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Effect of temperature on the drying characteristics, colour and ascorbic acid content of green and gold kiwifruits

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Abstract: The drying characteristics of green and gold kiwifruit were determined using an air velocity of 0.20 m/s at ambient humidity and different temperatures (60, 80 and 100°C). The colour values (L*, a* and b*) and ascorbic acid content were also measured for the different fresh and dried kiwifruits. The drying of green and gold kiwifruit slices consists of a constant rate period (CRP) and two parts of falling rate period (FRP). The CRP drying rate, first and second FRP drying coefficients increase with drying temperature for both the green and gold kiwifruit slices. The first critical moisture content (CMC) and the dynamic equilibrium MC decrease with drying temperature for both the green and gold kiwifruit slices. The second CMC for both green and gold kiwifruit slices were not affected by drying temperature. The values for chroma of the dried green kiwifruit increased while the dried gold kiwifruit decreased with higher temperature as compared with the fresh samples. The values for hue angle of dried green and gold kiwifruits decreased at higher temperature. Lastly, the values for browning index of dried green and gold kiwifruits increased at higher temperature. There was not much change on the ascorbic acid contents of fresh and dried green and gold kiwifruits when drying at 60 and 80°C. But there was about 19% decrease in the ascorbic acid content of dried green and gold kiwifruits after drying at 100°C.

Keywords: Drying characteristics, activation energy, colour, ascorbic acid, kiwifruit

Introduction

Kiwifruit (*Actinidia deliciosa* Planch) is well known as a nutritious fruit due to its high contents of ascorbic acid (vitamin C), potassium, folic acid and antioxidants (e.g. polyphenols, carotenoids). There are two well known cultivars the green kiwifruit (Hayward) and the gold kiwifruit (Hort16A) (Martin, 2003). Green kiwifruit has a vibrant green fleshed fruit, with small white core and black seeds that burst with a tangy, sweet sour taste combination of refreshing flavours, leaving the mouth feeling clean and alive. Gold kiwifruit has a smooth hairless skin that is bronze in colour, a golden flesh interior, and a white core with black seeds (Zespri Group Ltd., 2009). Kiwifruits are highly perishable in its fresh state and therefore need to be processed into stable products.

Hot air drying of fruits and vegetables is one of the most popular preservation methods because of its simplicity and low cost. The simplest form of hot air dryers consist of an insulated cabinet with drying trays where heated air pass through the food samples. Foods are exposed to the hot air for a certain period until dried. Packaged dried fruits and vegetables can last for several months even at ambient conditions (room temperature and humidity).

Drying of fruits and vegetables is a complicated process involving simultaneous, coupled heat and mass transfer, particularly under transient conditions. Drying studies are usually performed at constant drying conditions of temperature, velocity and humidity using a thin layer of sample. Basically, constant-condition batch thin layer drying experiments will consist of measurement of moisture loss with time. The plot of moisture content against time is known as the drying curve. The slope of a tangent to a point on the drying curve is the drying rate. The plot of drying rate against moisture content is called the drying rate curve (Watson and Harper, 1988).

The thin layer drying curves of agricultural products were usually modelled using empirical, semi-empirical and analytical equations. Togrul and Pehlivan (2003) summarised the different equations available and used them for modelling the drying kinetics of a single apricot. Some of the mathematical models used for fruits and vegetables include the logarithmic equation used for peas (Rahman *et al*., 1998), Page equation for red pepper (Doymaz and Pala, 2002), modified Henderson and Pabis equation

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for fruits (Karathanos, 1999), diffusion equation for okra (Doymaz, 2005) and simplified Fick's diffusion equation for sweet potato (Diamante and Munro, 1991, 1993). A number of studies have been carried out on thin layer drying of kiwifruit (Kaya *et al*., 2008; Orikasa *et al*., 2008; Simal *et al*., 2005; Chen *et al*., 2001).

A study of the drying curve and drying rate curve shows that the drying cycle can be described to consist of a number of stages. The first stage represents a "settling down" period during which the solid surface conditions come into equilibrium with the drying air. It is often a negligible proportion of the overall drying cycle but in some cases it may be significant. The second stage is known as the constant rate period (CRP) of drying. During this period the surface of the solid remains saturated with liquid water by virtue of the fact that movement of water within the solid to the surface takes place at a rate as great as the evaporation from the surface. The third stage is the falling rate period (FRP) of drying. As drying proceeds, a point is reached at which the rate of movement of moisture within the material to the surface is reduced to the extent that the surface begins to dry out. The transition point between the CRP and FRP is known as the critical moisture content (CMC). Often the FRP consists of two parts known as the first FRP and second FRP. In which case, there will be two critical moisture contents as well. At zero drying rate the corresponding moisture content is called the equilibrium moisture content (EMC) (Brennan *et al*., 1990). The EMC obtained from this method is known as the dynamic EMC compared with the static EMC obtained using gravimetric methods (Henderson and Perry, 1976). For a sample with a CRP and two parts of FRP, a number of drying characteristics can be derived from the drying curve and drying rate curve. These include the CRP drying rate, first CMC, first FRP drying coefficient, second CMC, second FRP drying coefficient and dynamic EMC. Toledo (2007) showed that using these drying characteristics, drying time prediction can be carried out on the sample for the range of the drying conditions used.

