Effect of microwave drying on quality kinetics of okra

Muhammad Aamir¹ · Waraporn Boonsupthip¹

Revised: 6 February 2017 / Accepted: 10 February 2017 / Published online: 10 March 2017
© Association of Food Scientists & Technologists (India) 2017

Abstract The effects of microwave drying on quality attribute of okra were evaluated. Microwave power values show significant effect on moisture diffusivity, color, hardness and sensory attributes of dried okra. The total color change (ΔE) increased whereas L^* , a^* and b^* decreased with an increase in both power and time. The kinetics of L^* and a^* were well expressed by zero-order kinetic models, while b^* and ΔE followed first-order kinetic models. Hardness was expressed by a first-order kinetic model. Sensory evaluation showed that okra dried at 800 W was most attractive in terms of color, texture, flavor and overall liking. Microwave drying at 800 W presented the shortest drying time with the least change in hardness, but the most change in color. Thus, high-power microwave drying potentially produces dried fruits and vegetables with minimum changes in hardness.

Keywords Microwave drying · Mathematical modeling · Physical quality · Sensory evaluation · Okra

List of symbols

D_{eff}	Effective moisture diffusivity ($m^2 s^{-1}$)
M_e	Equilibrium moisture content of sample (g water/g dry solid)
M_t	Moisture content at any time (g water/g dry solid)
M_i	Initial moisture content (g water/g dry solid)

MR	Moisture ratio
m	Mass of sample (g)
P	Microwave power (W)
N	The number of terms taken into consideration
Ea	Activation energy ($W g^{-1}$)
R^2	Correlation coefficient
k	Reaction rate
A	Pre-exponential constant
L	Half thickness of the sample
T	Drying time (min)
RMSE	Root means square error
RSM	Response surface methodology

Introduction

Okra (*Abelmoschus esculentus* (L) Moench) is an annual vegetable crop, belonging to the Malvaceae family. It probably originates in an east African region, quite possibly in Ethiopia. Okra plant is grown all over the world where there is a tropical or Mediterranean climate for its immature pods. It grows best in hot weather (Temperatures above 26 °C). Today, the most important okra-producing countries are India, Nigeria, Pakistan, Ghana and Egypt (FAO 2014). Okra can be consumed as a fresh vegetable, a snack, a cooked vegetable or as an additive for soups, salads and stews. Because of its sensitivity to storage, most fresh okras are preserved in some way. Okra is a good source of carbohydrate, protein, dietary fiber, calcium, magnesium, potassium, and vitamins A and C (Pendre et al. 2012).

Vegetables are highly perishable because of their high metabolic activity. About 10–15% of fresh vegetables shrivel and stale, leading to loss of their market value and consumer acceptability. Fresh harvested okra has a very high moisture content (88–90% wet basis), whereas

✉ Waraporn Boonsupthip
fagiwpb@ku.ac.th

Muhammad Aamir
aamirmuhammadbajwa@gmail.com

¹ Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, 50 Ngamwongwan Road, Ladyao, Chatuchak, Bangkok 10900, Thailand

the safe moisture level to store okra is 10% wet basis (Shivhare et al. 2000). Due to this high moisture content, okra is subject to rapid deterioration causing chemical, physical and biological changes. Therefore, drying is imperative to reduce the moisture content of okra to a safe level, as moisture reduction can control the growth of microorganisms and reduce deterioration processes (Falade and Omojola 2010).

Drying is one storage method that has the capability of extending the consumption period of a food product (Pokorny et al. 2001). Drying not only affects the moisture content of the product but also alters the physical, biological and chemical properties, such as enzymatic activity, microbial spoilage, viscosity, hardness, aroma, flavor, and palatability of foods (Barbosa-Cánovas and Vega-Mercado 1996). Drying improves product shelf life without the addition of any chemical preservative and reduces both the size of package and transportation cost (Figiel 2010). Drying also assists in reducing postharvest losses of fruits and vegetables, especially those with a moisture level higher than 70% (Guan et al. 2013).

