International Food Research Journal 19(1): 353-362 (2012)

Response surface methodology for optimisation of hot air drying of blackcurrant concentrate infused apple cubes

*Diamante, L. M. and Yamaguchi, Y.

Department of Wine, Food and Molecular Biosciences, Lincoln University, Christchurch, New Zealand

Abstract: Response surface methodology was used to investigate the effects of temperature, air velocity and loading density on the drying of infused apple and to determine the optimised conditions for hot air drying. The drying behaviour at different temperatures, air velocities and loading densities of infused apple cubes behaved similarly to fresh and osmotically pre-treated apples. The hot air drying of infused apple cubes consisted of a very short constant rate period and two falling rate periods. The drying of the samples was most influenced by temperature followed by air velocity, then loading density. The optimised conditions for drying the infused apple cubes were a drying temperature of 80°C, air velocities of 1.50 to 1.85 m/s and loading densities of 6.35 to 7.08 kg/m^2, which resulted in short drying times of 99 to 104 minutes.

Keywords: Apple, temperature, air velocity, loading density, hot air drying

Introduction

Apples are consumed either fresh or in processed forms such as juice, jam and marmalade and dried apples. Dried apples can be consumed directly or treated as a secondary raw material (Velic *et al*., 2004; Doymaz, 2009). Thus, it is very important to define the optimal parameters under which the characteristics of fresh apples can be preserved. One way of producing dried apples of good quality is to use a pre-drying treatment, such as osmotic dehydration (Simal *et al*., 1997; Nieto *et al*., 1998; Mandala *et al*., 2005; Altares *et al*., 2009). Apple juice concentrate can be used to replace the sugar syrup during osmotic dehydration of apple slices/cubes in order to produce dried products with natural sugar. In addition, the apple slices/cubes can be infused with a fruit juice concentrate to improve their nutritional qualities.

In order to attain a better quality dehydrated product, there is a need to understand the drying process by determining the drying characteristics of the sample at different drying conditions. Diamante *et al*. (2010) and Ihns *et al*. (2011) described the process of determining these drying characteristics for kiwifruit and apricot slices, respectively. Important drying conditions include temperature, air velocity and loading density. Dried apples can be processed by pre-treating the fresh apple cubes with a mixture of apple juice concentrate (AJC) and blackcurrant concentrate (BCC). Blackcurrant is a highly nutritious fruit that is rich in vitamin C, anthocyanins and polyphenols (Miller and Rice-Evans, 1997; Hummer and Barney, 2002; Mattila *et al*., 2011).

The AJC enables the osmotic dehydration of the samples while the BCC enriches the samples by infusing them with vitamin C, anthocyanins and polyphenols. The infused apple cubes can then be dried using a hot air dryer to produce a chewy dehydrated raisin-like product with a blackcurrant colour. The blackcurrant juice colour (maroon) of the dried apple cubes will be more attractive to consumers than the standard dried apples.

Response surface methodology (RSM) is a collection of statistical and mathematical techniques that has been successfully used for developing, improving and optimising processes (Myers *et al*., 2009). RSM enables a reduction in the number of experimental trials needed to evaluate multiple parameters and their interactions, thus, requiring less time and labour. RSM has been widely applied for optimising processes in the food industry (Kumar *et al*., 2009; Shih *et al*., 2009; Sobukola *et al*., 2009; Wang *et al*., 2010; Mercali *et al*., 2011; Suresh Kumar and Devi, 2011).

There are already a number of studies that have been carried out on fresh apples (Uretir *et al*., 1996; Velic *et al*., 2004; Akpinar, 2006; Menges and Ertekin, 2006; Kaya *et al*., 2007; Kaleta and Gornicki, 2010) and osmotically pre-treated apples (Simal *et al*., 1997; Vergara *et al*., 1997; Schulz *et al*., 2007) using these different drying conditions. However, very little information is available on apple cubes infused with fruit juice concentrate, hence, this study was conducted: to determine a difference in their drying behaviour with various factors and optimised the conditions for hot air drying of infused apple cubes.

Materials and Methods

Materials

Granny Smith apples were obtained from a local supermarket in Christchurch, New Zealand. The

*Corresponding author.
Email: *Lemuel.Diamante@lincoln.ac.nz*
Tel: +64 3 325-3838/8015; Fax: +64 3 325-3851

apples were stored at 4°C in a chiller until used in the experiments (up to 5 days). The apples were cut into cubes (1.2 cm x 1.2 cm x 1.2 cm). Apple juice concentrate (AJC) (70°Brix) was obtained from a local supplier while the blackcurrant concentrate (BCC) (65°Brix) was procured from New Zealand Pharmaceuticals, Ltd, Palmerston North, New Zealand. A syrup mixture of 80% AJC and 20% BCC (69°Brix) was used for infusing apple cubes for 24 hours at atmospheric conditions. After infusion, the samples were rinsed with water for about 30 seconds then drained for 5 minutes to lessen the stickiness of the samples drying experiments.

Hot air drying

The hot air dryer consisted of a fan-heater, metal pipe and drying tray (Figure 1). The fan-heater was connected to an electronic controller and operated through a laptop. The metal pipe was attached to the end of the fan-heater to increase the air velocity. The drying tray was connected to an electronic weighing balance (Sartorius ED5201, Germany) for monitoring the weight loss of the sample where its output was recorded by another laptop. The sample placed inside the drying tray was contained inside a short aluminium tube to prevent the sample from spreading as it started to dry out. The metal pipe discharging the hot air and the drying tray were placed inside an insulated cabinet to reduce the temperature fluctuations. Drying was carried out to a final moisture content of about 0.50 kg water/kg dry solids (DS) at temperatures of 60±1, 70±1 and 80±1°C and a constant air velocity of 0.20 m/s flowing perpendicularly to the sample. The drying temperature and ambient temperature and relative humidity were monitored using data loggers (Tinytag Ultra2, United Kingdom) during the whole duration of the experiment. A Psychrometric Chart (Carrier, USA) was used in determining the ambient humidity of the air.

