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Assessment of applied microwave power of intermittent microwave-dried carrot powders from Colour and NIRS

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Abstract. Applied microwave (MW) power level is an essential factor on the quality of the dried agricultural products. Even if higher MW powers result in shorter drying times, they lead to quality degradations. It is almost impossible to know the applied MW power of a dried and powdered product by human vision. Thus, the aim of this study was to predict the applied MW power of carrot powders by using two different instruments, a chromameter and FT-NIRS. The experiments were carried out at nine different power levels (100–500 W) with three replications (N = 27). The colour and NIR reflectance was measured using a chromameter and NIRS system. The data was analysed using PLS regression. The drying time of intermittent MW drying at the highest applied power of 500 W was 1.12–5.47 times shorter than those of other lower applied powers. Applied MW power was a crucial factor on all colour parameters of the powdered carrots. Brightness (L*) decreased significantly with the increase of applied MW power resulting in darker product colours. Data analysis results showed that the NIRS system ($R^2 = 0.99$; SEP = 16.1 W) can predict the microwave power of powdered carrots with significantly better performance than a chromameter ($R^2 = 0.95$; SEP = 29.9 W). But, the chromamater is far more inexpensive when compared with the NIRS system and hence, it can also be used to predict the applied MW power from the colour data relatively well. Also, a mathematical model was developed to predict applied MW power from the colour parameters.

Key words: Microwave drying, applied power, carrot, reflectance, chromameter, FT-NIRS.

INTRODUCTION

Water content of fresh agricultural products has to be decreased by using different drying methods to prolong their shelf life (Onwude et al., 2016). Drying methods can be divided into four groups including convective drying in cabinet, kiln, belt, and conveyors as first generation, spray and drum drying as second generation, freeze and osmotic drying as third generation and microwave and RF related drying as innovative fourth generation methods (Kumar & Karim, 2017). Microwave (MW) drying has some advantages including volumetric heating, higher drying rate, shorter process time, cost reduction and better product quality and is generally combined with other methods to improve its performance (Ekezie at al., 2017; Kumar & Karim, 2017). Applying MW continuously results in uneven heating, overheating and lower product quality; thus, intermittent or pulsed MW is applied to eliminate the drawbacks (Ekezie at al., 2017; Pham et al., 2017). Various studies were carried out on intermittent MW drying of agricultural products such as strawberry (Changrue, 2006), banana (Baini & Langrish, 2007), potato (Soysal, 2009), red pepper (Soysal et al., 2009a), oregano (Soysal et al., 2009b), carrot (Arikan et al., 2012), fig fruit (Sharifian et al. 2012), wheat seeds (Li et al., 2014), kiwi (Pham et al., 2016), pumpkin (Junqueira et al., 2017), pistachio nuts (Kermani et al., 2017), apple (Aghilinategh et al., 2016; Dehghannya et al., 2018) and mushroom (Das & Arora, 2018).

Drying temperature or applied microwave (MW) power is a crucial factor on the quality of the dried agricultural products. Even if higher drying temperatures and MW powers result in shorter drying times, they cause quality degradations (Moraes et al., 2013; Karam et al., 2016; Kumar & Karim, 2017). Cracks, casehardening, colour deterioration, phytochemical depletion, antioxidant activity reduction, degradation of nutrients, poor rehydration and shrinkages are the main damages occurring at high drying temperatures and MW powers (Cao et al., 2016; Karam et al., 2016). It is almost impossible to differentiate the food products dried by different methods and applied MW powers with human vision by consumers. On the other hand, chromatographic and spectroscopic methods along with chemometrics could be useful to differentiate the food products dried by different drying methods (Hwang et al., 2017). The food industry is often encountered with adulteration and it is hard to determine if products have been adulterated by a human observer; thus, practical systems could be used to detect adulteration. Some techniques such as FTIR have potential to monitor food adulteration (Rodriguez-Saona & Allendorf, 2011; Khan et al., 2015).

Some electro-optic instruments including digital camera, spectroradiometer, spectrophotometer, chromameter and near infrared reflectance spectroscopy (NIRS) can be utilized to evaluate the quality of food products (Rodriguez-Saona & Allendorf, 2011; Keskin et al., 2017). NIRS systems (800–2500 nm) and Fourier Transform (FT) NIRS systems are rapid, non-invasive, quick and non-destructive for food quality and adulteration studies (Tripathi & Mishra, 2009; Lim et al., 2015; Toledo-Martín et al., 2015; Wu et al., 2017; Li et al., 2018). Colour is an important feature in food product quality evaluation (Ordonez-Santos et al., 2014; Yang et al., 2018) and can be quantified by using a colorimeter (chromameter) or spectrophotometers (Pathare et al., 2013). Chromameters are regularly used in the colour assessment of food because of their easy usage and colour elucidation (Pathare et al., 2013). These systems have been used to assess fruit and vegetable ripeness, quality of the dried products and the colour of raw and processed foods including meat, bread, flour, dough, juice, molasses, chocolate, oils, milk, dairy products, pasta, jam, etc. (Keskin et al., 2017).

Carrot (*Daucus carota* L.) is an important root vegetable with carotenoids, flavonoids, vitamins and minerals that provide various nutritional and health benefits (da Silva Dias, 2014). It is a medicinal and industrial crop as it is a plentiful and inexpensive source of minerals, vitamins and fibre. It is consumed fresh or used for the production of dried powders for soups and other food products. The total global carrot production (including turnips) was about 42.7 million tonnes in 2016 (FAO, 2018). China was the first producer country with around 20.6 million tonnes followed by Uzbekistan and Russian Federation with about 2.3 and 1.9 million tonnes, respectively while Turkey ranked thirteenth with about 0.56 million tonnes (FAO, 2018).