The most common methods used for drying are sun drying and hot air drying. However, these two methods have many disadvantages such as inability to handle large quantities and to achieve consistent quality standards, contamination problems, long drying times, low energy efficiency and high cost. It may also cause serious damage to product flavor, color and nutrients, reducing bulk density and rehydration capacity, that is not desirable for the food industry (Soysal and Öztekin 2001). Microwave drying is an alternative method. It has high thermal conductivity to the inner sides of the material, space utilization, sanitation, energy savings, precise process control, and fast startup and shutdown conditions. It minimizes drying time and prevents food from being decomposing (Maskan 2000).

Microwave drying is a rapid drying technique that can be useful to specific foods. Increasing concerns over product quality and production costs motivated researchers to investigate, and the industry to adopt, microwave drying technology. The advantages of microwave drying include shorter drying time, improved product quality, and flexibility in producing a wide variety of dried products (Haghi and Amanifard 2008). The drying characteristics and quality of the final products dried by microwave are dependent on drying time and microwave power (Golpour et al. 2015). In the drying process of fruits and vegetables, mathematical models could be a good tool for predicting product quality after drying. In a drying process, mathematical models have succeeded in obtaining constant values that describe the process.

Microwave drying has been applied to a number of agricultural products, such as banana (Maskan 2000), kiwifruit (Maskan 2001), and spinach (Ozkan et al. 2007),

because it shortens drying time with minimal quality decline of the final product (Figiel 2009). Furthermore, microwave drying has several advantages, including the development of desirable characteristics in dry products due to the increased temperature in the center of the material and effective distribution of heat throughout the material (Díaz et al. 2003).

Microwave drying may affect the physical properties and chemical compositions of food including changes in color, texture, sensory parameters and the loss of water-soluble vitamins (mainly ascorbic acid). Color, texture and other sensory parameters are important indicators in the evaluation of dried fruits and vegetables. Color plays a significant role in the appearance, processing, and acceptability of food. At the sale point of, visual appearance is the first impact made by a food on a consumer. The color change during thermal processing takes place due to the reactions inside the food material. These reactions can be pigment degradation, especially carotenoids and chlorophyll, and/or browning reactions such as Maillard condensation of hexoses and amino components and oxidation of ascorbic acid (Dadali et al. 2007). A slight change in color, maintaining the color close to that of the fresh sample, is preferable, and this characteristic is thought to indicate a better quality of dry product. Texture degradation of thermally processed biomaterials is mainly due to enzymatic and non-enzymatic changes in pectin (a cell wall polysaccharide). Hardness of food occurring during processing is also measured, as it provides valuable insight into understanding changes of texture (Chong et al. 2008).

Based on the research described above, we examined the impact of microwave drying on the quality attributes of dried okra as compared to that of hot air drying.

The objective of this study were to (1) evaluate the effect of microwave drying power levels and times on drying characteristics of okra, (2) determine the changes in color, texture and sensory parameters of the product during microwave drying, (3) study the kinetics of color and texture parameter degradation during microwave drying of okra.

Materials and methods

Sample preparation

Green, fresh, mature (edible stage) okra samples were purchased from a local supplier in Bangkok, Thailand. They were washed and stored at 4–6 °C in a refrigerator for a period of one day, under equilibration of moisture. Okra pods were taken out and kept at ambient condition for 1 h before commencement of experiment. The pods were cut manually, using a cut and chop board, into 2.00 ± 0.2 cm

cubes. Both ends of the okra pods were rejected. For initial moisture content, 25 g of samples were dried in an oven at 105 °C for 24 h (Soysal 2004). The initial moisture content of okra was 89.90% (wb) with reproducibility of $\pm 5\%$.

Drying equipment and drying procedure

Drying was performed in a domestic digital microwave oven (Daewoo KOR 6L15, Germany) with technical features of 230 V, 50 Hz, and frequency of 2450 MHz (a wavelength of 12.24 cm). The microwave oven used has the capability to operate at three different microwave output powers (440, 618 and 800 W). The adjustment of microwave output power and processing time was done with the aid of a digital control tool located on the microwave oven. During drying, each sample (25 g) was spread uniformly in a single layer on the rotating glass of the microwave and was placed at the center of the microwave oven. Moisture loss was periodically measured by taking out the rotating glass and weighing it on a digital balance with a precision of 0.01 g. Three replications of each experiment were performed according to a preset microwave output power and time schedule, and the data given are an average of these results. The reproducibility of the experiments was within the range of $\pm 5\%$. Drying was carried out until the final moisture content reached a level of less than 10% (wb). All of the weighing processes during drying were completed in less than 10 s.