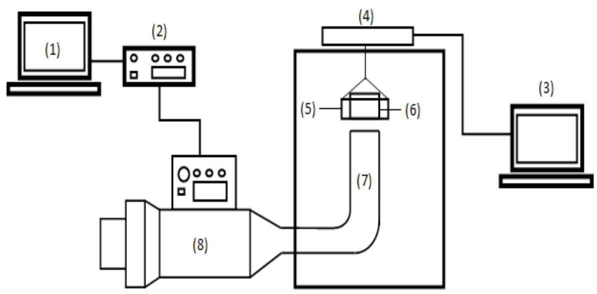


Figure 1. Hot air dryer used in the experiments (1- laptop used for controlling the heater; 2- electronic controller for the heater; 3- laptop used for the data logging sample weights; 4- electronic weighing balance; 5- drying tray; 6- aluminium tube; 7- metal pipe; and 8 - fan-heater).

Moisture content determination

At the end of the experiments, the moisture content of the dried samples was determined using the same equipment and method, as described in Ihns *et al*. (2011).

Determination of drying characteristics and drying time prediction

The drying curves and drying rate curves of the different samples were obtained and were used to determine the drying characteristics (constant rate period (CRP) drying rate, falling rate period (FRP) drying coefficient, critical moisture content (CMC) and equilibrium moisture content (EMC)) of the different samples using the procedure of Diamante *et al*. (2010). The predicted drying times were determined based on the derived drying characteristics and assumed initial and final moisture contents, using the method of Toledo (2007).

Experimental design

A Box-Behnken RSM design was used to derive mathematical models for describing the effects of the independent variables on the dependent variables (Myers *et al*., 2009). Three independent variables coded as -1, 0 and 1 were temperature (X_1), air velocity (X_2) and loading density (X_3). Three levels of each of the three independent variables were chosen for the study (Table 1). The dependent variables determined were CRP drying rate (Y_1), first FRP drying coefficient (Y_2), second FRP drying coefficient (Y_3), first critical MC (Y_4), second critical MC (Y_5) and equilibrium MC (Y_6) of the infused apple cubes.

Statistical analyses

The data were analysed using Design Expert 8 (Stat-Ease, Minneapolis, MN, USA) to obtain a quadratic mathematical model, as shown below,

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_1X_2 + a_5X_1X_3 + a_6X_2X_3 + a_7X_1^2 + a_8X_2^2 + a_9X_3^2$$

where: Y = dependent variable (actual values) (drying characteristics)

$a_0, a_1, a_3, a_4, a_5, a_6, a_7, a_8, a_9$ = coefficients

X_1 (temperature), X_2 (air velocity), X_3 (loading density) = independent variables coded as -1, 0 and 1

Analyses of variance were performed on the coefficients of the quadratic model and the probability level was used as the basis for determining the statistical significance of the coefficients for the different factors.

Table 1. Box Behnken response surface methodology design for hot air drying of infused apple cubes.

Coded Factors			Uncoded Factors		
Temperature	Air Velocity	Loading Density	Temperature (°C)	Air Velocity (m/s)	Loading Density (kg/m^2)
-1	-1	0	60	1.5	7.5
1	-1	0	80	1.5	7.5
-1	1	0	60	3.5	7.5
1	1	0	80	3.5	7.5
-1	0	-1	60	2.5	5
1	0	-1	80	2.5	5
-1	0	1	60	2.5	10
1	0	1	80	2.5	10
0	-1	-1	70	1.5	5
0	1	-1	70	3.5	5
0	-1	1	70	1.5	10
0	1	1	70	3.5	10
0	0	0	70	2.5	7.5
0	0	0	70	2.5	7.5
0	0	0	70	2.5	7.5

Using the quadratic model for each dependent variable, values were obtained at various conditions of temperature, air velocity and loading density and then used in making the surface plots using the SigmaPlot 11.0 (Systat Software Inc., San Jose, CA, USA).

An optimization was carried using the Design Expert 8 software, based on the procedure developed by Derringer and Suich (1980), to find the conditions (drying temperature, air velocity and loading density) that would give the maximum CRP drying rate, first and second FRP drying coefficients and minimum second critical and equilibrium moisture contents of the infused apple cubes. This method solved the problem of multiple responses through the use of a desirability function combining all responses into one measurement (Eren and Kaymak-Ertekin, 2007; Erbay and Icier, 2009). The second FRP drying coefficient was given a maximum weight of 5 while the other drying characteristics were each given a weight of 1.

Results and Discussion

Drying infused apples cubes at the different drying conditions

Figure 2 shows the three replicated runs of hot air drying curves of infused apple cubes using a drying temperature of 70°C, air velocity of 2.5 m/s, loading density of 7.5 kg/m^2 and at ambient humidity. The general shapes of the drying curves of the samples were very similar, which suggested that the data were good replicates. The drying curves of the samples behaved similarly to the drying curves of osmotically pre-treated apple cubes at different temperatures (30 to 90°C) (Simal *et al.*, 1997).

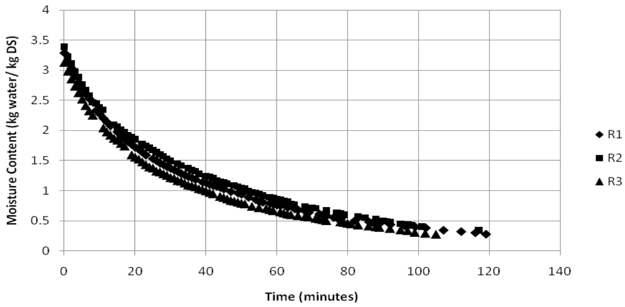


Figure 2. Drying curves of infused apple cubes using a drying temperature of 70°C, air velocity of 2.5 m/s, loading density of 7.5 kg/m^2 and at ambient humidity for three replicates.