Applied microwave power level in drying process is a vital factor for the final quality of the dried product. But, to our best knowledge, no study was found on the determination of applied microwave power of dried carrot powders using reflectance data. Thus, the aim of this study was to predict the applied microwave power of carrot powders dried by intermittent microwave drying with different applied power levels by using two different instruments, a chromameter and FT-NIRS.

MATERIALS AND METHODS

Carrot Samples

Carrots (*Daucus carota* 'Nantes') produced in open fields in Konya province of Turkey were obtained from a wholesale market located in Antakya, Hatay, Turkey (Fig. 1). They were stored at +4 °C in refrigerator until drying. The middle size carrots (15–20 cm) were selected and used in the study in November 2018.

Intermittent Microwave Drying of Carrot Samples

A lab-scale microwave oven (Beko, MD 1605, Turkey) with a maximum rated power of 900 W at 2450 MHz was used in the drying experiment. The size of the microwave cavity was about 22 x 35 x 33 cm. The actual power of the microwave oven was calculated as 736 W by using the IMPI-2L test (Buffler, 1993). The experiment were carried out at nine different power levels (100, 150, 200, 250, 300, 350, 400, 450 and 500 W) by changing the on and off times (T_{on} and T_{off}) of the microwave oven as controlled by a PLC (Table 1). The mass of the microwave turntable with the grated carrot sample and the microwave cavity inside air temperature were recorded at every minute during the drying process. A fan was used to aspirate air from the microwave cavity with about 2 ms^{-1} airflow speed. The ambient air entered the cavity at near room temperature (22 ± 2 °C). The drying procedure was repeated three times at each microwave power level giving a total 27 (9×3) drying experiments.

Table 1. Applied microwave power and related parameters used in the drying study

	AP (W)	IM (g)	SP (W g^{-1})	PP* (-)	T_{on} (s)	T_{off} (s)	PR** (-)	MCT (°C)
1	100	300	0.33	0.14	15	95	7.36	38.2
2	150	300	0.50	0.20	15	59	4.91	42.6
3	200	300	0.67	0.27	15	40	3.68	46.0
4	250	300	0.83	0.34	15	29	2.94	50.6
5	300	300	1.00	0.41	15	22	2.45	53.7
6	350	300	1.17	0.48	15	17	2.10	57.1
7	400	300	1.33	0.54	15	13	1.84	59.9
8	450	300	1.50	0.61	15	10	1.64	62.2
9	500	300	1.67	0.68	15	7	1.47	64.7

AP: Applied Power; IM: Initial Mass; SP: Specific Power; PP*: Power Proportion; T_{on}: On Time; T_{off}: Off Time; PR: Pulse Ratio; MCT: Mean Cavity Temperature; *PP was calculated by dividing the AP by microwave oven's actual power (736 W); **PR = (T_{on} + T_{off}) / T_{on} (Arikan et al., 2012).

Carrots were washed with tap water, peeled off and grated as long and thin strips (mean thickness: 1.1 ± 0.24 mm) by using a hand-operated stainless steel grater and placed homogenously on the microwave oven's turntable with sample thickness of about

10–15 mm. The initial water content of the fresh material was in the range of about 8.5–9.5 kg H_2O kg^{-1} DM (89.5–90.5% wet basis) as determined by oven method by drying a sample of about 50 g in oven at 103 °C for 24 hours. Fresh grated carrot of about 300 g was dried applying intermittent microwave energy until the water content declined to about 0.11 kg H_2O kg^{-1} DM for each drying procedure by recording the time, mass and temperature every minute during the drying process. The dried samples were ground by using an electric grinder to make them ready for colour and NIRS measurement (Fig. 1).

Figure 1. Whole carrots (left), grated fresh carrot and powdered carrot samples (right).

Colour Measurement

Colour of fresh and powdered carrots was measured by using a hand-held chromameter (Minolta CR-400, Osaka, Japan). Two colour models of CIE L*a*b* and L*C*h were employed. In both colour models, the colour is expressed in three dimensions and the meaning of each parameter is given below (Keskin et al., 2017):

L*: Brightness of the colour (0: black, 100: white),

a*: Redness-greenness (–60: green, +60: red),

b*: Yellowness-blueness (–60: blue, +60: yellow),

C* Chroma having a value from 0 to 60,

h: Hue angle (0°: red, 90°: yellow, 180°: green, 270°: blue).

The chromameter was utilized with illuminant C standard and calibrated using its white reflector plate. In measuring the colour of the samples, ground material measurement apparatus was employed. Colour change of the material was evaluated by using the total chromatic aberration (ΔE*) and colour difference values (ΔL*, Δa*, Δb*, ΔC* and Δh) (Soysal et al., 2009b):

$\Delta L^* = L^*_d - L^*_f$

$\Delta a^* = a^*_d - a^*_f$

$\Delta b^* = b^*_d - b^*_f$

$\Delta E^* = [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{0.5}$

$\Delta C^* = C^*_d - C^*_f$

$\Delta h = h_d - h_f$

where *d* and *f* refers to the dried and fresh products, respectively.