Mathematical modeling

In order to determine the moisture ratio as a function of drying time, a thin layer drying model, namely Fick's Law was used. The moisture ratio of okra was calculated by using the following equation:

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

where MR is the moisture ratio, M_t is the moisture content at a specific time (g/g (wb)), M_o is the initial moisture content (g/g (wb)), M_e is the equilibrium moisture content (g/g (wb)), and t is drying time (min). The equilibrium moisture content (M_e) was assumed to be zero for microwave drying as stated previously (Maskan 2000). A thin layer drying model was developed based on the data of required parameters, including initial moisture content, moisture content of samples at time, equilibrium moisture content, and microwave power and time.

Effective moisture diffusivity

In general, drying of food takes place in two periods, a constant rate and a falling rate. After a short heating period,

a constant rate period was followed by a falling rate period, which is a dominating period during drying process. The mechanism of moisture transfer includes molecular diffusion, liquid diffusion, vapor diffusion, and hydrodynamic flow. Moisture transfer in solid matter normally takes place through molecular diffusion. Fick's second law of diffusion was used to measure internal diffusion occurring in the falling rate interval (Feng et al. 2000).

$$MR = \left[\frac{8}{\pi^2} \right] \sum \frac{1}{(2n+1)^2} \exp - \left[\frac{\pi^2 (2n+1)^2 D_{eff} t}{4H^2} \right] \quad (2)$$

H = Half thickness of okra slab, 2.0×10^{-2} Half thickness (H) of okra slab was measured by using a digital vernier calliper (Neiko 0107A, Nieko Tools, USA).

The modified version of the above equation is as follows:

$$\ln \left[\frac{M}{M_0} \right] = \ln \frac{8}{\pi^2} - \left[\frac{\pi^2 D_{eff} t}{4H^2} \right] \quad (3)$$

$$\ln(MR) = \ln(0.81057) - 2.4674 \left[\frac{D_{eff} t}{H^2} \right] \quad (4)$$

Slope and moisture diffusivity were calculated by plotting $\ln MR$ against the time using a modified version of the following equation (Sacilik 2007).

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4H^2} \quad (5)$$

The closeness of fit of the tested mathematical models to the experimental data was evaluated with the correlation coefficient (R^2) and the root mean square error (RMSE). The best fit is the one resulting in high R^2 and low in RMSE (Orikasa et al. 2008; Radhika et al. 2011). The R^2 and RMSE were calculated as follows:

$$R^2 = 1 - \frac{\sum (\text{Actual } MR \text{ value} - \text{Predicted } MR \text{ value})^2}{\sum (\text{Actual } MR \text{ value} - \text{Average } MR \text{ value})^2} \quad (6)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (M_{exp,i} - M_{pre,i})^2}{N-1}} \quad (7)$$

where $M_{exp,i}$ is the i th experimentally observed moisture content, $M_{pre,i}$ is the i th predicted moisture content, and N is the number of observations.

Color analysis

During microwave drying okra samples were removed from the microwave oven at specific time intervals for color measurement. Their color (L^* , a^* , b^*) was measured with a Minolta colorimeter (Model No: CM-3500D, Minolta,

Japan) at room temperature with controlled light. The instrument was calibrated against white and black ceramic plate standards. This system uses three values (L^* , a^* , b^*) to describe the precise location of the color inside a three-dimensional visible color space. Since the okra samples did not cover the entire surface area, they were scanned at five different locations to determine the average L^* , a^* and b^* values during the measurements. The results are reported in L^* (lightness), a^* (greenness-redness) and b^* (blueness-yellowness) values. In addition the total color changes (ΔE^*) was calculated from the Hunter L^* , a^* and b^* values to describe the color change during drying as follows:

$$\Delta E = \sqrt{(L_0^* - L_t^*)^2 + (a_0^* - a_t^*)^2 + (b_0^* - b_t^*)^2} \quad (8)$$

where L_0^* , a_0^* , b_0^* are the initial color measurements of raw okra samples and L_t^* , a_t^* , b_t^* are the color measurements at specific time.