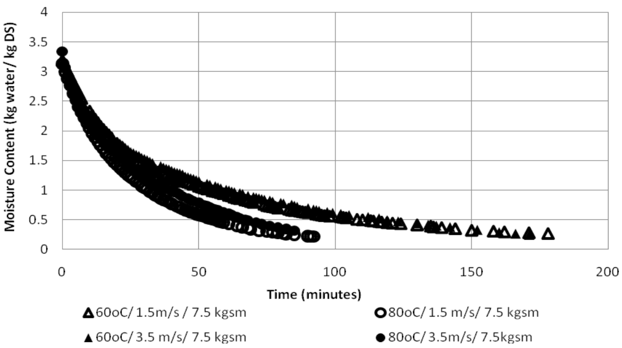


Figure 3. Drying curves of infused apple cubes using a loading density of 7.5 kg/m^2, at ambient humidity, drying temperatures of 60 and 80°C and air velocities of 1.5 and 3.5 m/s.

Figure 3 shows the hot air drying curves of infused apple cubes using drying temperatures of 60 and 80°C and air velocities of 1.5 and 3.5 m/s. The drying curves of the infused apple cubes behaved in a similar way as the previous section. It was observed that the higher the temperature the faster the drying of the samples and, at 80°C, the samples dried faster at higher air velocity. Velic *et al*. (2004) and Akpinar (2006) reported that the higher the temperature and air velocity the faster the drying of fresh apples. The higher the temperature the faster the drying of fresh apple slices (Menges and Ertekin, 2006; Vega-Galvez *et al* , 2008) and osmotically pre-treated apple cubes (Simal *et al*., 1997; Vergara *et al*., 1997).

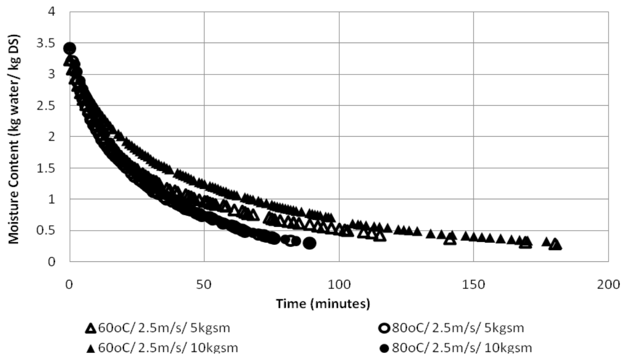


Figure 4. Drying curves of infused apple cubes using an air velocity of 2.5 m/s, at ambient humidity, drying temperatures of 60 and 80°C and loading densities of 5 and 10 kg/m^2.

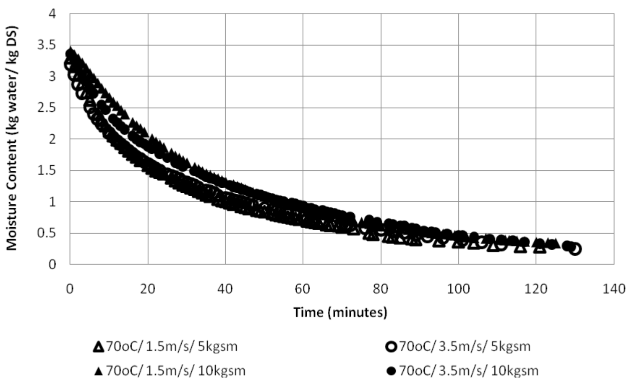


Figure 5. Drying curves of infused apple cubes using a drying temperature of 70°C, at ambient humidity, air velocities of 1.5 and 3.5 m/s and loading densities of 5 and 10 kg/m^2.

Figure 4 shows the hot air drying curves of infused apple cubes using drying temperatures of 60 and 80°C and loading densities of 5 and 10 kg/m^2. Again, the drying curves of the infused apple cubes behaved in a similar way to the previous sections. The results showed that the higher the temperature and the lower the loading density the faster the drying of the samples. The same observations were observed by Akpinar (2006) during drying of fresh apple slices at different temperatures (60 to 80°C) and sample dimensions (12.5x12.5x25 mm and 8x8x18 mm). The sample dimensions can be related to different loading densities because bigger samples would result in higher loading densities. The results showed that the higher the air velocity and the lower the loading density the faster the drying of the samples (Figure 5). Furthermore, the results showed that the loading density affected the drying of the samples more than the air velocity. The sample dimensions can be related to different loading densities because the larger samples would result in higher loading densities. However, Velic *et al*. (2004) reported that air velocity significantly affected the drying of fresh apple slices which might be due to a much greater air velocity range being used (0.64 to 2.75 m/s).

