Determination of the Drying Characteristics of Black Carrot Pulp During Drying in a Microwave Oven

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Abstract. In this study the drying behaviour of black carrot pulp was investigated in a microwave oven. The effect of different sample thicknesses (3, 5, and 7mm) and microwave powers (180, 540, and 900W) on the drying time of the samples were examined. The total drying times of the black carrot pulp samples ranged between 510 to 2430 seconds. Three thin-layer drying models, namely, Logarithmic, Two-Term, and Wang and Singh models were fitted to drying data and Two-Term model was found to satisfactorily describing the drying behaviour of black carrot pulp. The calculated effective moisture diffusivity values ranged between $2.822\text{x}10^{-7}$ and $8.532\text{x}10^{-6}$ m^2s^{-1}.The colour values of the samples were measured and it was observed that the best preservation of the reddish colour and L* (the brightness level) were obtained at 7 mm thickness and 180W microwave power. The flow ability and cohesiveness values were found to be in the medium level.

Keywords:

Black Carrot,
Microwave,
Drying Behavior,
Powder Properties

INTRODUCTION

Black carrot (*Daucus carota L.*) which contains high amounts of anthocyanins and antioxidants have a high amount of consumption in Turkey as the raw material of turnip juice, salad, pickles, and fruit juice. Black carrots contain aproximately 1750mg/kg anthocyanin, where anthocyanins are pigments which give purple, blue, and red color for fruit, vegetables, and flowers (Gür et al., 2013). With the intense anthocyanin content black carrots may have an inhibitory effect on cancer, diabetes, heart, and vascular diseases. Also, black carrot extract can be used as an alternative to synthetic colorants since black carrot anthocyanins are stable against heat, light, and pH increase (Gür et al., 2013).

In order to prolong the shelf life of black carrots and create new consumption areas canning, freezing and drying might be suitable techniques. Among these techniques drying constitutes an alternative way to increase the shelf life and consumption of black carrots by reducing physiological, microbial, and enzymatic degradation. Agricultural products continue their respiratory activity after harvesting process. Therefore they tend to deteriorate quickly. Many methods have been found to increase the post-harvest durability. One of these methods is the drying (Alibas, 2006; Ertekin and Yaldız, 2004). Drying can be accomplished in many different methods such as spray, freeze, sun, and microwave drying. The most common drying methods are sun and convective drying. These drying techniques have some disadvantages such as long drying time, microbial growth, loss of nutritional content and energy, etc. (Toğrul, 2006). For the given reasons above, the alternative drying methods must be used for decreasing the drying time and energy consumption and preventing the loss of nutritional compounds (Alibas- Özkan et al., 2007). Therefore in recent years microwave drying has become a widely used method due to low drying time and energy consumption and the protection of nutrients content (Alibas, 2006). The microwave drying method was used for several kind of foods such as nettle (Alibas, 2007; Alibas, 2010), Swiss chard leaves (Alibas, 2006), parsley (Soysal, 2004), spinach (Alibas- Özkan et al., 2007), mint (Özbek and Dadalı, 2007), yellow pea (Kadlec et all, 2001), celery leaves (Demirhan and Özbek, 2011), and pursuance (Demirhan and Özbek, 2010).The aims of this study are to observe the effects of different microwave powers and thicknesses on the drying characteristics of black carrot pulp, and to determine the powder properties of black carrot powders.

MATERIAL AND METHODS

Material

The black carrots were supplied from a local supermarket in Izmir, Turkey and were washed, peeled and the juice was removed after processing by a home type extractor (Premier PRJ-607, Turkey). The obtained black carrot pulp was placed in a layer of 3, 5, and 7mm in the petri dishes.