Texture analysis

Texture profile of the okra samples were measured using a Texture Analyzer TA-XT2 (Stable Micro Systems Ltd., Surrey, UK). A single blade probe (0.5 mm-thick blades with 40 mm blade length and 50 mm width) was used to measure shear force (N) of the samples. The probe was fitted to a Texture Analyzer equipped with a 5 kg load cell. Before measurement, the raw and heated samples were allowed to equilibrate to room temperature (approximately 20 °C), which took approximately half an hour. The samples were carefully placed on the support base so that the blade was perpendicular to the samples. The traveling speed for the blade was set at 1 mm/s and the distance was 5 mm. The force–time graphs were recorded by a computer and analyzed using the Texture Expert for Windows (version 1.15, Stable Micro Systems Ltd.). Shear force was measured as the peak height in the force–time profile. The texture profile analyzer enabled us to calculate the hardness of the sample seeds. Hardness (N) (maximum peak of first compression) was considered to evaluate the textural properties of the okra at different drying conditions (Setiady et al. 2009).

Sensory evaluation

Sensory tests were conducted at the Sensory Analysis Laboratory, Department of Food Science and Technology, Kasetsart University. Panelists were in the age range of 25–40 years with no report of food allergies. The 12 trained panelists in the test of dried okra reported consuming okra at least 1–2 times in a month. Pair samples containing dried okra and fresh okra (control) were presented to the panelists simultaneously. On the ballot the instruction stated “Taste the sample from left to right”. Answer the questions below and re-taste if necessary.

Take a bite of the cracker and rinse your palate with water. The serving order of samples was rotated to reduce potential bias caused by positions. Panelists were asked to score for color, texture, flavor and overall acceptability on a 9-point hedonic scale, that is, 1 = extremely dislike, 5 = neither like nor dislike, 9 = extremely like (Shams et al. 1999).

Kinetic consideration

Generally, reaction rates for quality degradation under isothermal conditions can be presented as follows (Dadali et al. 2007):

$$\frac{dC}{dt} = -k(C)^n \quad (9)$$

where k is the rate constant, C is the quantitative indicator of a quality attribute at time t , and n is the reaction order. To find the best empirical relationship, quality data were analyzed using zero, first and second order kinetic models as shown in Eqs. (10)–(12):

$$\text{Zero-order : } C_t = C_0 - k.t \quad (10)$$

$$\text{First-order : } \ln \frac{C_t}{C_0} = -k.t \quad (11)$$

$$\text{Second-order : } k_t = \frac{1}{C_t} - \frac{1}{C_0} \quad (12)$$

where C_0 is the initial value at time zero, C_t is the value at time t , k is the rate constant. The Arrhenius equation was used to determine the degradation rate constant (k) on temperature that is described as follows:

$$k = k_0 \exp\left(-\frac{E_a \cdot m}{P}\right) \quad (13)$$

where k is the kinetic rate constant of the quality parameter (min^{-1}), k_0 is the pre-exponential constant (min^{-1}), E_a is the activation energy (W g^{-1}), P is microwave output power (W), and m is the weight of raw sample (g).

Statistical analysis

A one-way analysis of variance (ANOVA) was performed using SPSS Version 16. Comparison between means were examined using a Duncan multiple range test (DMRT) at $p < 0.05$ as level of significance.

Results and discussions

Drying characteristics of Okra

Changes in the experimental and predicted moisture ratio (MR) values with drying time at different microwave

power levels are given in Fig. 1. As the microwave power increased, the drying time of the samples significantly decreased. The microwave drying process reduced the moisture content of okra from 89.90% (wet basis) to 10% (wet basis) during 4–7 min, depending on the microwave power level applied. At high microwave power level (800 W), the drying time was shortened. The variation in drying requirements was mainly due to the difference in the drying rate as related to the microwave power levels applied. Similar findings were also reported by several authors for various foods using microwave drying (Maskan 2000; Soysal 2004). The drying times obtained in this study were much shorter (4–7 min) as compared to the results reported by Pendre et al. (2012) using a convective hot air dryer for drying okra. The appearance of okra at different levels and time intervals is shown in Fig. 2. It can be seen that high microwave power (800 W) and short time (4 min) showed a more attractive color after drying as compared to low power (618, 440) and long time (5–7 min).

Fick's model, a thin layer drying model, was used to describe microwave drying characteristics. The established model was validated by comparing the predicted MRs to the experimental values from all drying experiments. Correlation coefficient data have a high value ($R^2 = 0.99$), that shows how well the model fits with the experimental data.