Drying characteristics of infused apple cubes under different conditions

The drying characteristics for all the drying data were derived and found to consist of a short CRP and two FRPs. Vergara *et al*. (1997) and Mandala *et al*. (2005) published the drying rate curves of osmotically dehydrated apples at different temperatures. Their drying rate curves distinctly showed two FRPs but no CRP. The results of the RSM analyses on the drying characteristics of infused apple cubes are shown in Table 2. Generally, the samples have high CRP drying rates and first FRP drying coefficients with a higher temperature and air velocity but lower loading density. The second FRP drying coefficient of the samples increased with temperature but was not affected by loading density or air velocity. The effects of temperature, air velocity and loading density of the first and second critical moisture contents were not clear. However, equilibrium moisture content of the samples decreased with increasing temperature but the effects of air velocity and loading density were not clear. A quadratic model was derived for the different drying characteristics and the analysis of variance for the coefficients is shown in Table 3. The results showed that the linear coefficients of temperature, air velocity and loading density significantly affected the CRP drying rate of the infused apple cubes. The first FRP drying coefficient of the samples was significantly affected by the linear coefficients of temperature and air velocity. The linear coefficients of temperature significantly affected the second FRP drying coefficient and equilibrium moisture content of the infused apple cubes. All the coefficients for the linear, quadratic and two-factor interaction of the temperature, air velocity and loading density had no significant effects on the first critical moisture content of the samples. However, the linear and quadratic coefficients of temperature and air velocity and the quadratic coefficient of loading density significantly affected the second critical moisture content of infused apple cubes. Lastly, the linear coefficient of temperature significantly affected the equilibrium

Table 2. Results of the response surface methodology experiments on the drying characteristics of infused apple cubes as affected by temperature, air velocity and loading density.

Temperature (°C)	Air Velocity (m/s)	Loading Density (kg/m²)	CRP Drying Rate (kg water/ kg DS.min)	1st FRP Drying Coeff. (min⁻¹)	1st Critical MC (% dry basis)	2nd Critical MC (% dry basis)	2nd FRP Drying Coeff. (min⁻¹)	Equilibrium MC (% dry basis)
60	1.5	7.5	0.0931	0.0484	290	156	0.0212	27
80	1.5	7.5	0.1192	0.0571	282	164	0.0355	15
60	3.5	7.5	0.0963	0.0656	271	174	0.0182	26
80	3.5	7.5	0.2121	0.1496	315	224	0.029	20
60	2.5	5	0.126	0.0703	294	166	0.026	28
80	2.5	5	0.1619	0.094	309	184	0.0269	10
60	2.5	10	0.0863	0.0537	290	180	0.0178	29
80	2.5	10	0.1299	0.0707	300	190	0.0306	15
70	1.5	5	0.1374	0.0776	296	175	0.0278	25
70	3.5	5	0.1524	0.0858	316	183	0.0244	25
70	1.5	10	0.0752	0.0333	286	163	0.0244	20
70	3.5	10	0.1083	0.0559	314	177	0.0183	15
70	2.5	7.5	0.1229	0.0686	319	212	0.0274	20
70	2.5	7.5	0.1242	0.0702	331	212	0.0206	15
70	2.5	7.5	0.1258	0.0874	286	200	0.0278	20

where:CRP = constant rate period; MC = moisture content; FRP = falling rate period; Coeff. = coefficient; DS = dry solids

Table 3. Coefficients for the quadratic equation of the different drying characteristics of infused apple cubes as affected by temperature, air velocity and loading density.

Drying Characteristics	Coefficient									
	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
CRP Drying Rate (Y_1)	0.12430*	0.02768**	0.01803*	-0.02225**	0.02243	0.00193	0.00453	0.00679	-0.00091	-0.00506
First FRP Drying Coefficient (Y_2)	0.07540	0.01668*	0.01756*	-0.01426*	0.01883	-0.00168	0.00360	-0.00690	-0.00213	-0.01013
Second FRP Drying Coefficient (Y_3)	0.02527	0.00485**	-0.00238	-0.00175	-0.00088	0.00298	-0.00068	0.00115	-0.00045	-0.00110
First Critical MC (Y_4)	312.00	7.6250	7.7500	-3.1250	13.0000	-1.2500	2.00000	-13.6250	-8.8750	-0.1250
Second Critical MC (Y_5)	208.00	10.7500*	12.5000*	0.2500	10.5000	-2.0000	1.50000	-11.5000*	-17.0000*	-16.500*
Equilibrium MC (Y_6)	18.33333	-6.25000**	-0.12500	-1.12500	1.50000	1.00000	-1.25000	1.45833	2.20833	0.70833

where: CRP = constant rate period; MC = moisture content; FRP = falling rate period
$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_1X_2 + a_5X_1X_3 + a_6X_2X_3 + a_7X_1^2 + a_8X_2^2 + a_9X_3^2$; X_1 = drying temperature (coded value); X_2 = air velocity (coded value); X_3 = loading density (coded value)
*- significant at $p < 0.05$; ** - significant at $p < 0.01$

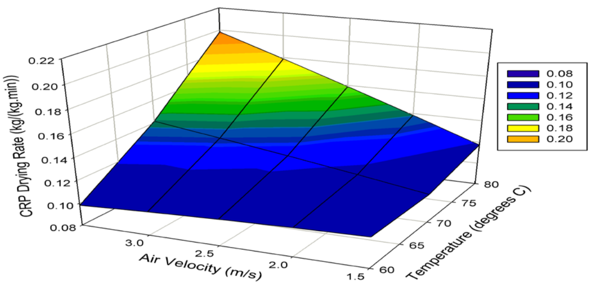
moisture content of the samples.