Methods

Microwave Drying

The experiments were performed in a domestic microwave oven (Arçelik MD 595, Turkey) at 2450 MHz with a maximum output power of 900 W. Drying experiments were performed at three different microwave powers (180, 540, and 900W). In order to determine the moisture losses, petri dishes were taken out at uniform intervals (30s) and weighed by using a digital balance with 0.01 precision (Ohaus AR2140, USA). The drying experiments were completed when the weight of the sequent samples reached the same weight. The powder was obtained by grinding the dried material for one minute in a home type blender (Tefal Smart, MB450141, Turkey). The powders were stored in the aluminium-laminated polyethylene packaging materials in the dark at room temperature until further tests were carried out.

Mathematical Modelling of the Drying Data

The moisture ratio (MR) of the black carrot pulp during the microwave drying was calculated by using Eq. (1).

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

Where the M_0, M_t and M_e are representing the initial, at any time and equilibrium moisture contents (kg water/ kg dry matter), respectively. The drying data were fitted to three well-known thin layer drying models (Logarithmic, Two-Term, and Wang and Singh) (Erbay and Içier, 2009).

The goodness of fit was determined by using the coefficient of determination (R^2) and the reduced chi-square ($\chi2$) that can be described as Eqs. (2) and (3), respectively.

$$R^2 = \frac{N\sum_{i=1}^{N} MR_{pre,i} MR_{\exp,i} - \sum_{i=1}^{N} MR_{pre,i} \sum_{i=1}^{N} \mathrm{MR}_{\exp,i}}{\sqrt{(N\sum_{i=1}^{N} MR^2{}_{pre,i} - (\sum_{i=1}^{N} MR_{pre,i})^2)(N\sum_{i=1}^{N} MR^2{}_{\exp,i} - (\sum_{i=1}^{N} MR_{\exp,i})^2)}} \qquad (2)$$

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{pre,i} - MR_{\exp,i})^2}{N - n} \qquad (3)$$

Where $MR_{exp,i}$ and $MR_{pre,i}$ are the experimental, and predicted moisture ratios at observation i; N is number of the experimental data points, and n is the number of constants in the model. The higher values of the coefficient of determination (R^2) and the lower values of reduced chi-square (x^2) were chosen for the goodness of fit (Celma et al., 2008).

For the determination of the effective moisture diffusivity (D_{eff}) values of the black carrot pulp Fick's diffusion model (Eq. 4) was used;

$$MR = \frac{8}{\pi} \sum_{i=1}^{\infty} \frac{1}{(2i-1)^2} \exp\left[-(2i-1)^2 \pi^2 \frac{D_{eff}}{4L^2} t \right] \qquad (4)$$

Where t is the time (s), D_{eff} is the effective moisture diffusivity (m^2/s) and L is the thickness of samples (m). For the long drying times, a limiting case of Eq. (5) is obtained, and expressed in a logarithmic form;

$$lnMR = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}\right) t \qquad (5)$$

The effective diffusivity is typically calculated by plotting the experimental moisture ratio in versus the drying time. From Eq. (5), a plot of ln MR versus the drying time gives a straight line with the slope given in Eq. (6).

$$Slope = \frac{\pi^2 D_{eff}}{4L^2} \qquad (6)$$

Physical analyses

The moisture content of the fresh black carrot pulp and the dried black carrot pulp powder were determined according to AOAC (2000). The water activity values of the samples were measured by using Testo-AG 400, Germany, water activity measurement device. The colour values (L* (lightness), a*(greenness/redness), and b*(blueness/yellowness) of the samples were measured with the Minolta CR-400 Colorimeter, Japan, and results were expressed in accordance with the CIE Lab system.

Analysis of the powder properties

In order to determine the tapped and bulk densities, the method explained by Jinapong et al. (2008) was used. The average wettability and solubility times (seconds) of the black carrot powders were determined by using the method explained by Gong et al., (2008), and Goula and Adamopoulos (2008), respectively. The flowability and cohesiveness of the black carrot powders were evaluated in terms of Carr index (CI) (Carr, 1965) and Hausner ratio (HR) (Hausner, 1967), respectively. Both CI and HR were calculated from the bulk (ρ_{bulk}) and tapped (ρ_{tapped}) densities of the powder as shown below Eq. (7) and (8).

$$CI = \frac{(\rho_{tapped} - \rho_{bulk})}{\rho_{tapped}} x\ 100 \quad (7)$$

$$HR = \frac{\rho_{tapped}}{\rho_{bulk}} \quad (8)$$

Statistical analysis

The data were analyzed using statistical software SPSS 16.0 (SPSS Inc., USA). The data were also subjected to analysis of variance (ANOVA) and Duncan's multiple range test (α=0.05) to determine the difference between means. The drying experiments were replicated twice and all the analyses were triplicated.