Effect of microwave power and time

Effective moisture diffusivity

There is a lack of information regarding the mechanism of moisture movement during drying process. Therefore, effective moisture diffusivity, which may include liquid

diffusion, vapor diffusion, vaporization, condensation, hydrodynamic flow, and other possible mass transfer mechanisms, was used to represent an overall mass transport property of water in the material (Khraisheh et al. 1997). Effective moisture diffusivity (D_{eff}) was calculated using Eq. 5. The natural logarithmic values of moisture ratio, $\ln(MR)$, were plotted against drying time (t) according to the experimental data obtained for different microwave output powers ranging between 440 and 800 W for drying okra. The calculated values of R^2 and $RSME$ are 0.98–0.99 and ± 0.17 to ± 0.20 , respectively at different microwave power levels. The slight deviation from the linearity seen at lower microwave output powers may be due to more shrinkage in the product, non-uniform distribution of moisture during drying, and variation in effective moisture diffusivity with moisture content (Khraisheh et al. 1997).

The combined effect of microwave power and time on moisture diffusivity is shown in Fig. 3. Dadali et al. (2007) observed that effective moisture diffusivities ranged from 20.54×10^{-10} to $86.17 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$ for various microwave power levels (180, 360, 540, 720 and 900 W). In another study on hot air drying of okra at temperatures of 60, 70, and 80 °C was conducted. It was found that effective moisture diffusivities ranged from 4.28×10^{-10} to $8.30 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$ (GÖGus and Maskan 1999). In the present study, although similar trends were observed, the range of effective moisture diffusivity of okra for microwave drying varied from 0.92 to 2.13 ($10^{-4} \text{ m}^2 \text{ s}^{-1}$). These values were higher than the values obtained in literature because of lower food loads and shorter drying times required under this method of microwave treatment of okra.

Color change kinetics of okra

The values of L^* , a^* , b^* , and total color change (ΔE) obtained from the experimental data during microwave drying are presented in Fig. 4a–d. L^* value decreased with drying time. It has been stated that the change in the brightness of dried samples can be taken as a measurement of browning, which reduced from 40.98 to 21.11, 24.57 and 22.41 during microwave drying of okra samples at the three different microwave power levels, 440, 618 and 800 W, respectively (Fig. 4a) (Ávila and Silva 1999). These three final L^* values were not significantly different. When measuring for greenness, we found that a^* value (Fig. 4b) decreased from -7.03 to -0.82 , -0.52 and -0.12 at power levels of 440, 618 and 800 W, respectively, indicating a decrease in greenness. However, these three final values were not significantly different. A decrease in the value of b^* (Fig. 4c) was also observed during microwave drying. The b^* values decreased from 21.00 to 2.52, 5.05 and 7.15 at 440, 618 and 800 W, respectively. This might be due to

Fig. 1 Moisture ratios (MR) for okra versus time at different microwave power levels, comparing experimental curve with predicted thin layer Fick's law

Fig. 2 Effect of microwave drying on physical appearance of okra at 440 W (a), 618 W (b) and 800 W (c) per minute

Fig. 3 Influence of microwave power and time on D_{eff} of okra seeds during drying 1 = 440 W, 2 = 618 W, 3 = 800 W

decomposition of chlorophyll and carotenoid pigments, non-enzymatic Maillard browning, and formation of brown pigments during the process (Weemaes et al. 1999). Those three final values of b^* were significantly different. As a whole, the total color change (ΔE) of okra increased significantly during microwave drying with drying time ranging from 6.20 to 24.19 as the microwave power level increased from 440 to 800 W (Fig. 4d). The large change in the ΔE values was likely related to a high change in the b^* value or browning color development. Previously, Kumar et al. (2014) reported that total color change in dried okra ranged from 25.92 to 29.56 using three power levels (0.5–2.5 W g⁻¹), which are slightly higher than in this study. This is probably due to the use of a microwave assisted with hot air drying which increased the total color change in dried okra.

For the color change kinetics of okra, zero, first and second order reaction kinetic models were used but the zero and first

order reaction kinetic models best fitted our data. The estimated kinetic parameters of these models, corresponding values of correlation coefficients (R^2), and root mean square errors (RSME) are represented in Table 1. L^* and a^* values were more closely fitted to zero-order models; but the values of b^* and ΔE followed first-order kinetic models.