NIRS measurement

The powdered carrot samples (N = 27) were placed on glass petri plates (9 cm of diameter). The near infrared (NIR) reflectance of the samples was quantified by using a FT-NIRS system (NIRFlex N-500, Büchi Labortechnik AG, Flawil, Switzerland) covering the wave numbers of 4,000–10,000 cm^{-1} (1,000–2,500 nm) with a resolution of 4 cm^{-1} (total number of reflectance variables: 1,500). All spectra were recorded as the average of 32 scans with three repetitions for each powder sample.

Data Analysis

Powdered carrot sample data included 27 samples (three samples for each of the nine microwave power levels). The colour data were analysed using PLS (Partial Least Squares) regression method in a multivariate statistics program (UnScrambler, v.9.7, Camo, Oslo, Norway). PLS regression was selected since it is more suitable in comparison to other methods (MLR and PCR) with many inter-correlated variables (Keskin et al., 2004; Keskin et al., 2008; Keskin et al., 2013). Correlation coefficients between applied microwave power and colour data were calculated in MS Excel program. The influence of applied microwave power on the colour of the powdered samples was statistically evaluated with a statistic software (SPPS, v.17, IBM, NY, USA) using one-way analysis of variance (ANOVA) and the means were compared with Duncan's test ($p = 0.05$). The NIRS data were explored using the chemometric software of the FT-NIRS system (NIRCal, v5.5, Büchi Labortechnik AG, Flawil, Switzerland) with PLS regression method. 2/3 of the data (n = 18) were used in calibration and the remaining 1/3 of the data (n = 9) were included in the validation set in both colour and NIRS data analysis. Outlying samples were determined and excluded from the colour data set (N = 4) and NIRS data set (N = 1) in the data analysis.

RESULTS AND DISCUSSION

Drying Kinetics of Carrots

Intermittent microwave drying (IMWD) at 500 W applied power with a pulse ratio (PR) of 1.47 had the lowest drying time (Fig. 2, a) among the drying treatments. The drying time of IMWD at 500 W was 1.12–5.47 times shorter than those of other lower applied powers (Fig. 2a). Similarly, the drying rate of IMWD at 500 W was 1.18–5.63 times higher than that of other applied powers (Fig. 2b). As PR increased from 1.47 to 7.33, the drying time increased from 34 to 186 min and the drying rate decreased 5.63 times. The drying rate curve became flatter with the increase in PR indicating gentle drying of the product (Fig. 2b and Fig. 3). After a short heating period, the drying rates of carrot samples dried at PRs from 1.47 (300 W) to 2.45 (300 W) reached to the maximum at specific moisture ratios and then, fast falling rate periods were observed. However, further increase in the PR from 2.45 (300 W) to 7.36 (100 W) resulted in significant changes in the drying rate curves and the constant rate drying periods revealed below the 2.47 PR value (Fig. 2b). As PR increased, the length of the constant rate period progressively increased since microwave power off time (T_{off}) provided a rest time for moisture and temperature redistribution inside the product during the following microwave on time after the warming-up period (Fig. 2b and Fig. 3) (Gunasekaran, 1999; Beaudry et al., 2003, Esturk, 2010).

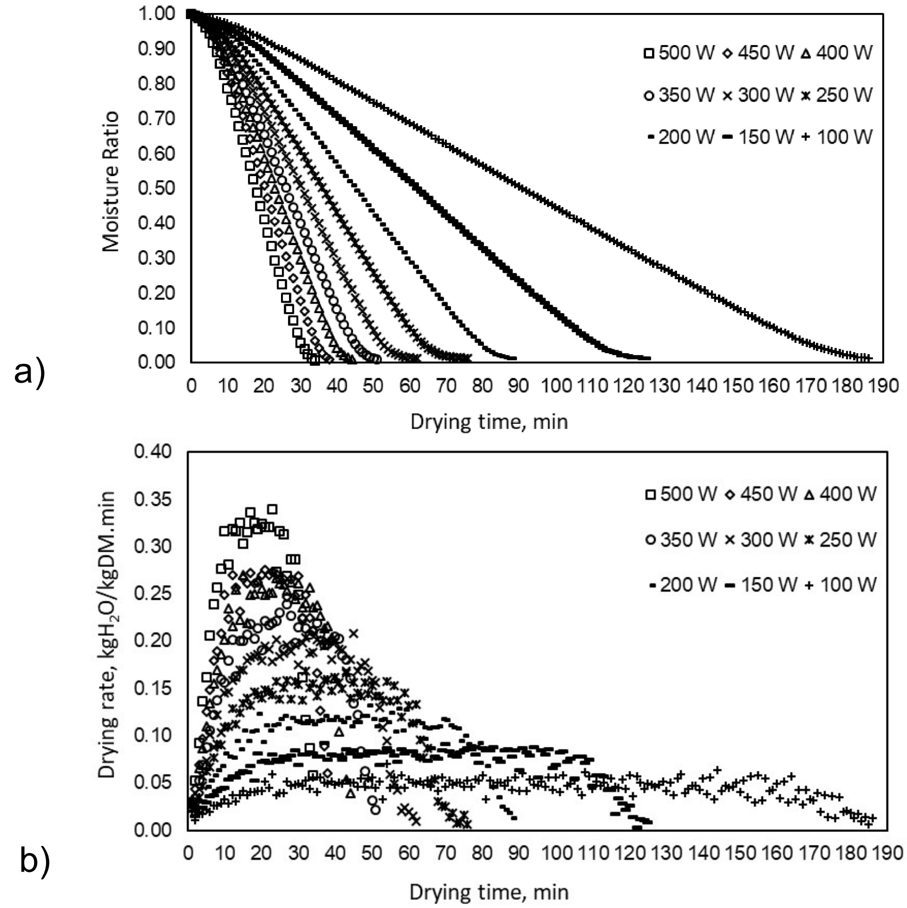

Figure 2. Intermittent microwave drying curves (a) and drying rates (b) of grated carrot at different microwave power levels (DM: dry matter, $v_a = 2.0 \text{ m s}^{-1}$).