RESULTS AND DISCUSSION

Drying Curves

The experimental moisture ratio (MR) values of the black carrot pulp at the different microwave powers were given in Fig 1. According to Fig. 1, it can be seen that the drying time decreased depending on the increasing of microwave power and the drying time of the samples at 540W was less than the half of the drying time at 180W.

In order to describe the drying kinetics of the black carrot pulp during drying three different semi empirical models (Logarithmic, Two-Terms, and Wang and Singh) were fitted to the experimental data and the summary of model parameters of these thin layer drying models as well as the statistical results (R^2, and χ^2) were presented in the Table 1. Calculated R^2 and $\chi 2$ values ranged between 0.872-0.992, and 0.0506-0.6402. As a result of statistical analysis the Two-Term model was found to be the most appropriate model with the high values of the coefficient of determination (R^2).

The effective moisture diffusivity values (D_{eff}) of microwave dried black carrot pulp samples were calculated from the Fick's diffusion model and the results were given in Table 2. The black carrot pulp was placed in the oven as a thin layer, that can be assumed as an infinite slab and in Eq. (4) L is taken as the thickness of the black carrot pulp. As can be seen from Table 2, the effective moisture diffusivity values increased with increasing microwave powers, as expected. The effective moisture diffusivity (D_{eff}) of the black carrot pulp powder ranged between 1.370E-6 and 8.617E-7 m^2/s which is in the same range as (10E−12 to 10E−6 m^2/s) most foods (Erbay and Icier, 2009). The effective moisture diffusivity values of the microwave dried apple pomace (150–600 W), okra (180–900 W) and spinach (180–900 W) ranged between 1.05E-8 – 3.69E-8 m^2/s (Wang et al., 2007), 2.05E-9 – 11.91E-9 m^2/s (Dadali et al., 2007a), and 7.6E-11 – 52.4E-11 m^2/s (Dadali et al., 2007b).

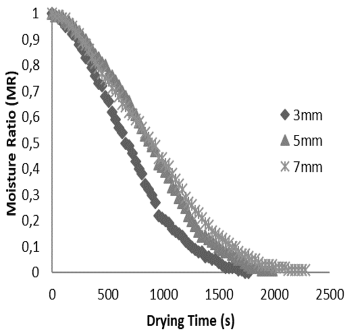

Figure (a)

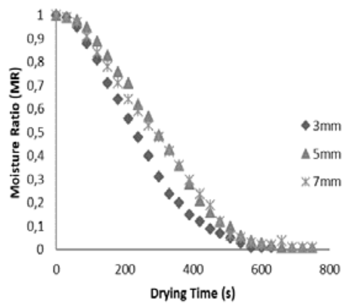

Figure (b)

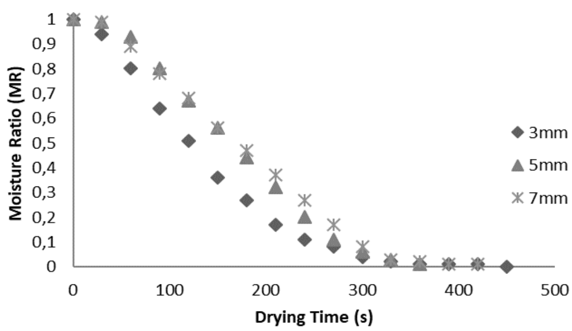

Figure (c)

Figure 1
The experimental moisture ratio values of black carrot pulp at different microwave powers (a); 180W, (b); 540W, and (c); 90im0W