In addition, many qualities such as colour, sensory properties (texture, acceptabilities) and ascorbic acid content of the fruits and vegetables are affected by drying conditions. Maskan (2001) reported that both hot air and microwave drying affected the colour characteristics of the dried green kiwifruit. Simal *et al*. (2005) found that green kiwifruits at different ripening stage and drying temperature affected the colour properties of the dried products. Kaya *et al*. (2009) reported that both drying temperature and relative humidity affected the ascorbic acid content of dried green kiwifruit. Hence, studies are needed to improve drying conditions and process parameters.

The previous thin layer drying studies mentioned were done at moderate and high air flows and all were on green kiwifruit. In addition, none of the study reported drying characteristics data usable for drying time prediction. The studies on the effect of drying on the colour and ascorbic acid content were also all on green kiwifruit. Hence this study was carried out to determine the drying characteristics, colour and ascorbic acid of green and gold kiwifruits at different temperatures and low air flow (0.20 m/s).

Materials and Methods

Materials

Green and gold kiwifruits were purchased from a local supermarket and stored in a refrigerator at 5°C before the experiment which lasted for about 4 weeks. The fruits were peeled and cut crosswise into 5 mm thick slices and used as the experimental samples.

Hot air drying experiments

The hot air dryer used was a modified oven dryer (Watson Victor Ltd., New Zealand). The oven door was cut open on the upper portion to serve as the outlet of used air. The temperature sensor was also transferred to the middle part of the oven so that it adjusted the temperature of the dryer very close to that of the drying tray. Figure 1 shows the schematic diagram of the hot air dryer which consist of fan, heaters with temperature controller, drying chamber where the drying tray is suspended and an electronic weighing balance (Sartorius ED5201, Germany) for monitoring the weight loss of the sample. Drying was

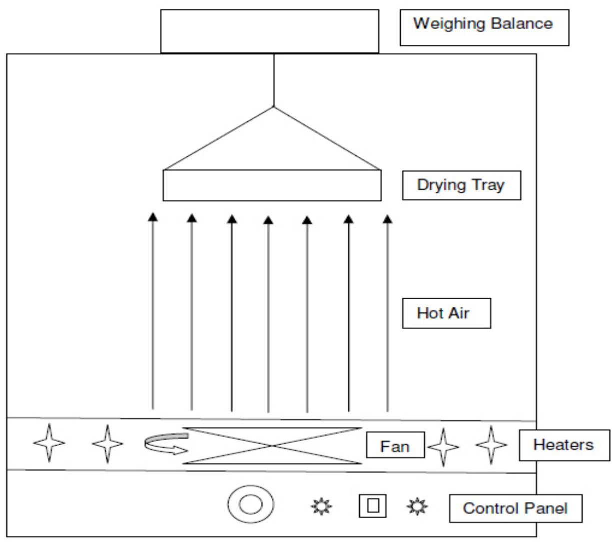

Figure 1. Schematic diagram of the hot air dryer used in the experiments.

carried out down to a final moisture content of about 0.20 kg water/kg dry solids (DS) at temperatures of 60±1, 80±2 and 100±2°C and a constant air velocity of 0.20 m/s flowing perpendicularly to the sample. Two experimental runs were done at each temperature and each kiwifruit for the drying characteristics study. Another complete set of experiments was carried out to obtain samples for the colour and ascorbic acid measurements. The drying temperature and ambient temperature and relative humidity were monitored using data loggers (Tinytag Ultra2, United Kingdom) for the whole duration of the experiment. A Psychrometric Chart (Carrier, USA) was used in determining the ambient humidity of the air. The air velocity was measured using a vane-anemometer (Extech Instruments, Taiwan).

Moisture content determination

At the end of the experiments, the moisture content of the dried samples was determined using an air oven (Watson Victor Ltd., New Zealand) set at 105°C. All the dried samples were used by dividing into three portions and dried following a standard method (Method 984.25) (AOAC, 2002). The moisture content of the samples was calculated on a percent dry basis and the average value of the triplicate samples was used.

Drying curve and drying rate curve determination

Using the average moisture content of the dried samples, the weight of dry solids of the sample was calculated. Using this value, the weight of the sample at a particular time was converted to moisture content using appropriate equation. A plot of moisture content against time yielded the drying curve. The drying rate of the initial straight line portion of the drying curve was determined from the slope of the regression of moisture content against time. The drying rates (dM/dt) were determined as described by Ceylan *et al*. (2007) using,

$$dM/dt = \frac{M_{t+dt} - M_t}{dt} \quad (1)$$

where M_{t+dt} is the moisture content at time, t+dt (kg water/kg dry solids), dt is the change in time (min) and M_t is the moisture content at time t (kg water/kg dry solids). A plot of drying rate against average moisture content or time gave the drying rate curve.

Drying characteristics determination

The constant rate period (CRP) drying rate was obtained from the slope of the regression line on the initial straight line portion of the drying curve. The first and second falling rate period (FRP) drying coefficients were determined from the slopes of the regression lines on the particular part of the drying rate curve. The first and second FRP regression lines were superimposed on the drying rate curve. The intersection of the CRP drying rate and the regression line of the first FRP yielded the first critical moisture content. While the intersection of the regression lines of the first and second FRP gave the second critical moisture content. The intersection of the regression line of the second FRP with the x-axis yielded the dynamic equilibrium moisture content.