Effect of temperature, air velocity and loading density on the CRP drying rate

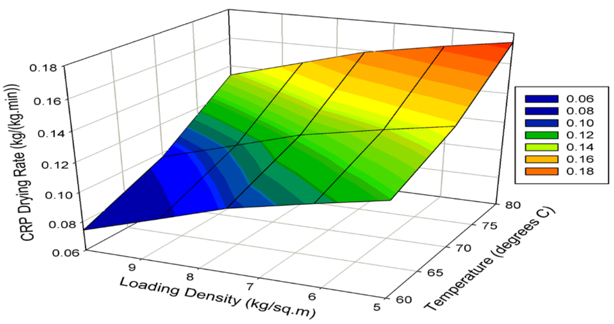
Figure 6 shows the surface plots for the CRP drying rates of the infused apple cubes as affected by temperature, air velocity and loading density. The results suggested that the CRP drying rate of the samples increased with increasing temperature (Figures 6a and 6b) and air velocity (Figures 6a and 6c) but decreased with increasing loading density (Figures 6b and 6c). Higher drying temperatures and air velocities would result to a faster initial drying of the samples while higher loading density slowed down the initial drying process, as expected from drying theory. From a heat balance equation, the CRP drying rate ($(dM/dt)_c$) can be derived (Toledo, 2007), as shown,

$$(dM/dt)_c = (h\,A\,(T_a - T_w)) / (\lambda_v\,W_{DS}) \qquad (1)$$

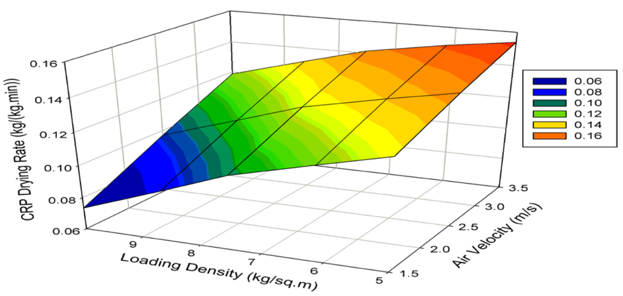
where h is the heat transfer coefficient (W/(m².°C)), A is the drying surface area (m²), T_a is the drying air temperature (°C), Tw is the drying air wet bulb temperature (°C), λv is the latent heat of vaporization of water at Tw (J/kg) and WDS is the weight of dry solids of sample (kg). Equation 1 shows that the higher the drying temperature the higher the CRP drying rate of the samples. Diamante *et al* (2010) and Inhs *et al*. (2011) also found that the CRP drying rates of fruits increased with higher temperature. The heat transfer coefficient is directly proportional to air velocity (Toledo, 2007), thus the higher the air velocity the higher the CRP drying rate. The weight of dry solids in a sample was dependent on the weight of the samples on a given tray area, hence, the lower the loading density the higher the CRP drying rate.



a) Loading Density = 7.5 kg/m^2



b) Air Velocity = 2.5 m/s



c) Temperature = 70^{o}C

Figure 6. Surface plots for the CRP drying rate of infused apple cubes as affected by temperature and air velocity (a), temperature and loading density (b), and air velocity and loading density (c) (third factor is set at the middle level).

Effect of temperature, air velocity and loading density on the first FRP drying coefficient

Figure 7 shows the surface plots for the first FRP drying coefficient of the samples as affected by temperature, air velocity and loading density. The results suggested that the first FRP drying coefficient of the samples increased with increasing temperature (Figures 7a and 7b) and air velocity (Figures 7a and 7c) but decreased with increasing loading density (Figures 7b and 7c). The observation for the effects of drying temperature and air velocity were expected, as mentioned in the previous section. However, the result for the effect of loading density was unexpected since its coefficients were found to be not significant. This meant that the observed differences shown in the surface plots were within the variations of the experiment based on the replicated runs at the centre point of the RSM design. The first FRP drying coefficient can be related to temperature using an Arrhenius-type relationship (Simal *et al*., 2005) using,

$$\ln F_1 = I - S\,(1/T_k) \quad (2)$$

$$F_1 = e^{(I-S(1/Tk))} \quad (2')$$

where F_1 is the first 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). Equation 2' shows that the higher the drying temperature the higher the first FRP drying coefficient of the samples. Diamante *et al* (2010) and Inhs *et al*. (2011) also found that the first FRP drying coefficient of the fruits increased with higher temperature. The air velocity and loading density affected the first FRP drying coefficient probably due to their strong influence at the initial stage of drying, as shown by the results of the CRP drying rate.

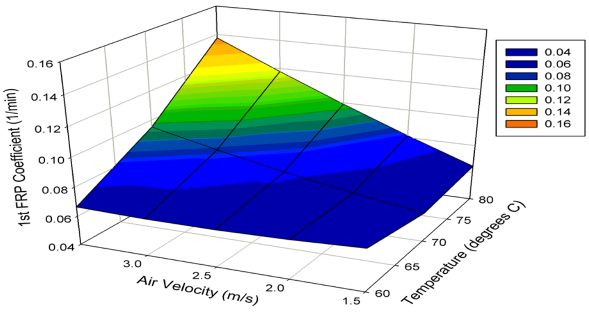
Effect of temperature on the second FRP drying coefficient

The results suggested that the second FRP drying coefficient of the samples increased with increasing temperature (Figures 8a and 8b) but decreased with air velocity and loading density. The observation for the effect of drying temperature was expected, as mentioned in the previous section. However, the results for the effects of air velocity and loading density were unexpected since their coefficients were found to be not significant. This meant that the observed differences shown in the surface plots were within the variations of the experiment based on the replicated runs at the centre point of the RSM design. The second FRP drying coefficient can also be related to temperature using an Arrhenius-type relationship (Simal *et al*., 2005) using,