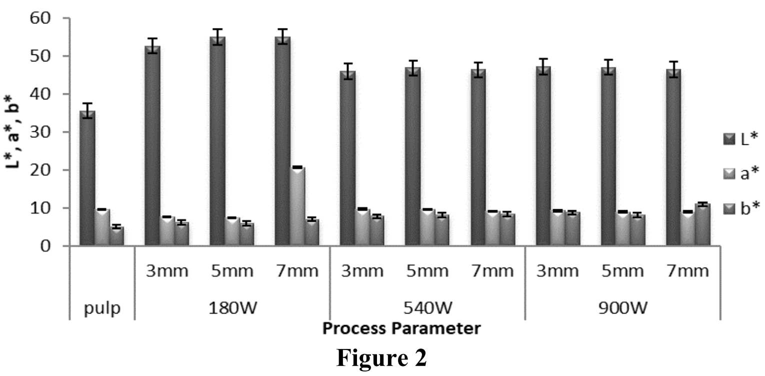

Figure 2
Color values of fresh black carrot pulp and black carrot pulp powder

Table 1: The coefficients of the model equations obtained from the statistical analysis of drying data.

Model	Microwave Power(W)/ Thickness(mm)	Model Constants	R^2	$\chi 2$
Logarithmic (MR=aexp(-kt)+b)	180W/3mm	k=0.001 a=1.546 b=-0.435	0.984	0.1243
	180W/5mm	k=0.001 a=1.975 b=-0.860	0.979	0.4932
	180W/7mm	k=0.001 a=1.540 b=-0.435	0.987	0.2503
	540W/3mm	k=0.003 a=1.379 b=-0.257	0.980	0.0651
	540W/5mm	k=0.002 a=1.468 b=-0.316	0.968	0.0796
	540W/7mm	k=0.002 a=1.346 b=-0.593	0.973	0.3213
	900W/3mm	k=0.006 a=1.196 b=-0.095	0.981	0.0576
	900W/5mm	k=0.004 a=1.352 b=-0.208	0.962	0.0883
	900W/7mm	k=0.004 a=1.294 b=-0.426	0.968	0.2546
Two-Term (MR=aexp($-k_0t$)+bexp($-k_1t$))	180W/3mm	k_0=0.003 k_1=0.003 a=93.946 b=-93.007	0.994	0.2853
	180W/5mm	k_0=0.003 k_1=0.003 a=121.097 b=-120.182	0.985	0.3598
	180W/7mm	k_0=0.002 k_1=0.002 a=104.132 b=-103.187	0.990	0.2469
	540W/3mm	k_0=0.009 k_1=0.009 a=96.733 b=-95.761	0.995	0.2771
	540W/5mm	k_0= 0.008 k_1=0.008 a=120.671 b=-119.723	0.989	0.3266
	540W/7mm	k_0=0.007 k_1=0.007 a=114.972 b=-114.006	0.989	0.2541
	900W/3mm	k_0=0.015 k_1=0.016 a=72.450 b=-71.457	0.999	0.2466
	900W/5mm	k_0=0.014 k_1=0.014 a=131.152 b=-130.180	0.990	0.2982
	900W/7mm	k_0=0.012 k_1=0.013 a=122.943 b=-121.967	0.990	0.2554
Wang and Singh (MR=1+at+bt^2)	180W/3mm	a=-0.001 b=1.575E-007	0.978	0.1361
	180W/5mm	a=-0.001 b=-5.053E-008	0.980	0.6402
	180W/7mm	a=-0.001 b=-1.080E-008	0.992	0.7118
	540W/3mm	a=-0.003 b=1.767E-006	0.976	0.1367
	540W/5mm	a=-0.002 b=9.320E-007	0.959	0.0862
	540W/7mm	a=-0.002 b=1.275E-006	0.973	0.1721
	900W/3mm	a=-0.005 b=6.464E-006	0.988	0.0506
	900W/5mm	a=-0.004 b=3.991E-006	0.962	0.0790
	900W/7mm	a=-0.004 b=3.690E-006	0.974	0.0692

Table 2: The estimated effective moisture diffusivity values (D_{eff}) for each microwave powers and thickness.