CRP drying rate prediction and activation energy in the FRP

The CRP drying rate ($(dM/dt)_C$) is heat transfer controlled and can be calculated using a heat balance equation (Toledo, 2007) as shown,

$$(dM/dt)_C = \frac{h\,A\,(T_a - T_w)}{\lambda_v\,W_{DS}} \quad (2)$$

where h is the heat transfer coefficient (W/(m^2.°C)), A is the drying surface area (m^2), T_a is the drying air temperature (°C), T_w is the drying air wet bulb temperature (°C), λ_v is the latent heat of vaporization of water at T_w (J/kg) and W_{DS} is the weight of dry solids of sample (kg).

The heat transfer coefficient can be predicted depending upon the flow involved.

for parallel flow,

$$h = 14.3\ G^{0.80} \quad (3)$$

for perpendicular flow,

$$h = 24.2\ G^{0.37} \quad (4)$$

where G is the mass velocity of air (kg/(m^2.s)) obtained as the product of air density and velocity.

The FRP drying coefficients for both stages can be related to temperature using an Arrhenius-type relationship (Simal *et al*., 2005) using,

$$\ln F = I + S\,(1/T_K) \quad (5)$$

where F is the FRP drying coefficient (min^{-1}), I is the intercept of the Arrhenius regression, S is the slope of the Arrhenius regression and T_K is the absolute drying air temperature (K). The activation energy (E_a) for drying in the FRP can be calculated as shown,

$$E_a = 8.314\ S \text{ (J/mole)} \tag{6}$$

Drying time prediction

Using the obtained drying characteristics, the predicted drying time was determined for all the drying data using the method of Toledo (2007). The time in the CRP (t_{CRP}) was calculated using,

$$t_{CRP} = \frac{M_i - M_{c1}}{(dM/dt)_c} \tag{7}$$

where M_i is the initial MC of the sample (kg water/kg dry solids), M_{c1} is the first critical MC (kg water/kg dry solids) and $(dM/dt)_c$ is the CRP drying rate of the sample (kg water/((kg dry solids.min)). The time in the first FRP (t_{FRP1}) was determined as shown,

$$t_{FRP1} = \frac{1}{F_1} \ln \left(\frac{M_{c1} - M_r}{M_{c2} - M_r} \right) \tag{8}$$

where F_1 is the first FRP drying coefficient (min^{-1}), M_r is the residual MC (kg water/kg dry solids) and M_{c2} is the second critical MC (kg water/kg dry solids). The residual MC is a theoretical value for mathematical modelling purposes and was solved using,

$$M_r = M_{c1} - \frac{(dM/dt)_c}{F_1} \tag{9}$$

The time in the second FRP (t_{FRP2}) was obtained as shown,

$$t_{FRP2} = \frac{1}{F_2} \ln \left(\frac{M_{c2} - M_e}{M_f - M_e} \right) \tag{10}$$

where F_2 is the second FRP drying coefficient (min^{-1}), M_e is the dynamic equilibrium MC (kg water/kg dry solids) and M_f is the final MC of the sample at the end of drying (kg water/kg dry solids). The predicted drying time is the sum of the times in the CRP, first FRP and second FRP.

Colour properties determination

The colour values (CIE *L**, *a** and *b**) of the fresh and dried kiwifruits were determined with a Minolta Reflectance Chroma Meter CR 210 (Minolta, Japan). The instrument was calibrated before each measurements with a white ceramic tile (*L**=98.06, *a**=-0.23 and *b**=1.87). The fresh kiwifruit slices were chopped until the biggest pieces were less than 3 mm. While the dried samples were milled in a coffee grinder until the biggest pieces were less than 3 mm. The chopped/milled samples were placed on petri dishes before measurement. Two replicates of each sample were measured three times to get the average *L**, *a** and *b** values. In addition, the total colour change (ΔE), chroma, hue angle and Browning Index (BI) were calculated from the *L**, *a** and *b** values (Dadali *et al*., 2007).

$$\Delta E = [(L^*_i - L^*_f)^2 + (a^*_i - a^*_f)^2 + (b^*_i - b^*_f)^2]^{1/2} \tag{11}$$

where L^*_i, a^*_i and b^*_i are the initial colour values of fresh samples and L^*_f, a^*_f and b^*_f are the final colour values of the dried samples.

$$\text{Chroma} = (a^{*2} + b^{*2})^{1/2} \tag{12}$$

$$\text{Hue Angle} = [\tan^{-1}(|b^*/a^*|)][180/\Pi] \tag{13}$$

$$BI = \frac{[100(x - 0.31)]}{0.17} \tag{14}$$

$$\text{where } x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)}$$

Ascorbic acid measurements

The ascorbic acid contents of fresh and dried kiwifruits was measured by titration using 2, 6-dichloroindophenol following a standard method (Method 967.21) (AOAC, 2002). Measurements were automated using a modified Metrohm titrimetric method (Application bulletin No. 98/2e). The method uses a Pt Titrode connected to a 670 Titroprocessor with sample changer with a 16-position 100 ml beaker carousel. Data capture and equipment control was performed using a Tiamo software version 1.2.41 (Metrohm AG, Switzerland). Triplicate measurements were done on each sample.