The kinetic rate constant increased with microwave power from 2.96 to 3.66 min⁻¹, 0.66 to 1.41 min⁻¹, 0.21 to 0.27 min⁻¹ and 0.23 to 0.29 min⁻¹ for L^* , a^* , b^* and ΔE respectively. This implies that an increase in microwave output power level causes the degradation rate to increase. This is possibly related to the fact that the transfer of high energy inside a food causes an increase in the temperature of the product (Dadali et al. 2007). Some studies show that the first-order kinetic model was better for L^* value and zero-order for a^* , b^* and ΔE values of concentrated tomato paste, pear puree and kiwifruits (Ibarz et al. 1999).

The activation energy (E_a) values for color degradation of L^* , a^* , b^* and ΔE were 4.44, 19.97, 3.72 and 5.47 W g⁻¹, respectively. This suggests that a^* value was the most sensitive to a microwave power change. The b^* value was the least sensitive.

Texture change kinetics of okra

The initial texture measurement values for hardness of control sample were 4.38 ± 1.02 , which rapidly increased during first 2 min (12.72 ± 1.05 to 16.13 ± 0.71) at different microwave power levels and times (Fig. 4e). The rapid increase in hardness corresponded with the abrupt reduction of water content in okra (Fig. 1). At the highest hardness, it is likely that the surface of okra is low in moisture, and becomes firmer (crust-formation-liked).

Fig. 4 Color change parameters **a** L^* value, **b** a^* value, **c** b^* value **d** total color change (ΔE) and **e** hardness of okra as a function of drying time at different microwave power levels

After the initial drying of okra point the decreased sharply, while the moisture evaporation rate was slow. At this point, the temperature of okra was probably high causing the okra to cook. Its texture became soft and hardness decreased. At 800 W drying, dried okra had a stronger texture than that at the other powers. This hardness change pattern is consistent with the results obtained elsewhere (Bourne 1987) for carrots and (Kahyaoglu and Kaya 2006) for sesame.

The values for resultant rate constants (k), R^2 , $RMSE$ and activation energy (Ea) are presented in Table 1. The reaction rate constants (k) increased, as the microwave power and time increased. A modified version of the Arrhenius equation (Eq. 13) was used to express the power dependence of rate constants (k) and estimate activation energy values (Ea). The kinetics of hardness was evaluated as a first-order kinetic model and best fitted the

Table 1 Kinetic parameters at different temperatures as zero and first order models for L^* , a^* , b^* , ΔE , and hardness for microwave dried okra at different power and time

Color parameters	Power (W)	k (min ⁻¹)	R^2	$\pm RMSE$	E_a (KJ/mol)
L^{*a}	440	2.96	0.97	0.96	4.44
	618	2.86	0.98	0.53	
	800	3.66	0.97	0.69	
a^{*a}	440	0.66	0.97	0.21	19.97
	618	1.40	0.97	1.69	
	800	1.41	0.96	0.39	
b^{*b}	440	0.27	0.94	0.12	3.72
	618	0.21	0.97	0.05	
	800	0.24	0.99	0.01	
ΔE^{*b}	440	0.23	0.88	0.16	5.47
	618	0.26	0.95	0.07	
	800	0.29	0.92	0.09	
Hardness(N) ^b	440	0.21	0.94	0.10	8.75
	618	0.27	0.87	0.12	
	800	0.31	0.94	0.15	

^a zero order, ^b first order reaction**Table 2** Sensory attributes of microwave dried okra at different power and time values