Microwave Power(W)/ Thickness(mm)	**D_{eff} ($m^2.s^{-1}$)**	**R^2**
180W/3mm	2.822E-7	0.910
180W/5mm	6.582E-7	0.889
180W/7mm	1.370E-6	0.892
540W/3mm	8.617E-7	0.914
540W/5mm	2.267E-6	0.924
540W/7mm	3.320E-6	0.864
900W/3mm	1.550E-6	0.956
900W/5mm	4.634E-6	0.928
900W/7mm	8.532E-6	0.939

Table 3: The moisture content and water activity values of black carrot pulp and the powders

Samples	**Thickness (mm)**	**Moisture Content (%, wb)**	**Water Activity (a_w)**
Fresh puree		19.50±0.02	0.986±0.02
Powder Dried at 180W	3	4.35 ± 0.12^{az}	0.242 ± 0.01^{az}
	5	4.48 ± 0.05^{az}	0.292 ± 0.01^{bz}
	7	4.61 ± 0.06^{bz}	0.371 ± 0.01^{cy}
Powder Dried at 540W	3	2.70 ± 0.08^{ay}	0.160 ± 0.01^{ax}
	5	2.82 ± 0.04^{ay}	0.171 ± 0.01^{bx}
	7	2.99 ± 0.05^{by}	0.242 ± 0.01^{cx}
Powder Dried at 900W	3	2.16 ± 0.01^{bx}	0.182 ± 0.02^{ay}
	5	1.99 ± 0.02^{ax}	0.209 ± 0.01^{by}
	7	2.16 ± 0.01^{bx}	0.245 ± 0.01^{cx}

Different letters (a–c) in the same column indicate significant difference between the microwave powers $P < 0.05$.
Different letters (x-z) in the same column indicate significant difference between the amounts of samples at $P < 0.05$

Results of the physical analyses

The moisture content and water activity values of the powders ranged between 1.99 and 4.61 % (wet basis, wb) and 0.160 and 0.371 (Table 3). Results showed that the moisture content and water activity values of the black carrot powders decreased with respect to increasing the microwave power and increased with the thickness. It may be due to a high transfer rate at high microwave powers. These values are in acceptable limits for the safe storage of the products. Although, the lowest moisture content values were obtained from the samples which dried at 900W microwave powder, the lowest water activity values were obtained at 540W microwave power.

The colour values of the fresh and microwave dried black carrot pulp powders were given in Figure 2. According to the Figure 2; significant differences were observed between the black carrot pulp and the black carrot pulp powders ($P<0.05$). The brightness value of the powders decreased according to increasing microwave powers and decreasing of the sample thickness. The degradation of the pigments or browning reactions may be related to the pigment destruction and may caused the colour loss (L^*). The different microwave powers and the sample thicknesses did not cause any significant differences in the a^* and b^* values of the powders.

Results of the powder properties

On Dried products are usually grounded that have uniform size for further utilization. In this study, it was also aimed that to have powdered form of the black carrot pulp that will be suitable for different applications as food additive. The powder properties of the black carrot pulp powder were given in Table 4. The average wettability and solubility times of powders ranged between 2.5- 7s, and 3.5-8s, respectively indicating highly soluble powders. It was observed that the average wettability time of the samples at 180W was less than the wettability time of samples which were dried at 540, and 900W microwave powers. The tapped and bulk density values of the powders range between 224-277, 235-299, and 218-240 and 289-333, 297-404, and 281-301 kg/m^3 for 3, 5, and 7mm thickness, respectively. The flowability and cohesiveness properties of microwave dried black carrot pulp powders in terms of Carr Index and Hausner ratio were evaluated. The classification of powder flowability based on Carr index (CI) is very good (<15), good (15-20), fair (20-35), bad (35-45), and very bad (>45). The powder cohesiveness based on the Hausner ratio (HR) is classified as low (<1.2), intermediate (1.2-1.4), and high (>1.4) (Jinapong et al., 2008). According to powder properties flowability and cohesiveness values of the black carrot powders were generally found to be fair and intermediate, respectively.