Statistical analyses

All statistical analyses (one-way analysis of variance (ANOVA), descriptive and regression) for drying characteristics, colour properties and ascorbic acid data of the green and gold kiwifruits were carried out using Minitab 15 (Minitab Inc., USA). The Bartlett's test was used to test for homogeneity of variances.

Results and Discussion

Drying curves and drying rate curves of kiwifruit slices

Figures 2 and 3 show the representative drying curves of green and gold kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity (0.0052 to 0.0066 kg water/kg dry air) and different temperatures. The results show that the drying curves of both the green and gold kiwifruit slices move closer to the origin as the drying temperature increased which means that the higher the drying temperature the faster the drying process. Hence drying green kiwifruit slices down to a final moisture content of 26% dry basis gave drying times of 250 minutes at 60°C, 144 minutes at 80°C and 96 minutes at 100°C. While drying gold kiwifruit slices down to a final moisture content of 26% dry basis gave drying times of 333 minutes atr 60°C, 147 minutes at 80°C and 108 minutes at 100°C. The results further show that green kiwifruit slices dry faster than gold kiwifruit slices at the same drying conditions.

The representative drying rate curves of green and gold kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity and different temperatures are shown in Figures 4 and 5. The results show that the drying of green and gold kiwifruit slices consists of a constant rate period (CRP) and two parts of falling rate period (FRP). Orikasa *et al*. (2008) and Simal *et al*. (2005) found that the drying of green kiwifruit slices/cubes also consist of two parts of FRP but no CRP. Both studies used higher airflows of 1.1 to 3 m/s which hasten the disappearance of the CRP. However Chen *et al*. (2001) reported that the drying of green kiwifruit puree consists of a CRP and only one part FRP. In the succeeding section, the presence of a CRP during drying of green and gold kiwifruit slices for the given drying conditions will be established.

Drying characteristics of kiwifruit slices

Figure 6 show the initial part of the drying curve showing the CRP drying rate regression for replication 2 of green kiwifruit dried at 80°C (Data 4). The plot also shows the "settling down" period for this data occurs in the first 6 minutes of drying. The drying rate curve of Data 4 showing the FRP drying coefficients regression, critical moisture contents (CMC), residual moisture content and dynamic equilibrium moisture content (EMC) is presented in Figure 7.

Tables 1 and 2 show the drying characteristics of green and gold kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity and different temperatures. As expected, the CRP drying rate, first and second FRP drying coefficients increase with drying temperature for both the green and gold kiwifruit slices. Temperature is a major factor affecting the drying of fruits and vegetables and hence influenced all the stages of drying. While the first CMC and the dynamic EMC decrease with drying temperature for both the green and gold kiwifruit slices. The second CMC for both green and gold kiwifruit slices were not affected by drying temperature. Hence the mean value of the second CMC for green kiwifruit slices is 0.93±0.02 kg water/kg dry solids and for gold kiwifruit slices is 1.10±0.04 kg water/kg dry solids.

Chen *et al*. (2001) also found that the CRP drying rate of green kiwifruit puree increase with temperature. Orikasa *et al*. (2008) and Simal *et al*. (2005) also reported that the drying constant/coefficient of green kiwifruit slices/cubes in the

Table 1. Drying characteristics of green kiwifruit slices using an air velocity of 0.20 m/s at ambient humidity and different temperatures.

Data	Temp. (°C)	M_i (kg water/ kg dry solids)	$(dM/dt)_c$ (kg water/ (kg dry solids.min))	M_{c1} (kg water/ kg dry solids)	F_1 (min^{-1})	M_{c2} (kg water/ kg dry solids)	F_2 (min^{-1})	M_e (kg water/ kg dry solids)
1	60	5.747	0.0378	3.822	0.0072	0.956	0.0218	0.157
2	60	5.329	0.0338	3.533	0.0066	0.933	0.0221	0.169
3	80	5.546	0.0553	3.556	0.0105	0.911	0.0335	0.125
4	80	5.748	0.0607	3.511	0.0120	0.933	0.0381	0.147
5	100	5.417	0.0782	2.711	0.0180	0.933	0.0545	0.070
6	100	5.889	0.0831	2.800	0.0205	0.911	0.0551	0.085
Mean±95% CI		5.613±0.228	**	*	**	0.930±0.018	**	**

where: M_i = initial moisture content; $(dM/dt)_c$ = constant rate period drying rate; M_{c1} = first critical moisture content; F_1 = first falling rate period drying coefficient; M_{c2} = second critical moisture content; F_2 = second falling rate period drying coefficient; M_e = dynamic equilibrium moisture content

Note: ** - significant at P<0.01
* - significant at P<0.05

Table 2. Drying characteristics of gold kiwifruit slices using an air velocity of 0.20 m/s at ambient humidity and different temperatures.

