acid (AA) with different concentrations (0.1 – 0.5 mg/ml) were used as standard solution to construct a calibration curve for determination of vitamin C in the sample by using the same method. Vitamin C of the sample (V) is expressed in mg ascorbic acid/g dry weight and can be calculated using Equation (10) as shown below:

$$V = \frac{C \times V_s}{W_d} \quad (10)$$

Where V_s, C and W_d represent volume of supernatant (ml), concentration of AA solution (mg / ml) and dry weight of kiwi slices (g), respectively.

Both drying kinetics and quality evaluation of

dried kiwi slices were carried out in triplicate.

Results and Discussion

Mathematical modeling

Statistical analysis was conducted to obtain the mathematical model which best fit with the experimental results. Nine mathematical models were analyzed based on coefficient of correlation (r), root mean square error (RMSE) and reduced chi-square (χ^2) parameters as compared with experimental data. It was concluded that most of the drying kinetics of kiwi slices at drying temperature of 40 to 60°C and slice thickness of 0.3 cm and 0.6 cm could be well fitted by Approximation of Diffusion model, with the highest r and lowest RMSE and χ^2 values. The coefficient of correlation (r) was found in the range of 0.9980 to 0.9999, root mean square error (RMSE) ranged from 0.0052 to 0.0255 and reduced chi-square (χ^2) ranged from 9.275 x 10-5 to 6.72 x 10^{-4}. The variation of moisture ratio with drying time for Approximation of Diffusion model (predicted model) and experimental data at different drying temperatures and slice thickness were shown in Figure 1.

Drying kinetics

Figure 1 shows that drying of kiwi slices at higher drying temperature will shorten the total drying time. Moisture ratio of the kiwi slices decreased with increasing of drying time, until it reached equilibrium moisture content (EMC). At drying temperature of 40°C, the total drying time required for drying of kiwi slices at thickness of 0.3 cm was 3200 minutes. Whereas for 50°C and 60°C, the total drying time required was 1500 minutes and 1200 minutes, respectively. It was clearly observed that higher drying temperature will enhance the kinetic energy of water molecules, and eventually stimulates the rate of water evaporation. Hence shorter total drying time was required. When drying temperature increased from 40°C to 60°C, the total drying time was shortened up to 63%. Similar results were obtained for drying of kiwi slices at thickness of 0.6 cm, where the total drying time was reduced from 24% to 47% when drying temperature increased from 40°C to 50°C and 60°C. Figure 1 also depicted that at constant drying temperature, higher reduction of moisture ratio was observed with the thinner kiwi slice (0.3 cm) compared to the thicker kiwi slice (0.6 cm). Therefore, the thinner kiwi slice will achieve EMC faster than the thicker kiwi slice, which also contributed to a shorter total drying time. As thickness of kiwi slices decrease, the distance

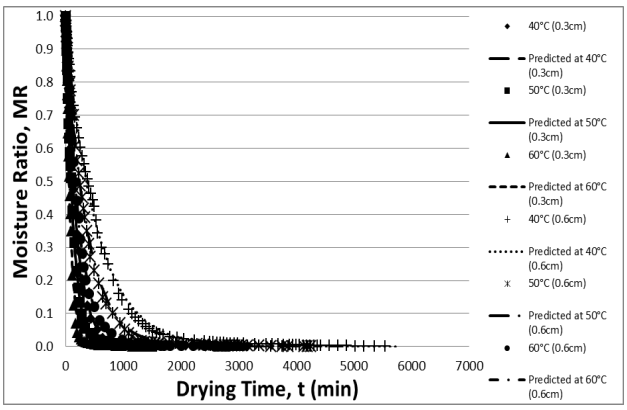

Figure 1.Variation of moisture ratio with drying time at different drying temperatures and constant slice thickness of 0.3 cm and 0.6 cm

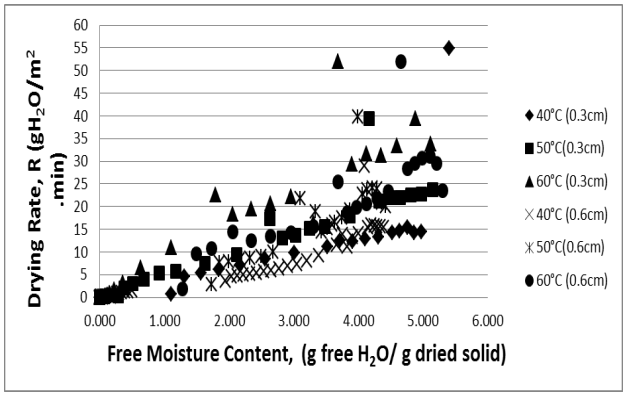

Figure 2. Variation of drying rate with free moisture content at different drying temperatures and constant slice thickness of 0.3 cm and 0.6 cm

travelled for moisture from interior to surface (and eventually evaporated) also decreases, as a result, shorter total drying time is required. A total of 42% to 64% reduction in the total drying time was recorded for kiwi slices at thickness of 0.3 cm as compared to those at 0.6 cm, during drying at constant temperature of 40°C, 50°C and 60°C.