Sensory attribute	Microwave power (W) and time (min)								
	440 W			618 W			800 W		
	1 min	3 min	7 min	1 min	3 min	5 min	1 min	2 min	4 min
Color	5.67 ^{aA}	4.00 ^{aA}	4.67 ^{aAB}	4.67 ^{aAB}	5.33 ^{abABC}	6.42 ^{bBC}	5.67 ^{aABC}	6.33 ^{aBC}	6.75 ^{aC}
	±0.58	±1.00	±1.53	±0.58	±0.58	±0.52	±0.58	±0.58	±2.17
Texture (hardness)	4.00 ^{aA}	5.00 ^{aAB}	6.17 ^{aAB}	5.00 ^{aAB}	5.00 ^{aAB}	6.58 ^{aAB}	6.33 ^{aAB}	7.00 ^{aB}	7.00 ^{aB}
	±1.00	±1.00	±2.36	±1.00	±1.00	±1.66	±0.58	±1.00	±1.73
Flavor	5.00 ^{aAB}	5.33 ^{aABC}	7.08 ^{aCD}	4.33 ^{aA}	5.00 ^{abAB}	7.08 ^{bCD}	5.67 ^{aABC}	6.67 ^{abBCD}	7.67 ^{bD}
	±1.00	±1.53	±1.94	±0.58	±0.58	±1.01	±1.00	±0.58	±1.44
Overall Acceptability	5.00 ^{aAB}	5.33 ^{aAB}	6.42 ^{aAB}	4.67 ^{aA}	5.33 ^{abAB}	6.42 ^{bAB}	6.00 ^{aAB}	6.00 ^{aAB}	7.17 ^{aB}
	±1.00	±1.53	±1.94	±0.58	±0.58	±1.01	±1.00	±0.58	±1.44

^{abc} Show significant difference within each power and similar parameter at $p < 0.05$ ^{ABC} Show significant difference between all powers and similar parameter at $p < 0.05$

experimental curves for hardness. The resultant value of R^2 was 0.87–0.94 for first-order reaction kinetics. The activation energy (E_a) value for texture degradation as hardness was 8.75 W g⁻¹. The activation energy values determined for textural parameter (hardness) were lower than the values suggested by Alvarez and Canet (2002) (40–125 kJ/mol).

Sensory attributes of okra

Changes in sensory attributes (color, texture, flavor and overall acceptability) are shown in Table 2. Microwave drying of okra at 800 W was preferred over the other power levels. Overall color, texture and flavor of 800 W dried okra were significantly better ($p < 0.05$) than 440 W treatments.

However, okra dried with 800 W at 4 min and 618 W at 5 min had comparable sensory ratings, while that with 440 W at 7 min had poor sensory ratings. No significant difference was observed at 440 W for all the sensory parameters at each time interval, while a significant difference was found in color, flavor and overall acceptability at 618 W (5 min). A significant difference was also observed in overall acceptability at 4 min as compared to the other tested times at 800 W.

Conclusion

Microwave is a tool for rapid drying of okra. Microwave power and time had strong impact on effective moisture diffusivity, color, hardness changes and sensory attributes

of dried okra. The greenness of okra was well preserved throughout however, brownness was obvious. The texture/hardness fluctuated during microwave drying. However, the final hardness of dried okra was similar to fresh okra. Sensory evaluation suggested well accepted quality of the dried okra in terms of color, texture, flavor and overall liking. Microwave drying is a potent process for rapid drying of food.