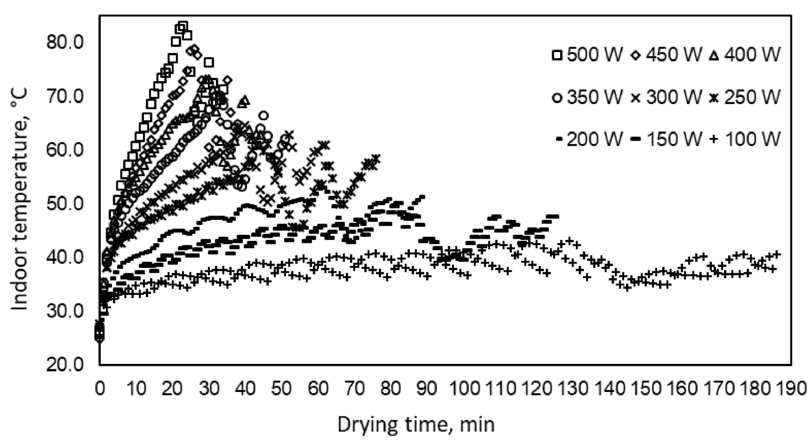

Figure 3. Within-cavity air temperature during intermittent microwave drying of grated carrot

The findings of the current study are supported by several previous studies. Arikan et al. (2012) reported that there was a short heating up period which was followed by a constant rate period until the product moisture content decreased to 1.5–2.0 kg H_2O kg^{-1} DM during IMWD of grated carrots. They further stated that the constant rate period was 3/5 of the total drying time. Changrue (2006) reported that there was a constant rate period observed in continuous and IMWD of carrot and strawberry without pre-drying. Cui et al. (2004) stated that drying took place at a constant rate period of microwave-vacuum drying of carrot slices with 3–5 mm thickness until the moisture content decreased to 2.0 kg H_2O kg^{-1} DM. It was reported that there was a long constant rate period in convective air drying of carrot until the moisture content decreased to 1.5 kg H_2O kg^{-1} DM (May & Perre, 2002). Cui et al. (2004) conducted continuous and IMWD under vacuum for carrot slices with the thickness of 4, 8 and 10 mm. They stated that the temperature recorded on the surface and in the center of the product was same and there was a uniform temperature distribution in the product less than 8 mm in thickness. They also observed the heating up and constant rate periods followed by a falling rate period in drying of carrots with less than 8 mm thickness.

Effect of Applied Microwave Power on the Colour of Powdered Carrots

The relations between applied microwave (MW) power level determined by the IMPI-2L test (Buffler, 1993) and colour values were also studied (Table 2). The data presented are the means of nine independent measurements from three subsamples and the values after the ± sign represent the standard deviation. The mean L*, a* and b* colour values of fresh carrot samples were 49.79, 21.20 and 37.54, respectively which relates to matte yellowish–orange colour. L* values of the dried samples were higher compared to fresh samples which means that the dried samples were darker than the fresh ones. Also, L* decreased significantly at higher applied MW powers (400, 450 and 500 W) resulting in darker product colours (lower L* values). Similar findings of reduction in L* when the drying temperature increased were reported in dried carrot (Arikan et al., 2012) and dried red peppers (Ning et al., 2012; Swain et al., 2014; Keskin et al., 2018). The a*, b* and C* values were close to the values of the fresh samples for lower applied MW powers (100, 150 and 200 W) while they significantly decreased at higher MW powers (400, 450 and 500 W) which means that the colour of the dried samples got matte at higher applied MW powers. On the other hand, h value was similar to the values of the fresh samples for lower applied MW powers but they significantly increased as the applied MW power was increased meaning that higher powers made the samples matte and more yellowish orange colour.

Table 2. Influence of applied microwave power on the colour of the powdered carrots

AMP* (W)	L*	a*	b*	C*	h
Fresh	49.79 ± 0.65^{a}	21.20 ± 0.56^{e}	37.54 ± 0.81^{b}	43.11 ± 0.96^{cd}	60.55 ± 0.28^{a}
100	71.46 ± 0.81^{def}	22.18 ± 1.15^{e}	39.12 ± 0.22^{b}	44.98 ± 0.72^{d}	60.46 ± 1.18^{a}
150	74.33 ± 1.06^{f}	16.79 ± 4.61^{d}	37.87 ± 1.73^{b}	41.43 ± 3.58^{bcd}	66.15 ± 4.59^{b}
200	72.95 ± 0.69^{ef}	16.12 ± 4.60^{cd}	39.54 ± 1.53^{b}	42.72 ± 3.42^{cd}	67.83 ± 4.61^{b}
250	70.50 ± 2.65^{cde}	12.87 ± 2.08^{ab}	39.66 ± 1.84^{b}	41.72 ± 2.51^{bcd}	72.08 ± 1.64^{c}
300	68.48 ± 2.97^{cd}	12.74 ± 1.09^{ab}	39.07 ± 1.19^{b}	41.12 ± 1.52^{bcd}	71.98 ± 0.71^{c}
350	67.38 ± 0.52^{c}	11.87 ± 2.55^{ab}	39.04 ± 0.55^{b}	40.81 ± 1.15^{bc}	73.11 ± 2.70^{c}
400	67.56 ± 1.73^{c}	13.44 ± 1.50^{bc}	39.17 ± 0.92^{b}	41.43 ± 0.97^{bcd}	71.13 ± 1.98^{c}
450	63.35 ± 4.26^{b}	10.33 ± 2.64^{ab}	36.68 ± 0.81^{ab}	38.12 ± 1.60^{ab}	74.35 ± 3.08^{c}
500	61.16 ± 1.46^{b}	10.13 ± 2.76^{a}	34.47 ± 0.97^{a}	35.95 ± 1.79^{a}	73.69 ± 3.15^{c}