Data	Temp. (°C)	M_i (kg water/ kg dry solids)	$(dM/dt)_c$ (kg water/ (kg dry solids.min))	M_{c1} (kg water/ kg dry solids)	F_1 (min^{-1})	M_{c2} (kg water/ kg dry solids)	F_2 (min^{-1})	M_e (kg water/ kg dry solids)
7	60	6.076	0.0374	4.133	0.0063	1.111	0.0211	0.234
8	60	6.305	0.0364	4.000	0.0057	1.067	0.0232	0.228
9	80	6.082	0.0633	3.800	0.0094	1.067	0.0414	0.161
10	80	5.916	0.0624	3.622	0.0113	1.156	0.0379	0.203
11	100	5.720	0.0782	3.444	0.0137	1.133	0.0466	0.106
12	100	5.331	0.0762	3.467	0.0123	1.089	0.0462	0.085
Mean±95% CI		5.905±0.359	**	**	**	1.104±0.038	**	**

where: M_i = initial moisture content; $(dM/dt)_c$ = constant rate period drying rate; M_{c1} = first critical moisture content; F_1 = first falling rate period drying coefficient; M_{c2} = second critical moisture content; F_2 = second falling rate period drying coefficient; M_e = dynamic equilibrium moisture content

Note: ** - significant at P<0.01

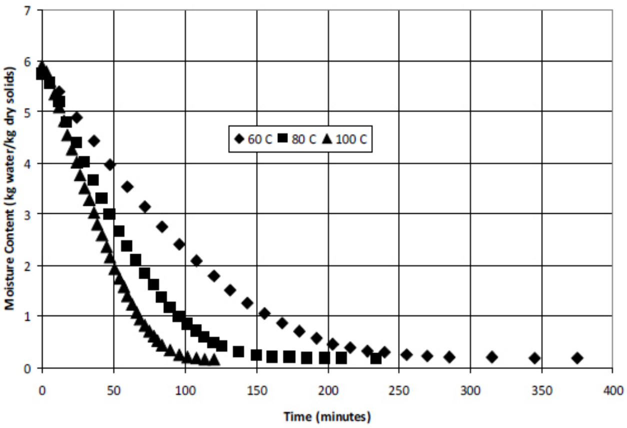

Figure 2. Representative drying curves of green kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity and different temperatures.

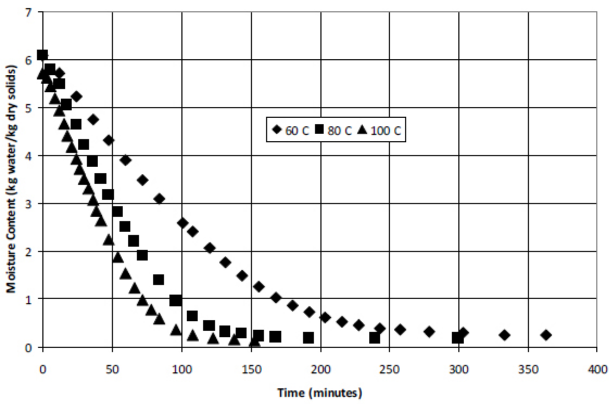

Figure 3. Representative drying curves of gold kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity and different temperatures.

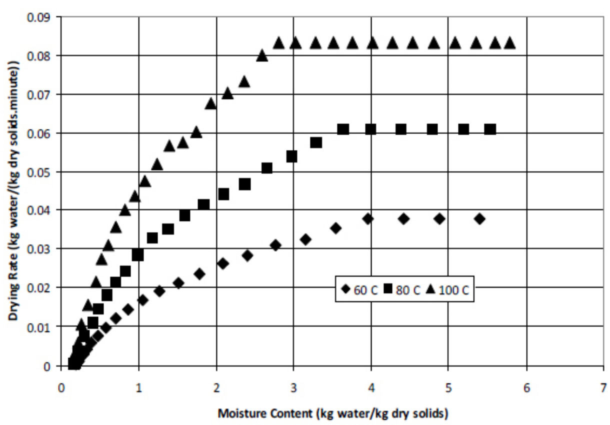

Figure 4. Representative drying rate curves of green kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity and different temperatures.

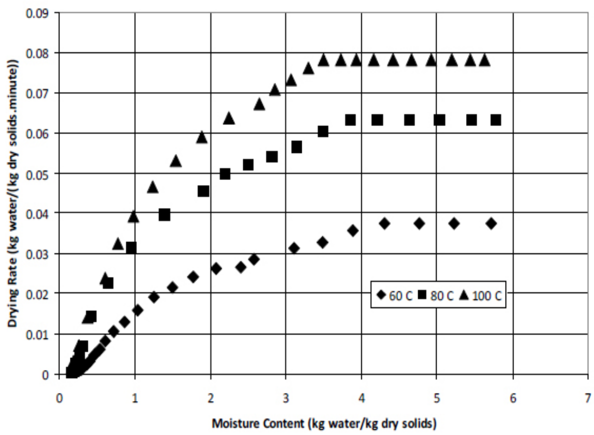

Figure 5. Representative drying rate curves of gold kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity and different temperatures.

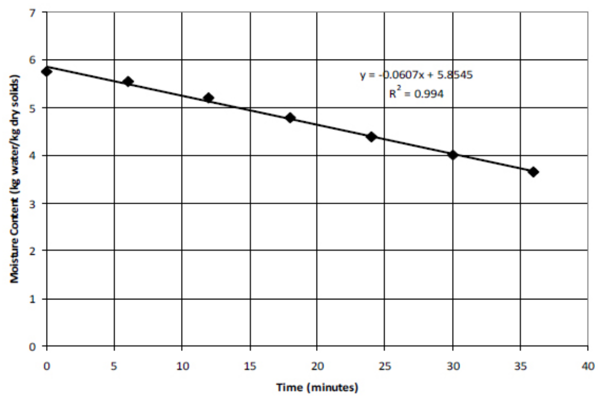

Figure 6. Drying curve of green kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity and temperature of 80°C for replication 2 of green kiwifruit (Data 4) showing the CRP drying rate regression.