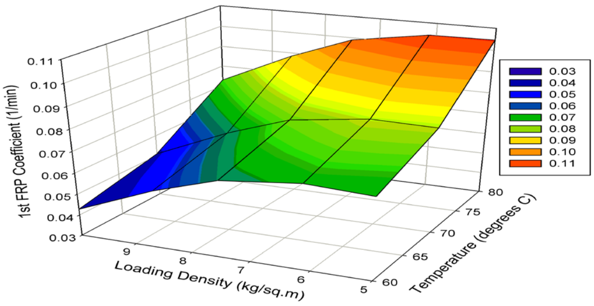
$$\ln F_2 = I - S\,(1/T_k) \quad (3)$$

$$F_2 = e^{(I-S(1/Tk))} \quad (3')$$

where F_2 is the second 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). Equation 3'



a) Loading Density = 7.5 kg/m^2



b) Air Velocity = 2.5 m/s

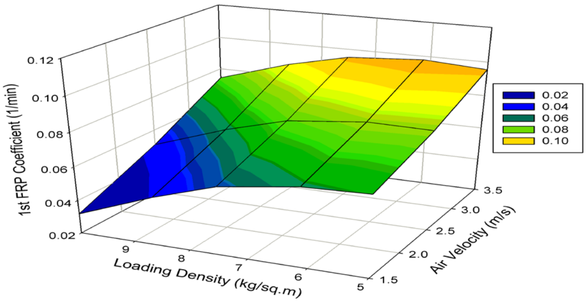
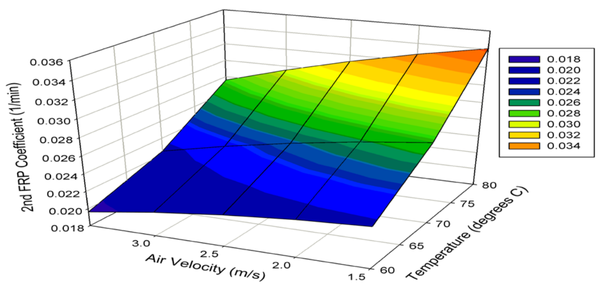


Figure 7. Surface plots for the first FRP drying coefficient of infused apple cubes as affected by affected by temperature and air velocity (a), temperature and loading density (b), and air velocity and loading density (c) (third factor is set at the middle level).



a) Loading Density = 7.5 kg/m^2

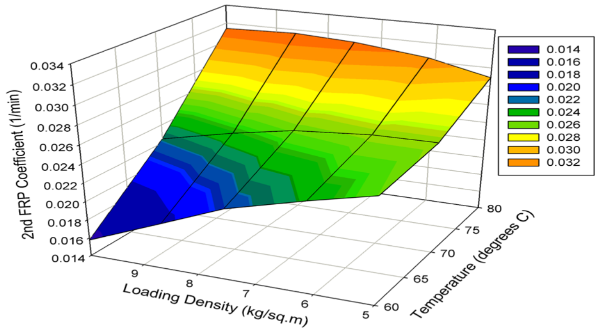


Figure 8. Surface plots for second FRP drying coefficient of infused apple cubes as affected by affected by temperature and air velocity (a), and temperature and loading density (b) (third factor is set at the middle level).

shows that the higher the drying temperature the higher the second FRP drying coefficient of the samples. Diamante *et al*. (2010) and Inhs *et al*. (2011) also found that the second FRP drying coefficient of the fruits increased with higher temperature.

Effect of temperature, air velocity and loading density on the second critical moisture content

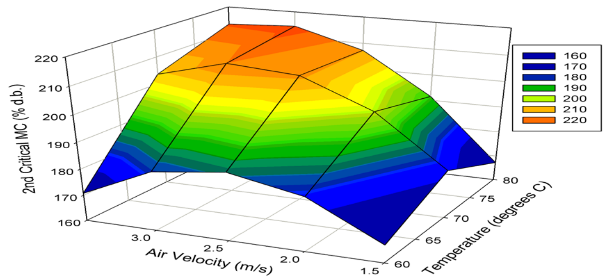
The results showed that generally the second critical moisture content of the samples had higher values at the middle range of temperature (Figures 9a and 9b), air velocity (Figures 9a and 9c) and loading density (Figures 9b and 9c). The use of the middle ranges of drying temperature, air velocity and loading density would result in a sample with higher second critical moisture content. However, Diamante *et al*. (2010) and Ihns *et al*. (2011) found that the drying temperature did not affect the second critical moisture content of fresh gold kiwifruit and apricot slices, respectively. The observed difference in the second critical moisture content was probably due to the pre-treatment of the infused apple cubes.

Effect of temperature on the equilibrium moisture content

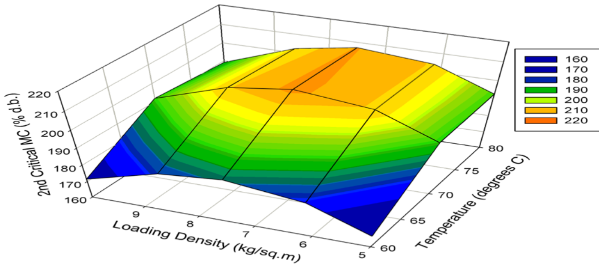
Figure 10 shows the surface plots for the equilibrium moisture content of the infused apple cubes as affected by temperature, air velocity and loading density. The results suggested that the equilibrium moisture content of the samples decreased with increasing temperature (Figures 10a and 10b) but not with air velocity and loading density. Moisture content at equilibrium usually decreases with increase in temperature (Barbosa-Canovas and Juliano, 2007). Maroulis *et al*. (1988) reported that the equilibrium moisture content of dried fruits decreased with increasing temperature.