Same letters within the same column are not significantly different ($p < 0.05$); *AMP: Applied Microwave Power (W).

The colour difference data that is essential in the assessment of dried material quality is shown in Table 3. It was found that the change of brightness (ΔL*) and total colour change (ΔE*) was lower at higher applied microwave (MW) powers. A similar finding was reported by Keskin et al. (2018) for powdered peppers dried by infrared energy. Also, Rhim & Hong (2011) reported that the ΔE value depended on both drying temperature and water activity (Aw) and ΔE was lower in high temperature (50 °C) only in low Aw conditions. Even if the total colour difference (ΔE*) values were lower at higher applied powers (400, 450 and 500 W), the higher power levels made the samples darker which is not preferable. However, since bright coloured products are more preferred by consumers, the ΔE* value should not be considered as a single indicator of colour evaluation and thus, ΔL* should also be taken into account. Also, the hue angle difference (Δh) can be considered as a good indicator to explain the colour changes of the carrot powders at different MW powers. The Δh value was relatively smaller at lower applied MW powers (100, 150 and 200 W) as compared to higher MW powers (Table 3).

Table 3. Effect of applied microwave power on the colour difference of powdered carrots

AMP* (W)	ΔL*	Δa*	Δb*	ΔC*	Δh	ΔE*
100	21.67 ± 0.81^{cd}	0.98 ± 1.15^{d}	1.58 ± 0.22^{b}	1.86 ± 0.72^{d}	-0.09 ± 1.18^{a}	21.78 ± 0.73^{cd}
150	24.54 ± 1.06^{d}	-4.41 ± 2.08^{c}	0.33 ± 1.84^{b}	-1.68 ± 2.51^{bcd}	5.60 ± 1.64^{b}	25.03 ± 1.29^{e}
200	23.16 ± 0.69^{d}	-5.08 ± 1.50^{bc}	2.00 ± 0.92^{b}	-0.40 ± 0.97^{cd}	7.28 ± 1.98^{b}	23.84 ± 0.46^{de}
250	20.71 ± 2.65^{bcd}	-8.32 ± 2.22^{a}	2.12 ± 1.00^{b}	-1.39 ± 1.65^{bcd}	11.53 ± 2.43^{c}	22.53 ± 2.31^{cde}
300	18.69 ± 2.97^{bc}	-8.46 ± 1.85^{a}	1.53 ± 0.57^{b}	-2.00 ± 1.03^{bcd}	11.43 ± 2.30^{c}	20.71 ± 2.01^{bc}
350	17.59 ± 0.52^{b}	-9.32 ± 1.15^{a}	1.50 ± 1.13^{b}	-2.31 ± 1.42^{bc}	12.56 ± 1.07^{c}	20.00 ± 0.83^{bc}
400	17.77 ± 1.73^{bc}	-7.76 ± 2.13^{ab}	1.63 ± 2.09^{b}	-1.68 ± 2.57^{bcd}	10.59 ± 2.12^{c}	19.60 ± 1.77^{bc}
450	13.56 ± 4.26^{a}	-10.86 ± 1.95^{a}	-0.86 ± 3.17^{ab}	-4.99 ± 3.58^{ab}	13.81 ± 1.53^{c}	17.90 ± 2.27^{ab}
500	11.37 ± 1.46^{a}	-11.07 ± 1.44^{a}	-3.07 ± 2.21^{a}	-7.16 ± 2.50^{a}	13.14 ± 1.22^{c}	16.33 ± 1.04^{a}

Same letters within the same column are not significantly different ($p < 0.05$); *AMP: Applied Microwave Power (W).

Consequently, statistical analysis showed that applied MW power level was a crucial factor on all colour parameters of the powdered carrots (Table 2 and Table 3). The colours of carrot samples dried at lower applied MW powers (100, 150 and 200 W) were comparatively brighter and more vivid yellowish-orange and increase of applied MW power (400, 450 and 500 W) led to development of matte darker yellowish-orange product colour, which was considered as unacceptable for consumer preference.

Estimating Applied Microwave Power from Colour Data

Correlation coefficients between applied microwave (MW) power and colour parameters were also investigated (Fig. 4). It was observed that high correlation and dependence was present between applied MW power and the colour parameters. The highest correlation coefficient was found as –0.87 for the colour parameter of L* while the parameter b* had the lowest correlation (–0.55). Parameters of L*, a*, b* and C* were in a decreasing trend as response to increasing applied MW power while h was in a rising trend as the applied MW power increased.