Drying rate

Figure 2 shows the effect of drying temperature on drying rate at constant slice thickness of 0.3 cm and 0.6 cm. It was found that increasing of drying temperature will increase the drying rate of the kiwi slices as higher drying temperature contributes to higher rate of heat transfer and stimulates the diffusion of moisture from the interior to the surface for evaporation. From the results obtained, drying rate decreased with decreasing free moisture content along the drying process. Similar results were also reported in drying of organic apple slices (Sacilik and Elicin, 2006). Drying rate was found to occur at falling rate period for all drying temperatures which indicates that drying rate of drying kiwi slices was dominant by internal moisture diffusion.

At constant thickness of 0.3 cm, the average

Table 1. Total drying time, average drying rate and effective moisture diffusivity of kiwi slices dried at different slice thickness and drying temperature of 40°C to 60°C

Drying temperature, °C	Slice thickness, cm	Final moisture content, g H_2O / g dry solid	Total drying time, min	Average drying rate, g free H_2O/m^2. min	Effective moisture diffusivity (D_{eff}), m^2/min
40	0.3	0.231	3200	6.832	4.8318×10^{-9}
	0.6	0.230	5500	5.006	6.5639×10^{-9}
50	0.3	0.184	1500	11.681	7.1109×10^{-9}
	0.6	0.203	4200	9.308	9.4821×10^{-9}
60	0.3	0.145	1200	14.615	1.1122×10^{-8}
	0.6	0.188	2900	12.787	1.5681×10^{-8}

drying rate at 40°C is 6.832 g free H_2O/m^2.min. When temperature increased to 50°C and 60°C, there was an increment of 71% and 114% in the average drying rate with respect to average drying rate at 40°C. For drying of kiwi slices at thickness of 0.6 cm, the average drying rate at 40°C, 50°C and 60°C were recorded as 5.006 g free H_2O/m^2.min, 9.308 g free H_2O/m^2.min and 12.787 g free H_2O/m^2.min, respectively. Increasing drying temperature stimulated the rate of moisture evaporation prominently, which was up to 155% as compared to those dried at 40°C.

Similarly, thickness of kiwi slices will also affect drying rate. Higher drying rate was found in the thinner slice of kiwi at constant drying temperature. This is because thinner slice of kiwi enable the moisture to travel in a shorter distance from interior to the surface, thus, it leads to higher drying rate. A total reduction of 27% in the average drying rate was observed when slice thickness increased to 0.6 cm at 40°C. While at constant drying temperature of 50°C and 60°C, total of 20% and 13% reduction of drying rate for thicker kiwi slice were observed, respectively. Table 1 summarized the total drying time and average drying rate for different slice thickness of kiwi at drying temperature of 40°C to 60°C.

Effective moisture diffusivity, diffusivity constant and activation energy

Effective moisture diffusivity is defined as the rate of moisture transfer from the interior to external surface of product to be evaporated. Table 1 summarized the effective moisture diffusivity of kiwi slices dried at different slice thickness under different drying temperatures. Effective moisture diffusivity was affected by drying temperature and slice thickness. Increasing drying temperature increased the effective moisture diffusivity as higher drying temperature and lower relative air humidity enhanced the rate of moisture transfer from the interior to the surface, and eventually, evaporated to the surrounding. Besides that, effective moisture diffusivity increased with increasing thickness. This is because in thin kiwi slices, diffusion takes place from only one direction, which is from inside to the surface of kiwi slices, while side diffusion is negligible. However in thick kiwi slices, some side diffusion might occur and enhance removal of moisture. In addition, surface hardening effect occurs faster at thinner kiwi slices which will hinder the diffusion of moisture in thin kiwi slices, resulting lower effective moisture diffusivity in thinner kiwi slices. The effective diffusivity values recorded for drying of kiwi slices in Table 1 are similar with other fruits such as lemon slices and cocoa (10^{-9} to 10^{-10} m^2/min.) which were dried at similar drying conditions (Hii *et al*., 2009; Lee *et al*., 2014).