CONCLUSION

Microwave drying technique has been effectively used in drying of the black carrot pulp. Drying behaviour of the black carrot pulp powder was investigated in the microwave oven at different microwave powers (180, 540, and 900W) and the different thicknesses (3, 5, and 7mm). Results showed that, the total drying time and moisture content of black carrot pulp decreased according to increasing microwave powers and decreasing sample thickness. Drying time decreased with increase the evaluation of three thin layer drying models with the comparison based on the coefficient of determination (R^2)

and the reduced chi-square (χ^2), Two term model was found to be satisfactorily describing the kinetics of microwave drying of black carrot pulp.

Table 4: The results of the analysis of powder properties for black carrot pulp powders

Microwave Power	**Thickness (mm)**	**Wettability (s)**	**Solubility (s)**
180W	3	3.75 ± 0.35^{bx}	4.50 ± 0.50^{ax}
	5	2.50 ± 0.70^{ax}	4.75 ± 0.35^{ax}
	7	2.25 ± 0.35^{ax}	3.50 ± 0.70^{ax}
540W	3	6.00 ± 0.00^{bz}	4.00 ± 0.00^{ax}
	5	5.00 ± 0.70^{ay}	6.00 ± 0.90^{by}
	7	5.00 ± 0.80^{ay}	5.50 ± 0.70^{by}
900W	3	5.00 ± 0.90^{ay}	4.00 ± 0.00^{ax}
	5	6.00 ± 0.89^{ay}	5.50 ± 0.70^{bx}
	7	7.00 ± 0.90^{bz}	8.00 ± 0.00^{cz}

Microwave Power	**Bulk Density (kg/m^3)**	**Tapped Density (kg/m^3)**	**Flowability**	**Cohesiveness**
180W	224.74 ± 3.57^{ax}	289.92 ± 5.94^{ax}	22.48 ± 0.36^{cy} (Fair)	1.29 ± 0.01^{cy} (Intermediate)
	256.60 ± 0.28^{by}	313.50 ± 2.12^{ay}	18.15 ± 0.46^{bx} (Good)	1.22 ± 0.02^{bx} (Intermediate)
	277.12 ± 8.79^{cz}	333.72 ± 1.58^{bz}	16.95 ± 0.56^{ax} (Good)	1.21 ± 0.05^{ax} (Intermediate)
540W	235.63 ± 1.05^{ay}	297.06 ± 0.00^{ax}	20.68 ± 0.35^{ax} (Fair)	1.26 ± 0.01^{ax} (Intermediate)
	298.61 ± 6.12^{bz}	404.08 ± 11.21^{bz}	29.05 ± 0.65^{bz} (Fair)	1.35 ± 0.06^{cz} (Intermediate)
	243.41 ± 4.15^{cy}	315.63 ± 0.00^{by}	22.88 ± 0.90^{cy} (Fair)	1.30 ± 0.02^{by} (Intermediate)
900W	221.74 ± 6.15^{ax}	289.92 ± 5.94^{bx}	23.52 ± 0.55^{bz} (Fair)	1.31 ± 0.01^{by} (Intermediate)
	240.48 ± 3.37^{bx}	301.52 ± 2.14^{bx}	20.24 ± 1.10^{ay} (Fair)	1.25 ± 0.03^{ay} (Intermediate)
	218.11 ± 2.05^{ax}	280.82 ± 0.37^{ax}	22.33 ± 0.83^{by} (Fair)	1.28 ± 0.01^{ay} (Intermediate)

Different letters (a–c) in the same column indicate significant difference between the microwave powers $P < 0.05$.
Different letters (x-z) in the same column indicate significant difference between the amounts of samples at $P < 0.05$.

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