Colour data were used to develop a mathematical model to estimate applied microwave (MW) power of the samples using PLS regression. Three different models were investigated with X variables of L*a*b, L*C*h and L*a*b*C*h (all colour parameters) and Y variable of applied MW power (100, 150, 200, 250, 300, 350, 400, 450, 500 W). The model with all colour values (L*a*b*C*h) provided better outcomes in terms of R^2 and SEP as compared to other two models with L*a*b and L*C*h. The validation R^2 and SEP values were around 0.95 and 29.9 W for the model with L*a*b*C*h while they were around 0.94 and 35.3 W for the model with L*a*b and around 0.95 and 31.9 W with the L*C*h, respectively.

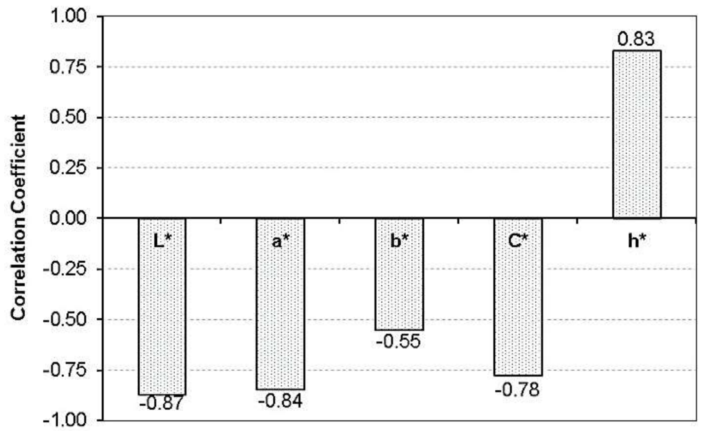

Figure 4. Correlation coefficients between applied MW power and colour parameters.

The score plot for PC1 and PC2 for the model with L*a*b*C*h (Fig. 5) revealed that the powdered carrot samples dried by different power rates were dispersed very well in a way that the samples which were dried with higher power rates (400, 450, 500 W) were on the right-hand side as the ones with lower power levels (100, 150, 200 W) were on the left-hand side. The model had three significant PCs and they explained 100% of the variability of X (colour) and 96% of variability of Y (power). It can be stated that PC1 significantly explained the differences of powdered carrot samples dried by different applied MW power rates.

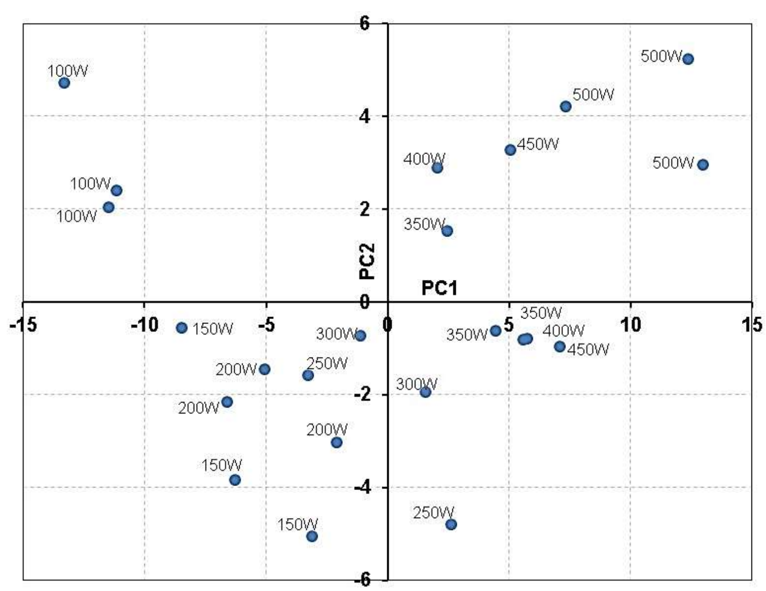

Figure 5. Score plot of PLS regression model of powdered carrots using colour data.

The original vs. predicted applied microwave (MW) power for the model of L*a*b*C*h is presented on Fig. 6. The validation R^2 and SEP values were around 0.95 and 29.9 W for the model with L*a*b*C*h. This means that the applied MW power of the dried and powdered carrot samples can be estimated relatively well using L*a*b*C*h colour data obtained from the hand-held chromameter. Similarly, Keskin et al. (2018) reported that the drying temperature of infrared-dried powdered peppers could be predicted from the colour data ($R^2 = 0.98$). The mathematical model to predict the applied MW power of dried and powdered carrot samples was computed as:

$$AMWP = 1227.78 - 21.03 \times L^* - 6.18 \times a^* + 1.92 \times b^* - 0.99 \times C^* + 8.28 \times h$$

where AMWP: Applied microwave power (W);

L*: Brightness of colour (0: black, 100: white);

a*: Redness and greenness (–60: green, +60: red);

b*: Yellowness and blueness (–60: blue, +60: yellow);

C*: Chroma value (0–60);

h: Hue angle value (0°: red, 90°: yellow, 180°: green, 270°: blue).