References

- Alvarez MD, Canet W (2002) A comparison of various rheological properties for modelling the kinetics of thermal softening of potato tissue (c.v. Monalisa) by water cooking and pressure steaming. *Int J Food Sci Tech* 37:41–55
- Ávila IMLB, Silva CLM (1999) Modelling kinetics of thermal degradation of colour in peach puree. *J Food Eng* 39:161–166
- Barbosa-Cánovas GV, Vega-Mercado H (1996) Dehydration of foods. Springer, Berlin
- Bourne MC (1987) Effect of blanch temperature on kinetics of thermal softening of carrots and green beans. *J Food Sci* 52:667–675
- Chong CH, Law CL, Cloke M, Abdullah LC, Daud WRW (2008) Drying kinetics, texture, color, and determination of effective diffusivities during sun drying of Chempedak. *Dry Technol* 26:1286–1293
- Dadali G, Apar DK, Özbek B (2007) Estimation of effective moisture diffusivity of okra for microwave drying. *Dry Tech* 25:1445–1450
- Díaz GRZ, Martínez-Monzó J, Fito P, Chiralt A (2003) Modelling of dehydration-rehydration of orange slices in combined microwave/air drying. *Innov Food Sci Emerg Tech* 4:203–209
- Falade KO, Omojola BS (2010) Effect of processing methods on physical, chemical, rheological, and sensory properties of okra (*Abelmoschus esculentus*). *Food Bioprocess Tech* 3:387–394
- FAO(2014). FaoStat Database. <http://faostat.fao.org>. Accessed 20 June 2016
- Feng H, Tang J, John DWS (2000) Determination of moisture diffusivity of red delicious apple tissues by thermogravimetric analysis. *Dry Tech* 18:1183–1199
- Figiel A (2009) Drying kinetics and quality of vacuum-microwave dehydrated garlic cloves and slices. *J Food Eng* 94:98–104
- Figiel A (2010) Drying kinetics and quality of beetroots dehydrated by combination of convective and vacuum-microwave methods. *J Food Eng* 98:461–470
- Göğüs F, Maskan M (1999) Water adsorption and drying characteristics of okra (*Hibiscus Esculentus* L). *Dry Tech* 17:883–894
- Golpour I, Amiri CR, Amiri PJ, Khazaei J (2015) Prediction of paddy moisture content during thin layer drying using machine vision and artificial neural networks. *J Agric Sci Tech* 17:287–298
- GuanZ Wang X, Li M, Jiang X (2013) Mathematical modeling on hot air drying of thin layer fresh tilapia fillets. *Pol J Food Nutr Sci* 25:1524–1532
- Haghi AK, Amanifard N (2008) Analysis of heat and mass transfer during microwave drying of food products. *Braz J Chem Eng* 25:491–501
- Ibarz A, Pagán J, Garza S (1999) Kinetic models for colour changes in pear puree during heating at relatively high temperatures. *J Food Eng* 39:415–422
- Kahyaoglu T, Kaya S (2006) Modeling of moisture, color and texture changes in sesame seeds during the conventional roasting. *J Food Eng* 75:167–177
- Khraisheh MAM, Cooper TJR, Magee TRA (1997) Shrinkage characteristics of potatoes dehydrated under combined microwave and convective air conditions. *Dry Tech* 15:1003–1022
- Kumar D, Suresh P, Ganti SM (2014) Optimization of microwave-assisted hot air drying conditions of okra using response surface methodology. *J Food Sci Technol* 51:221–232
- Maskan M (2000) Microwave/air and microwave finish drying of banana. *J Food Eng* 44:71–78
- Maskan M (2001) Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. *J Food Eng* 48:177–182
- Orikasa T, Wu L, Shiina T, Tagawa A (2008) Drying characteristics of kiwifruit during hot air drying. *J Food Eng* 85:303–308
- Ozkan IA, Akbudak B, Akbudak N (2007) Microwave drying characteristics of spinach. *J Food Eng* 78:577–583
- Pendre NK, Nema P, Sharma H, Rathore SS, Kushwah SS (2012) Effect of drying temperature and slice size on quality of dried okra (*Abelmoschus esculentus* (L.) Moench). *J Food Sci Tech* 49:378–381
- Pokorny J, Yanishlieva N, Gordon MH (2001) Antioxidants in food: practical applications. CRC Press, Cambridge
- Radhika GB, Satyanarayana SV, Rao DG (2011) Mathematical model on thin layer drying of finger millet (*Eleusine coracana*). *Adv J Food Sci Tech* 3:127–131
- Sacilik K (2007) Effect of drying methods on thin-layer drying characteristics of hull-less seed pumpkin (*Cucurbita pepo* L.). *J Food Eng* 79:23–30
- Setiady D, Tang J, Younce F, Swanson BA, Rasco BA, Clary CD (2009) Porosity, color, texture, and microscopic structure of russet potatoes dried using microwave vacuum, heated air, and freeze drying. *Appl Eng Agric* 25:719–724
- Shams EL, Din M, Shouk A (1999) Comparative study between microwave and conventional dehydration of okra. *Grasas Aceites* 50:454–459
- Shivhare U, Gupta A, Bawa A, Gupta P (2000) Drying characteristics and product quality of okra. *Dry Tech* 18:409–419
- Soysal Y (2004) Microwave drying characteristics of parsley. *Biosys Eng* 89:167–173
- Soysal Y, Öztekin S (2001) pH-postharvest technology: comparison of seven equilibrium moisture content equations for some medicinal and aromatic plants. *J Agric Eng Res* 78:57–63
- Weemaes CV, Ooms V, Oey I, Ludikhuyze L, Van den Broeck I, Loey AV, Hendrickx M (1999) Pressure-temperature degradation of green color in broccoli juice. *J Food Sci* 64(3):504–508. doi:10.1111/j.1365-2621.1999.tb15072.x