The diffusivity constant (D_o) and activation energy (E_a) were calculated as 5.04×10^{-3} m^2/min. and 36.12 kJ/mol, respectively for drying of kiwi slices at thickness of 0.3 cm. Higher value of D_o and Ea were found for drying of kiwi slices at 0.6 cm thickness as compared those at thickness of 0.3 cm, which recorded as 1.24×10^{-2} m^2/min. and 37.70 kJ/mol, respectively. Equation (11) and (12) show the relation of effective diffusivities with variation in drying temperatures for drying of kiwi slices at different slice thickness. R^2 indicates the coefficient of determination.

For 0.3 cm slices thickness:

$$D_{eff} = 5.04 \times 10^{-3} \exp\left[-\frac{36.12}{R\,(T+273.15)}\right];\ R^2 = 0.9964 \qquad (11)$$

For 0.6 cm slices thickness:

$$D_{eff} = 1.24 \times 10^{-2} \exp\left[-\frac{37.70}{R\,(T+273.15)}\right];\ R^2 = 0.9885 \qquad (12)$$

Based on the results, activation energy increased with increasing kiwi slice thickness. This is because thicker kiwi slice requires higher energy to activate the water molecules to diffuse out from the interior part of the slices. On the other hand, lower diffusivity

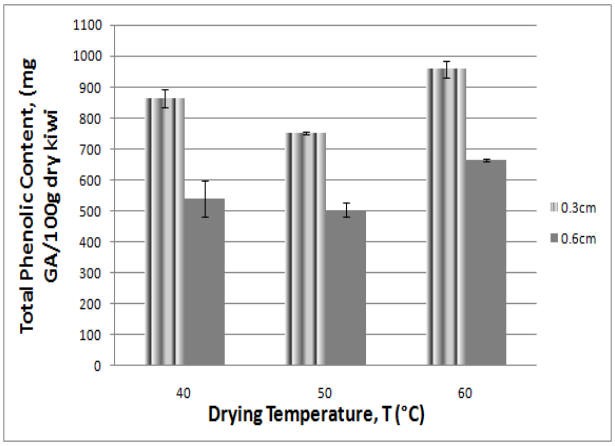

Figure 3.Comparison of TPC in kiwi slices dried at different drying temperatures and slice thickness

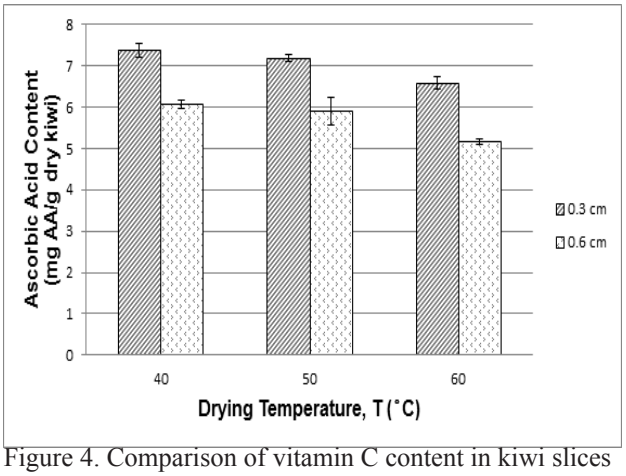

Figure 4. Comparison of vitamin C content in kiwi slices dried at different drying temperatures and slice thickness

constant was found in kiwi slices with smaller slice thickness. This is due to lower effective moisture diffusivity, D_{eff} values found in smaller kiwi slice thickness as compared to those found in thicker kiwi slices, as mentioned earlier.

Total phenolic content (TPC)

The Total Phenolic Content (TPC) of kiwi slices was affected by both drying temperature and thickness of kiwi slices, as shown in Figure 3. At drying temperature of 40°C, TPC of dried kiwi slices was recorded as 863.42 mg Gallic Acid/100g dry slice. When drying temperature increased to 50°C and 60°C, the TPC value of dried kiwi slices was found to decrease to 751.31 mg Gallic Acid/100g dry slice and increase prominently to 958.70 mg Gallic Acid/100g dry slices respectively. The high retention of phenolic compounds in kiwi slices dried at 60°C could be due to the availability of precursors of phenolic molecules by non-enzymatic interconversion between phenolic molecules (Vega-Galvez *et al*., 2009). Furthermore, fast drying rate of the kiwi slices at 60°C (up to 114% higher drying rate than 40°C) also prevents the degradation of TPC through heat destruction and oxidation process. Low amount of TPC was found in kiwi slices dried at 40°C as this could be due to long total drying time required (167% longer total drying time as compared to those dried at 60°C) which in turn enhances the oxidation of TPC. The lowest amount of TPC was recorded in kiwi slices dried at 50°C as heat destruction of TPC at this temperature is unavoidable.