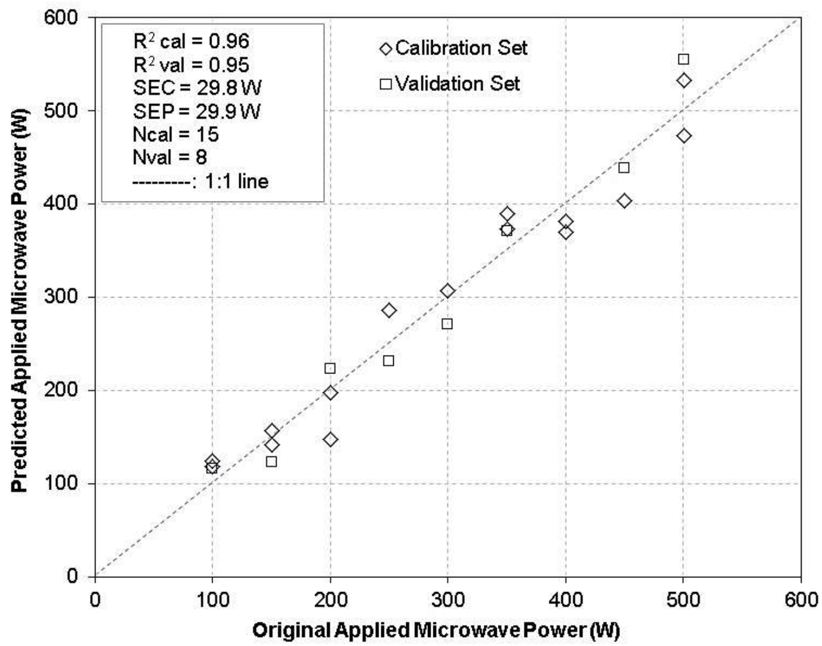

Figure 6. Original vs. Predicted applied microwave power of powdered carrots with colour data.

Estimating Applied Microwave Power from FT-NIRS Data

The raw mean near infrared (NIR) reflectance data is shown on Fig. 7. Each line in the figure represents the average reflectance of the three replicated powdered carrot samples. It was observed that the fresh carrot samples had lower reflectance (higher absorbance) values as compared to the dried powdered samples. The important absorbance bands were found to be around the wavenumbers of 4,300–4,400 cm^{-1} (CH2, aminoacid, CH3, starch), 4,700–4,800 cm^{-1} (CONH2, CONHR, starch), 5,100−5,200 cm^{-1} (H2O, CO2R, CONH2, amide), 6,700–6,900 cm^{-1} (CONHR, CONH2, cellulose) and 8,200–8,400 cm^{-1} (CH2, CH3).

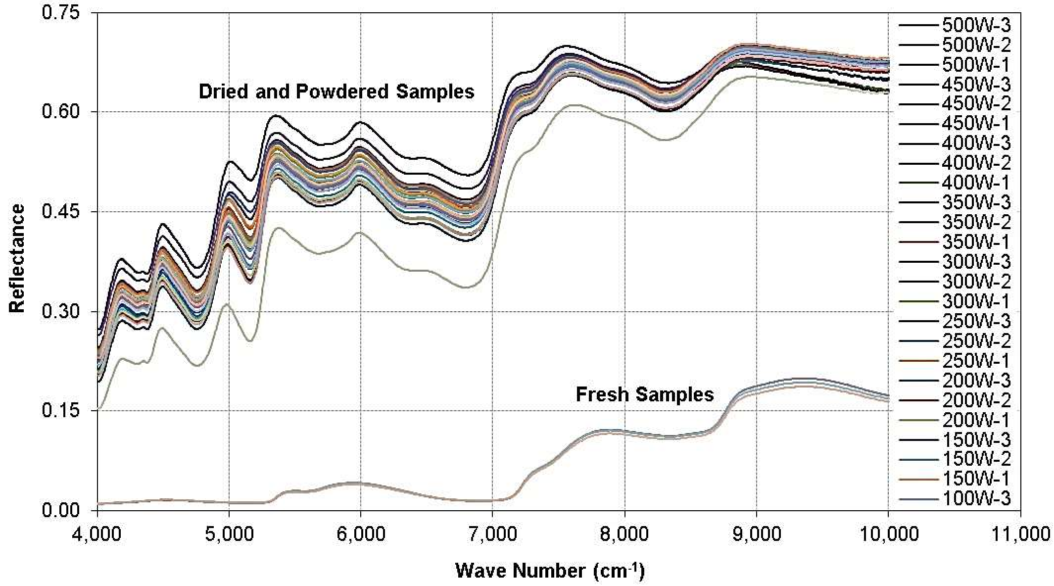

Figure 7. Near infrared reflectance spectra of the powdered carrot samples from FT-NIRS.

In the NIRS data analysis with PLS regression, different data pre-treatment methods were utilized and combination of four treatments being SNV (Standard Normal Variate), First Derivative BCAP, Variance Scaling and MSC Offset (Multiplicative Scatter Correction) provided better results in terms of higher R^2 and lower SEP. Based on the PC1 and PC2 score plot (Fig. 8), it was seen that the samples were separated very well in a way that the samples dried with lower applied microwave power (100, 150, 200 W) were on the left-bottom side and the ones from higher applied microwave power (400, 450, 500 W) were on the right-top hand side. From this observation, it can be inferred that a successful model can be developed to estimate applied microwave power from the NIR reflectance data.