Optimised conditions for hot air drying infused apple cubes

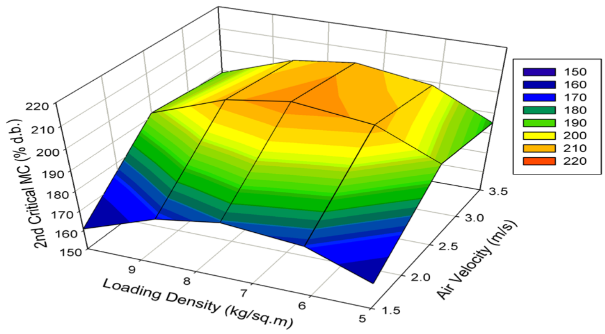
Based on the results, the CRP drying rate and the first FRP drying coefficient of the samples increased with temperature and air velocity but decreased with loading density. The second FRP drying coefficient of the samples increased with temperature but was not affected by air velocity or loading density. There was no effect of temperature, air velocity and



a) Loading Density = 7.5 kg/m2

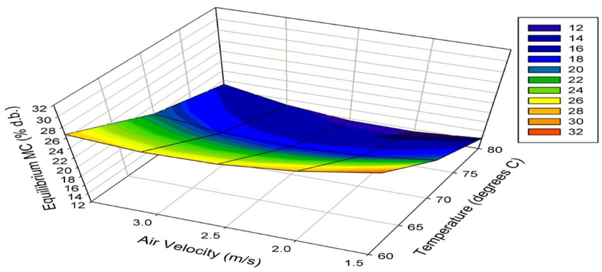


b) Air Velocity = 2.5 m/s

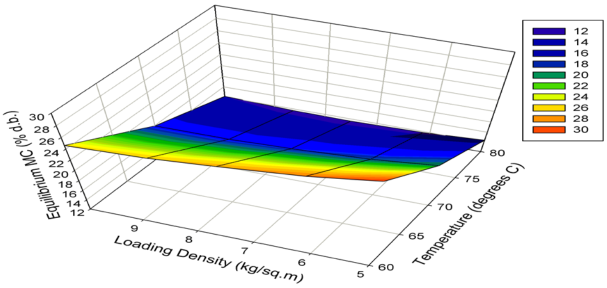


c) Temperature = 70°C

Figure 9. Surface plots for the second critical moisture content of infused apple cubes as affected by affected by temperature and air velocity (a), temperature and loading density (b), and air velocity and loading density (c) (third factor is set at the middle level).



a) Loading Density = 7.5 kg/m^2



b) Air Velocity = 2.5 m/s

Figure 10. Surface plots for the equilibrium moisture content of infused apple cubes as affected by affected by temperature and air velocity (a), and temperature and loading density (b) (third factor is set at the middle level).

loading density on the first critical moisture content of the samples. However, the second critical moisture content of the samples generally had higher values at the middle ranges of temperature, air velocity and loading density. The equilibrium moisture content of the samples was not affected by air velocity and loading density but decreased with temperature.

The predicted values for CRP drying rate, first and second FRP drying coefficients, second critical and equilibrium moisture contents of infused apple cubes using the coefficients in Table 3, at different conditions, were obtained using the optimization procedure. By applying desirability function method, five solutions were obtained for the optimum covering criteria with desirability values of 0.68 to 0.69. The predicted values of the drying characteristics at these optimum conditions were used in predicting the drying times and the results shown in Table 4. The use of a drying temperature of 80°C, air velocities of 1.50 to 1.85 m/s and loading densities of 5.98 to 7.08 kg/m^2 resulted in the time in the CRP of 2.18 to 2.36 minutes, time in the first FRP of 14.62 to 18.38 minutes, time in the second FRP of 82.34 minutes and total drying times of 99 to 104 minutes.

Conclusions

The drying behaviour at different temperatures, air velocities and loading densities of AJC/BCC infused apple cubes behaved in a similar way to fresh and osmotically pre-treated apples. The hot air drying of infused apple cubes consisted of a very short CRP and two FRPs. The CRP drying rate and the first FRP drying coefficient of the samples increased with temperature and air velocity but decreased with loading density. The second FRP drying coefficient of the samples increased with temperature but was not affected by air velocity or loading density. There was no effect of temperature, air velocity and loading density on the first critical moisture content of the samples. However, the second critical moisture content of the samples generally had higher values at the middle ranges of temperature, air velocity and loading density. The equilibrium moisture content

Table 4. Predicted drying times for infused apple cubes using the quadratic models to derive the drying characteristics at optimised conditions of temperature, air velocity and loading density (Assumed M_i = 3.30 kg water/kg dry solids; M_{c1} = 3.00 kg water/kg dry solids; and M_f = 0.25 kg water/kg dry solids).

Temperature		Air Velocity		Loading Density		Desirability	Drying Times (minutes)			
Coded	Uncoded	Coded	Uncoded	Coded	Uncoded		CRP	First FRP	Second FRP	Total
1.00	80°C	-0.65	1.85 m/s	-0.21	6.98 kg/m²	0.678	2.36	14.62	82.39	99.37
1.00	80°C	-0.82	1.68 m/s	-0.17	7.08 kg/m²	0.686	2.33	15.87	82.81	101.00
1.00	80°C	-0.86	1.64 m/s	-0.28	6.80 kg/m²	0.687	2.31	16.26	83.17	101.74
1.00	80°C	-1.00	1.50 m/s	-0.46	6.35 kg/m²	0.684	2.35	18.38	82.34	103.07
1.00	80°C	-0.82	1.68 m/s	-0.61	5.98 kg/m²	0.684	2.18	15.81	86.42	104.41

where: M_i = initial moisture content; M_{c1} = first critical moisture content; M_f = final moisture content; CRP = constant rate period; FRP = falling rate period

of the samples is not affected by air velocity and loading density but decreased with temperature. The use of the highest temperature (80°C) and low to medium levels of air velocity and loading density would give shorter drying times for the infused apple cubes.

References

Akpinar, E. K. 2006. Determination of suitable thin layer drying curve model for some vegetables and fruits. Journal of Food Engineering 73: 75-84

Altares, L., Chiralt, A. and Gonzalez-Martinez, C. 2009. Effect of the impregnated solute on air drying and rehydration of apple slices (cv. Granny Smith). Journal of Food Engineering 91: 305-310.

Barbosa-Canovas, G. V. and Juliano, P. 2007. Desorption phenomena in food dehydration processes. In Water Activity in Foods: Fundamentals and Applications (G. V. Barbosa-Canovas, A. J. Fontana, Jr., S. J. Schmidt and T. P. Labuza,editors). Blackwell Publishing Profesional, Ames, Iowa, USA.