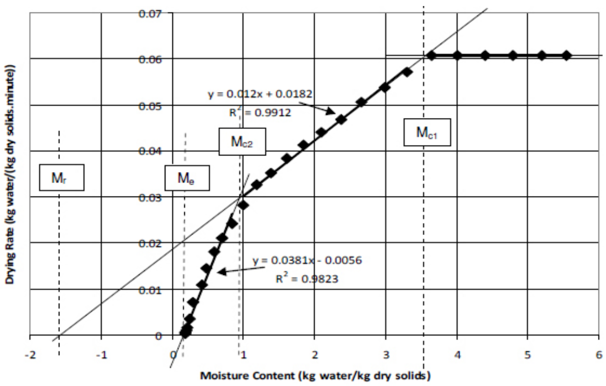

Figure 7. Drying rate curve of green kiwifruit slices with an air velocity of 0.20 m/s at ambient humidity and temperature of 80°C for replication 2 of green kiwifruit (Data 4) showing the FRP drying coefficients regressions, critical moisture contents, residual moisture content and dynamic equilibrium moisture content (where: M_{c1} = first critical moisture content; M_{c2} = second critical moisture content; M_r = residual moisture content; M_e = dynamic equilibrium moisture content).

first and second FRP increase with temperature. The second CMC of green and gold kiwifruit slices of 0.93 to 1.10 kg water/kg DS was very close to the value reported by Orikasa *et al*. (2008) for green kiwifruit slices of about 1.2 kg water/kg DS which was obtained at drying temperatures of 40 to 70^{o}C.

CRP drying rate prediction and activation energies in the FRP

One way of proving that there is indeed a CRP during drying of kiwifruit at the given drying conditions is to determine the CRP drying rate using the heat balance equation (equation 2). The CRP drying rates for both green and gold kiwifruit slices were calculated using the given drying conditions. Table 3 shows the experimental and predicted CRP drying rates of green and gold kiwifruit slices. The percentage differences between the experimental and predicted values were 13% or less which is satisfactory for most engineering purposes. The bigger difference observed at higher drying temperatures were probably due to the higher temperature fluctuations occurring during drying. The results therefore show the existence of the CRP during drying of kiwifruit slices for the given drying conditions.

The first and second FRP drying coefficients were fitted with an Arrhenius regression (equation 5) and the slopes were used in determining the activation energies (equation 6). The first and second FRP of the green kiwifruit gave activation energies of 26.5 and 23.6 kJ/mole, respectively. While the first and second FRP of the gold kiwifruit yielded activation energies of 20.1 and 19.3 kJ/mole, respectively. Orikasa *et al*. (2008) reported activation energies for green kiwifruit of 16.2 kJ/mole for the first FRP and 29.6 kJ/mole for the second FRP obtained at drying temperatures of 40 to 70^{o}C. While Simal *et al*. (2005) found that the activation energies of green non-ripe kiwifruit in the first FRP was 21.9 kJ/mole and in the second FRP was 32.3 kJ/mole determined at drying temperatures of 40 to 80^{o}C. The results obtained in the experiments compared well with the published reports.

Drying time prediction for kiwifruit slices

Using equations 7, 8 and 10, the predicted drying times for all the drying data were obtained. Table 4 shows the experimental and predicted drying times of green and gold kiwifruit slices at the given drying conditions. The results show that the higher the drying temperature the shorter the time at all stages of drying. Generally the CRP has the shortest drying time and the second FRP has the longest drying time. Gold kiwifruit slices has better drying time prediction than green kiwifruit slices. The mathematical model used was satisfactory for drying time prediction since the percentage difference with the experimental drying time was 12% or less.

Colour properties of green and gold kiwifruits

The colour values and the total colour change as calculated using equation 11 for green and gold kiwifruits are shown in Table 5. The initial L*, a* and b* values of fresh green kiwifruit are lower than fresh gold kiwifruit. This is expected since the gold kiwifruit has lighter colour than green kiwifruit. The final L* values of dried green kiwifruit increased with temperature while the opposite trend was observed for the dried gold kiwifruit. Simal *et al*. (2005) also reported that the L* values of dried green, half-ripe and ripe green kiwifruits increased with temperature. Drying at higher temperature lighten the colour of green kiwifruit while it cause some darkening for gold kiwifruit. Increasing the drying temperature increased the final a* values for dried gold kiwifruit and also increased the final a* values for dried green kiwifruit for the lowest and highest temperature. This is in accordance with the findings of Simal *et al*. (2005) for drying of green, half-ripe and ripe green kiwifruits. The redness of gold and green kiwifruits increased with drying temperature. The final b*values of dried green increased at high temperature but the final b* values of dried gold kiwifruit decreased at high temperature. Simal *et al*. (2005) also found that the b*values of dried ripe green kiwifruit increased with temperature. High drying temperature increased the yellowness of dried green kiwifruit but caused opposite effect on dried gold kiwifruit. The colour changes in green and gold kiwifruit is may be due to decomposition of chlorophyll and carotenoid pigments (Weemaes *et al*., 1999; Lee and Coates, 1999), nonenzymatic Maillard browning and formation of brown pigments (Maskan, 2001; Rhim *et al*., 1989; Lopez *et al*., 1997). There was less total colour change at 80^{o}C for the dried green kiwifruit and highest total colour change at 100^{o}C for the dried gold kiwifruit.