Similar results were found for drying of kiwi slices at 0.6 cm thickness and drying temperatures of 40 to 60°C. The above findings were in accordance with the results reported by Vega-Galvez *et al.* (2009) and Mrad *et al.* (2012) on the TPC studies of red pepper and pears dried at different drying temperatures.

On the other hand, the TPC content of kiwi slice also affected by the slice thickness during drying. Dried kiwi slice at 0.6 cm thickness showed 31% to 38% lower TPC value as compared to at 0.3 cm thickness. This could be caused by longer total drying time required by the thicker slices to reach EMC which in turn intensifies the thermal degradation and oxidation of TPC in the kiwi slices. This is in accordance with the findings from Mrad *et al.* (2012) and Garau *et al*. (2007) on drying of pears and oranges respectively. It was found that longer drying time reduced the TPC value of the dried samples significantly.

Vitamin C

The quality of hot air dried kiwi slices was also assessed in terms of vitamin C content due to its high sensitivity in drying temperature. The vitamin C content decreases with increasing drying temperature during hot air drying. Furthermore, higher dying temperature also enhanced the rate of oxidation reaction of vitamin C (Vega-Galvez *et al.*, 2009). Figure 4 shows the vitamin C content of kiwi slices dried at different slice thickness and drying temperatures. As shown in Figure 4, the vitamin C content obtained for slice thickness of 0.3 cm at drying temperature of 40°C was 7.377 mg AA/g d.b. When drying temperature increased to 50 and 60°C, the vitamin C content obtained were 7.191 and 6.588 mg AA/g d.b, respectively. Lowest retention of vitamin C content in dried kiwi slice was observed at drying temperature of 60°C due to the heat liable nature of ascorbic acid. Higher drying temperature will result a greater degradation in vitamin C content due to the increase in rate of oxidation of ascorbic acid to dehydroascorbic acid (Santos and Silva, 2008).

It is believed that, longer drying time will also contribute to an increase in vitamin C degradation. However, results showed that the degradation of

vitamin C in kiwi slices is significantly affected by drying temperature as compared to drying time. For instance, at slice thickness of 0.3 cm, despite having the longest drying time (2700 minutes) at drying temperature of 40°C, the retention of vitamin C was still the highest which was 7.377 mg AA/d.b. On the other hand, shortest drying time (1300 minutes) at 60°C retained the lowest amount of AA content which was 6.588 mg AA/d.b. This observation is in agreement reported by Santos and Silva (2008) on ascorbic acid degradation of pineapples. Similar results were found for drying of kiwi slices at slice thickness of 0.6 cm at drying temperature from 40°C to 60°C. The above findings were in accordance with the results reported by Kaya *et al.* (2010) and Mrad *et al*. (2012) on ascorbic acid studies of kiwifruits and pears.

Slice thickness also influences the vitamin C content in dried kiwi slices. Based on Figure 4, at any constant drying temperature, lower vitamin C content was observed at thicker dried kiwi slices (0.6 cm). A reduction of 18 to 22 % in vitamin C content was obtained as compared to dried kiwi slices at 0.3 cm. This is because, longer drying period is needed for the thicker slices to achieve EMC which in turn causing higher vitamin C degradation due to thermal damage and irreversible oxidative reactions (Ekow *et al.*, 2014). Similar findings were reported by Adam *et al.* (2000) on drying of onion slices.

Conclusions

Approximation diffusion model was found to be the best fit model to represent the drying characteristics of kiwi slices, which are dominated by the drying condition. Drying of kiwi slices at elevated temperature intensified the effective moisture diffusivity and drying rate, which consequently reduced the total drying time required for kiwi slices to reach EMC. However, increasing the thickness of kiwi slices reduced the drying rate. Generally, the drying rates of kiwi slices are controlled by internal moisture diffusion at all drying conditions.

In terms of quality analysis, TPC of hot air dried kiwi slices were affected by both drying temperature and total drying time whereas the vitamin C content of the dried kiwi slices only significantly affected by the drying temperature. Kiwi slices dried at elevated temperature retained the highest TPC due to fast drying rate, but the vitamin C content in dried slices was found to be degraded prominently due to thermal degradation. Drying of thin kiwi slices could preserve higher amount of antioxidant phytochemicals (TPC and vitamin C) as compared to thick slices. The results found in this study are essential for hot air drying process of kiwi slices in order to produce dried products with high retention of total phenolic content and / or vitamin C.

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