Derringer, G. and Suich, R. 1980. Simultaneous optimization of several response variables. Journal of Quality Technology 12: 214-219.

Diamante, L., Durand, M., Savage, G. and Vanhanen, L. 2010. Effect of temperature on the drying characteristics, colour and ascorbic acid content of green and gold kiwifruits. International Food Research Journal 17: 441-451.

Doymaz, I. 2009. An experimental study on drying of green apples. Drying Technology 45: 1956-1962.

Erbay, Z. and Icier, F. 2009. Optimization of hot air drying of olive leaves using response surface methodology. Journal of Food Engineering 91: 533-541.

Eren, I. and Kaymak-Ertekin, F. 2007. Optimization of osmotic dehydration of potato using response surface methodology. Journal of Food Process Engineering 79: 344-352.

Humner, K.E. and Barney, D.L. 2002. Currants. HortTechnology 12: 377-387.

Ihns, R., Diamante, L.M., Savage, G. and Vanhanen, L. 2011. Effect of temperature on the drying characteristics, colour, antioxidant and beta-carotene contents of two apricot varieties. International Journal of Food Science and Technology 46: 275-283.

Kaleta, A. and Gornicki, K. 2010. Evaluation of drying models of apple (var. McIntosh) dried in a convective dryer. International Journal of Food Science and Technology 45: 891-898.

Kaya, A., Aydin, O., and Demirtas, C. 2007. Drying kinetics of red delicious apples. Biosystems Engineering 96: 517-524.

Kumar, Y.S., Prakasam, R.S., and Reddy, O.V.S. 2009. Optimisation of fermentation conditions for mango (*Mangifera indica* L.) wine production by employing response surface methodology. International Journal of Food Science and Technology 44: 2320-2327.

Mandala, I.G., Anagnostaras, E.F. and Oikonomou, C.K. 2005. Influence of osmotic dehydration conditions on apple air-drying kinetics and their quality characteristics. Journal of Food Engineering 69: 307-316.

Maroulis, Z.B., Tsami, E. And Marinos-Kouris, D. 1988. Application of the GAB model on the moisture sorption isotherms for dried fruits. Journal of Food Engineering 7: 63-78.

Mattila, P.H., Hellstrom, J., McDougall, G., Dobson, G., Pihlava, J.M., Tiirikka, T., Stewart and Karjalainen, R. 2011. Polyphenol and vitamin C contents in European commercial blackcurrant juice products. Food Chemistry. doi:10.1016/j.foodchem.2011.01.129.

Menges, H. O. and Ertekin, C. 2006. Mathematical modelling of thin layer drying of golden apples. Journal of Food Engineering 77: 119-125.

Mercali, G.D., Marczak, L.D.F., Tessaro, I.C. and Norena, C.P.Z. 2011. Evaluation of water, sucrose and NaCl effective diffusivities during osmotic dehydration of banana (*Musa sapientum, shum*.). LWT – Food Science and Technology 44: 82-91.

Miller, N.J. and Rice-Evans, C.A. 1997. The relative contributions of ascorbic acid and phenolic antioxidants to the total antioxidant activity of orange and apple fruit juices and blackcurrant drink. Food Chemistry 60: 331-337.

Myers, R.H., Montgomery, D.C. and Anderson-Cook, C.M. 2009. Response Surface Methodology: Process and Product Optimization Using Designed Experiments. John Wiley & Sons, Inc., Hoboken, New Jersey, USA.

Nieto, A., Salvatori, D., Castro, M.A. and Alzamora, S.M. 1998. Air drying behaviour of apples as affected by blanching and glucose impregnation. Journal of Food Engineering 36: 63-79.

Schultz, E.L., Mazzuco, M.M., Machado, R.A.F., Bolzan, A., Quadri, M.B. and Quadri, M.G.N. 2007. Effect of pre-treatments on drying, density and shrinkage of apple slices. Journal of Food Engineering 78: 1103-1110.

Shih, M.C., Yang, K.T. and Kuo, S.T. 2009. Optimization process of black soybean natto using response surface methodology. Journal of Food Science 74: M294-M301.

Simal, S., Deya, E., Frau, M. and Rosello, C. 1997. Simple modelling of air drying curves of fresh and osmotically pre-dehydrated apple cubes. Journal of Food Engineering 33: 139-150.

Sobukola, O.P., Awonorin, S.O., Oladimeji, S.L. and Olukayode, B.F. 2009. Optimization of pre-fry drying of yam slices using response surface methodology. Journal of Food Process Engineering 33: 626-648.

Suresh Kumar, P. and Devi, P. 2011. Optimization of some process variables in mass transfer kinetics of osmotic dehydration of pineapple slices. International Food Research Journal 18: 221-238.

Toledo, R. T. 2007. Fundamentals of Food Process Engineering. Third edition. Springer Science+Business Media, New York, New York.

Uretir, G., Ozilgen, M. and Katnas, S. 1996. Effects of velocity and temperature of air on the drying rate constants of apple cubes. Journal of Food Engineering 30: 339-350.

Velic, D., Planinic, S., Tomas, S. and Bilic, M. 2004. Influence of air flow velocity on kinetics of convection apple drying. Journal of Food Engineering 64: 97-102.

Vergara, F., Amezaga, E., Barcenas, M.E. and Welti, J. 1997. Analysis of the drying processes of osmotically dehydrated apple using the characteristic curve model. Drying Technology 15: 949-963.

Wang, R., Zhang, M. and Mujumdar, A.S. 2010. Effect of food ingredient on microwave freeze drying of instant vegetable soup. LWT – Food Science and Technology 43: 1144-1150.