Table 6 presents the chroma, hue angle and browning index as calculated using equations 12, 13 and 14 for green and gold kiwifruits. The initial values for chroma, hue angle and browning index of green kiwifruit were lower than those of gold kiwifruit. The initial and final values for chroma decreased for gold kiwifruit at all temperatures up to 80^{o}C for the green kiwifruit. Maskan (2001) also reported the decrease of the initial and final values of chroma for hot air drying of green kiwifruit. The initial and final values for hue angle decreased for gold kiwifruit and increased for green kiwifruit. However, Maskan (2001) found that

Table 3. Experimental and predicted constant rate period (CRP) drying rates of green and gold kiwifruit slices using an air velocity of 0.20 m/s at ambient humidity and different temperatures.

Data	Drying temperature (°C)	Ambient temperature (°C)	Ambient relative humidity (%)	Humidity ratio of air (kg water/ kg dry Air)	Specific volume of air (m^3/ kg dry Air)	Drying air wet bulb temperature (°C)	Weight of sample (kg)	CRP drying rate (kg water/kg dry solids.min) Experimental	Predicted	Percentage difference (%)
Green kiwifruit										
1	60	20.5	37.5	0.0056	0.839	25.0	0.1267	0.0378	0.0380	0.53
2	60	20.0	47.0	0.0068	0.840	25.5	0.1286	0.0338	0.0346	2.37
3	80	19.0	43.0	0.0058	0.835	29.5	0.1306	0.0553	0.0519	6.15
4	80	21.0	37.5	0.0056	0.841	29.5	0.1276	0.0607	0.0547	9.88
5	100	20.5	43.0	0.0064	0.841	34.0	0.1266	0.0782	0.0688	12.02
6	100	20.5	36.0	0.0056	0.839	33.5	0.1258	0.0831	0.0749	9.87
Mean±95% CI		20.3±0.7	41.7±4.5	0.0060±0.0005	0.839±0.002					
Gold kiwifruit										
7	60	25.0	32.5	0.0062	0.853	25.0	0.1270	0.0374	0.0395	5.61
8	60	26.5	30.5	0.0066	0.858	25.5	0.1287	0.0364	0.0396	8.79
9	80	24.0	30.5	0.0056	0.849	29.5	0.1190	0.0633	0.0613	3.16
10	80	24.0	29.0	0.0052	0.849	29.5	0.1220	0.0624	0.0584	6.41
11	100	24.5	30.0	0.0058	0.851	33.5	0.1299	0.0782	0.0704	9.97
12	100	25.0	29.5	0.0058	0.853	33.5	0.1294	0.0762	0.0665	12.73
Mean±95% CI		24.8±1.0	30.3±1.3	0.0059±0.0005	0.852±0.004					

Note: CI = confidence interval; Available drying area (A) = 0.0583 m^2

Table 4. Experimental and predicted drying times of green and gold kiwifruit slices using an air velocity of 0.20 m/s at ambient humidity and different temperatures.

Data	Mi (kg water/ kg dry solids)	M_r (kg water/ kg dry solids)	M_f (kg water/ kg dry solids)	Experimental drying time (minutes)	Constant rate period time (minutes)	1st falling rate period time (minutes)	2nd falling rate period time (minutes)	Predicted drying time (minutes)	Percentage difference (%)
Green kiwifruit									
1	5.747	-1.404	0.187	345	51	110	149	310	10.01
2	5.329	-1.621	0.196	348	53	107	151	311	10.73
3	5.546	-1.725	0.168	210	36	66	87	189	10.00
4	5.748	-1.526	0.174	210	37	59	89	185	11.90
5	5.417	-1.632	0.151	114	35	29	43	107	6.14
6	5.889	-1.258	0.172	114	37	31	41	109	4.39
Gold kiwifruit									
7	6.076	-1.794	0.266	330	52	113	157	322	2.42
8	6.305	-2.347	0.259	333	63	108	142	313	6.00
9	6.082	-2.901	0.192	192	36	56	81	173	9.90
10	5.916	-1.913	0.204	260	37	52	178	267	2.69
11	5.720	-2.242	0.164	138	29	38	62	129	6.52
12	5.331	-2.707	0.194	120	25	39	48	112	6.67

where: M_i = initial moisture content; M_r = residual moisture content; M_f = final moisture content

the initial and final values for hue angle decreased for hot air drying of green kiwifruit. The initial and final values for browning index increased for green and gold kiwifruits and at all temperatures. This is in concurrence with the findings of Maskan (2001) for hot air drying of green kiwifruit. The final values for chroma of the dried green kiwifruit increased while the dried gold kiwifruit decreased with higher temperature. The final values for hue angle of dried green and gold kiwifruits decreased at higher temperature. Lastly, the final values for browning index of dried green and gold kiwifruits increased at higher temperature.