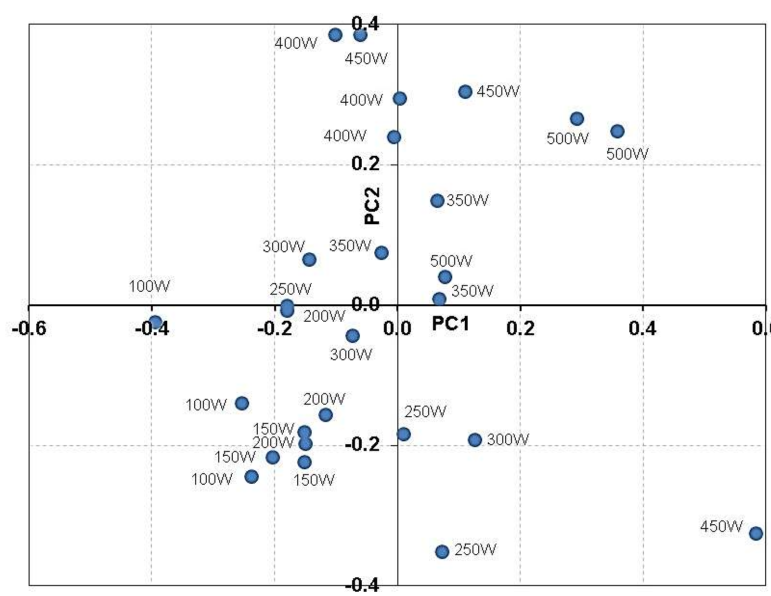

Figure 8. Score plot of FT-NIRS model of powdered carrots dried by intermittent microwave.

Based upon the original vs. predicted applied microwave power for the model using NIRS reflectance data (Fig. 9), the validation R^2 and SEP values were around 0.99 and 16.1 W. This means that the applied microwave power of the dried and powdered carrot samples can be estimated very well using NIR reflectance data. Similarly, Keskin et al. (2018) reported that the drying temperature of infrared-dried powdered peppers could be predicted from the NIRS data (R^2 = 0.98). Thus, it can be inferred that NIRS is a useful tool for the estimation of drying temperature or applied microwave power for dried and powdered carrot samples.

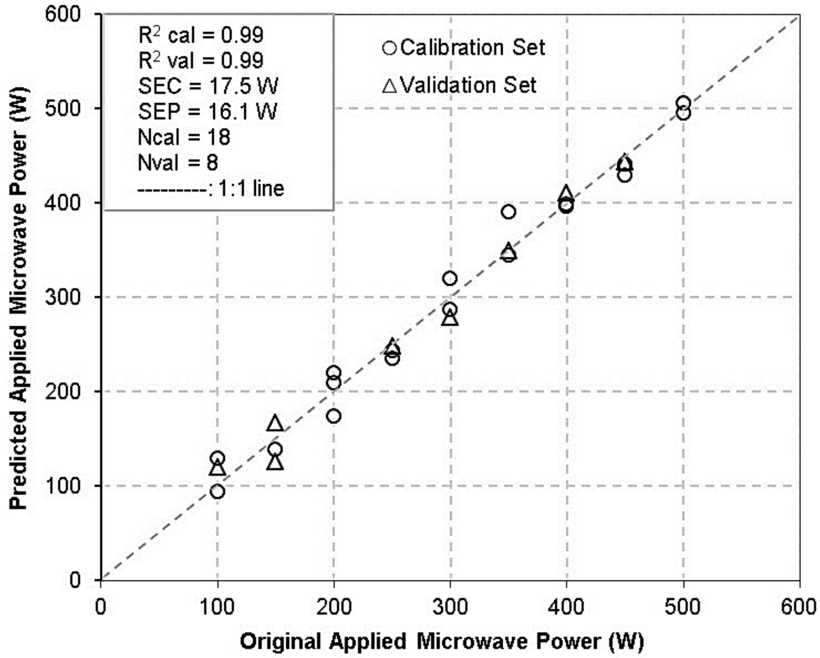

Figure 9. Original vs. Predicted applied microwave power of powdered carrots using FT-NIRS.

As a comparison between the chromameter and the NIRS system, it was observed that the NIRS system (R^2 = 0.99; SEP = 16.1 W) can predict the applied microwave (MW) power of powdered carrots with significantly better performance than a chromameter (R^2 = 0.95; SEP = 29.9 W). Yet, cost of the equipment is also a crucial factor. The chromamater is far more inexpensive as compared with the NIRS system and it can predict the applied MW power from the colour data relatively well.

It is not feasible to assess the quality of fresh or dried agricultural products by human vision since it is not subjective and standard (Keskin at al., 2008; Keskin et al., 2017); thus, various electro-optical instruments including chromameters and NIRS systems are used for this purpose owing to their benefits being non-destructive, fast, inexpensive, repeatable, environment-friendly and performing analysis in situ and online (Garcia-Sanchez et al., 2017). In intermittent microwave (MW) drying, applied MW power, pulse ratio and temperature are crucial factors to obtain high quality dried products (Ekezie et al., 2017). The current study aimed at prediction of applied MW power of powdered carrots dried by intermittent MW energy. Further studies have been planned to include other drying methods including hot air convective and infrared drying methods and the combined drying methods at different drying temperatures for other agricultural products.

CONCLUSIONS

This study was conducted to predict the applied microwave (MW) power of carrot powders dried by intermittent MW drying with varying applied MW powers (100-500 W) by using two different instruments, a chromameter and FT-NIRS.

The drying time with the highest applied power of 500 W was 1.12–5.47 times shorter than those of lower applied powers. However, intermittent MW drying with longer power-off time (lower applied power) resulted in a more stable and gentle drying process and could be preferred as a drying method to produce higher quality products in terms of product colour. Statistical analysis showed that applied MW power was a crucial factor on all colour parameters of the powdered carrots. Brightness (L*) decreased significantly with the increase of applied MW power resulting in darker product colours.

Results showed that the NIRS system ($R^2 = 0.99$; SEP = 16.1 W) can predict the microwave power of powdered carrots with comparatively better performance than a chromameter ($R^2 = 0.95$; SEP = 29.9 W). The chromamater is far more inexpensive when compared with the NIRS system and it can predict the applied microwave power from the colour data relatively well.

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