Ascorbic acid contents of green and gold kiwifruits

The mean values of ascorbic acid and moisture contents of green and gold kiwifruits are shown in Table 7. The initial ascorbic acid content of green kiwifruit ranged from 536 to 600 mg/100g dry solds which encompassed the value of 576 mg/100g dry solids for green kiwifruit (Salunkhe *et al*., 1991). While the initial ascorbic acid content of gold kiwifruit ranged from 528 to 641 mg/100g dry solids which is close to the value of 641 mg/100g dry solids for gold kiwifruit (Lesperance, 2009). The initial and final ascorbic acid contents of dried green and gold kiwifruits at 60 and 80°C were not significantly different from each other ($P<0.05$). The results obtained were a bit surprising and so repeat measurements were done but the values obtained were still in the same range as the previous results. This means that there was not much change in the ascorbic acid content of fresh and dried green and gold kiwifruits at these temperatures. But there was about 19% decrease in the ascorbic acid contents of dried green and gold kiwifruits after drying at 100°C. In contrast Kaya *et al*. (2009) found that there was considerable ascorbic acid loss in drying green kiwifruit at 65°C. The difference

Table 5. Colour values and total colour change for green and gold kiwifruits.

Sample/Drying temperature	Initial L*	Final L*	Initial a*	Final a*	Initial b*	Final b*	Total colour change (no unit)
Green kiwifruit							
60°C	56.91	48.16	-12.61	1.02	36.19	30.38	17.20
80°C	56.32	57.19	-12.84	0.17	34.61	33.66	13.07
100°C	56.23	58.95	-12.67	2.69	34.21	40.62	16.89
	ns	**	ns	**	ns	**	**
Gold kiwifruit							
60°C	69.11	57.31	-3.08	6.45	49.92	39.76	18.26
80°C	69.33	57.98	-4.48	7.50	48.47	40.70	18.27
100°C	69.99	52.16	-3.86	10.70	48.96	37.80	25.59
	ns	**	ns	**	ns	**	**

Note: ns – not significant ** - significant at $P<0.01$

Table 6. Chroma, hue angle and browning index for green and gold kiwifruits.

Sample/Drying temperature	Initial chroma (no unit)	Final chroma (no unit)	Initial hue angle (degrees)	Final hue angle (degrees)	Initial browning index (no unit)	Final browning index (no unit)
Green kiwifruit						
60°C	38.32	30.39	70.79	88.09	73.93	94.25
80°C	36.91	33.66	69.65	89.72	68.70	83.73
100°C	36.47	40.70	69.68	86.22	67.66	109.79
	ns	**	ns	**	ns	**
Gold kiwifruit						
60°C	50.01	40.27	86.48	80.79	110.58	116.34
80°C	48.68	41.38	84.72	79.57	102.98	119.69
100°C	49.11	39.29	85.50	74.19	103.90	131.27
	ns	**	ns	**	ns	**

Note: ns – not significant ** - significant at $P<0.01$

Table 7. Mean and 95% confidence interval of ascorbic acid and moisture contents for green and gold kiwifruits.

Sample/Drying temperature	Initial ascorbic acid (mg/100g dry solids)	Initial moisture content (kg water/kg dry solids)	Final ascorbic acid (mg/100g dry solids)	Final moisture content (kg water/kg dry solids)	% Decrease
Green kiwifruit					
60°C	536±28	5.08±0.15	554±39	0.22±0.01	0
80°C	600±39	5.05±0.09	575±23	0.18±0.01	0
100°C	552±25	5.25±0.16	446±27	0.19±0.00	19.2
Gold kiwifruit					
60°C	641±19	5.18±0.12	676±44	0.22±0.01	0
80°C	580±17	5.30±0.10	620±46	0.22±0.01	0
100°C	528±41	6.14±0.04	428±16	0.23±0.00	18.9

observed was probably due to longer drying time that the green kiwifruit samples were subjected to which was about 12 hours for Kaya *et al*. (2009) work and about 6 hours for this study. The longer the drying time would result to more ascorbic acid degradation in the kiwifruit sample.

Optimum temperature for drying of kiwifruit slices

From the drying characteristics results, the higher the drying temperature used for drying kiwifruits the shorter the drying time. However, the total colour change and browning index were lowest at 80°C for green kiwifruit and 60-80°C for the gold kiwifruit. Hence, in order to have a faster drying but still have an acceptable dried product qualities kiwifruits can be dried at an optimum temperature of 80°C.

Conclusions

The hot air drying of green and gold kiwifruit slices consists of a constant rate period (CRP) and two parts of falling rate period (FRP). The CRP drying rate, first and second FRP drying coefficients increase with drying temperature for both the green and gold kiwifruit slices. The first critical moisture content (CMC) and the dynamic equilibrium MC decrease with drying temperature for both the green and gold kiwifruit slices. The second CMC for both green and gold kiwifruit slices were not affected by drying temperature.

The CRP drying rate can be predicted using a heat balance equation. The first and second FRP of the green kiwifruit gave activation energies of 26.5 and 23.6 kJ/mole, respectively. While the first and second FRP of the gold kiwifruit yielded activation energies of 20.1 and 19.3 kJ/mole, respectively.

The values for chroma of the dried green kiwifruit increased while the dried gold kiwifruit decreased with higher temperature as compared with fresh samples. The values for hue angle of dried green and gold kiwifruits decreased at higher temperature. Lastly, the values for browning index of dried green and gold kiwifruits increased at higher temperature.

There was not much change on the ascorbic acid contents of fresh and dried green and gold kiwifruits when drying at 60 and 80^{o}C. But there was about 19% decrease in the ascorbic acid content of dried green and gold kiwifruits after drying at 100^{o}C.

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