

Impact of Microwave Drying on the Quality Attributes of Okra Fruit

Lam Van Mana¹, Takahiro Orikasab², Yoshiki Muramatsuc³ and Akio Tagawaa^{1*}

¹Graduate School of Horticulture, Chiba University, 648 Matsudo, Matsudo, Chiba 271-8510, Japan

²Faculty of Agriculture, Iwate University, 3-18-8 Ueda, Morioka, Iwate, 020-8550, Japan

³Faculty of Bioindustry, Tokyo University of Agriculture, 196 Yasaka, Abashiri, Hokkaido, 099-2493, Japan

Abstract

The impact of microwave drying on quality attributes of dried okra was investigated at three levels of power between 500 and 800 W during microwave drying and was compared with that of hot air drying at four temperatures ranging from 40 to 70°C. The drying characteristics, the decreasing rate of the ascorbic acid and the total color change of okra during microwave and hot air drying were examined. An exponential model was suitable to describe the microwave and the hot air drying characteristics of okra. The drying constant k_1 ranged from 0.27 to 0.36 min^{-1} for microwave drying and from 0.15 to 0.49 h^{-1} for the hot air drying. The ascorbic acid content during microwave and hot air drying was measured and then a first-order reaction equation was used to calculate the decomposition rate of the ascorbic acid. Values of the coefficient of decomposition rate ranged from 0.40 to 0.46 min^{-1} for microwave drying. Using the change on standing in the total color difference during microwave and hot air drying, the extent of browning, B and the coefficient of browning rate k_2 were estimated. In addition, the rehydration rate of the sample which was dried with the seven conditions in this test was highest at 800 W for the microwave drying. Therefore, it was confirmed that the microwave drying at 800 W was most suitable for okra drying within this test.

Keywords: Microwave drying; Okra; Ascorbic acid; Decomposition; Browning; Rehydration

Nomenclature: B : Extent of browning (no dimension); C : Ascorbic acid content (mg/kg); E : Activation energy (kJ/mol); ΔE^* : Total color difference (TCD); K_1 : Drying constant during falling rate period (h^{-1}) calculated by diffusion equation; k_1 : Drying constant during falling rate period (h^{-1}) calculated by Lewis' equation; k_2 : Coefficient of browning rate (h^{-1}); k : Coefficient of decomposition rate; L : Characteristic length (m); M : Moisture content (d.b. decimal); M_e : Equilibrium moisture content (d.b. decimal); $M_{\text{exp},i}$: i^{th} experimentally observed moisture content; $M_{\text{pre},i}$: i^{th} predicted moisture content; m_a : Measured value of ascorbic acid ($\text{mg} \cdot \text{L}^{-1}$); N : Number of observations; R : Gas constant (8.314 J/mol/K); R_2 : Coefficient of determination; RMSE: Root mean square error; T : Absolute temperature (K); t : Drying time (s or h); V_{ox} : Volume of oxalic acid (mL); W : Weight of sample (g)

Introduction

Okra (*Abelmoschus esculentus* L.) is an annual vegetable crop that is grown for its fruits and seeds in tropical and subtropical regions. It is highly valued for its mature, tender green fruits and is a good source of fiber, minerals, and vitamins, including vitamin A, the B complex and ascorbic acid. The young fruits are consumed as cooked vegetables and in canned, frozen or dehydrated forms.

Dehydration plays an important role in preserving highly perishable products, such as fruits and vegetables, and can be accomplished by several methods, including sun drying, hot air drying, vacuum drying, freeze drying, and microwave drying.

Hot air drying is widely used to dry fruits and vegetables, such as apple [1,2], potato [3], tomato [4], and kiwifruit [4]. Recently, microwave drying has been applied to a number of agricultural products, such as banana [5], kiwifruit [6], spinach and sliced radish [7], because it shortens the drying time and minimizes the reduction in quality of the final product [8,9]. 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 [10] and the more effective distribution of heat throughout the material [11]. However, hot air drying and microwave drying cause changes in these materials physical properties and chemical compositions, including the loss of water-soluble vitamins (mainly ascorbic acid) and changes in

their color and rehydration ratios. Ascorbic acid is one of the main nutrient constituents of okra. Unfortunately, it is quite sensitive to the drying conditions of temperature and microwave energy [12]. Color change and the rehydration ratio are also important characteristics in the evaluation of dry fruits and vegetables. A small amount of color change, i.e. maintaining a color close to that of the fresh sample, is preferable, and this characteristic is thought to indicate a better quality dry product. Most dry vegetables require rehydration before they are used in cooking, and the degradation of dry fruits and vegetable caused by their drying conditions can determine their rehydration ratios [13,14]. Based on the research described above, the authors examined the impact of the microwave drying on the quality attributes of dried okra and compared that of the hot air drying.

The objectives of this study were to:

Confirm the drying characteristics of okra during microwave and hot air drying

Evaluate the decomposition rate of ascorbic acid and the rate of color change during microwave and hot air drying

Examine the difference in the rehydration ratio between microwave and hot air drying

Material and Methods

Sample preparation

Okra fruits (cv. unknown, Kagoshima prefecture, Japan) were purchased from a local market and stored in a refrigerator at 8°C for

*Corresponding author: Akio Tagawaa, Graduate School of Horticulture, Chiba University, 648 Matsudo, Matsudo, Chiba 271-8510, Japan, Tel: 81-47-308-8847; Fax: 81-47-308-8847; E-mail: tagawa@faculty.chiba-u.jp

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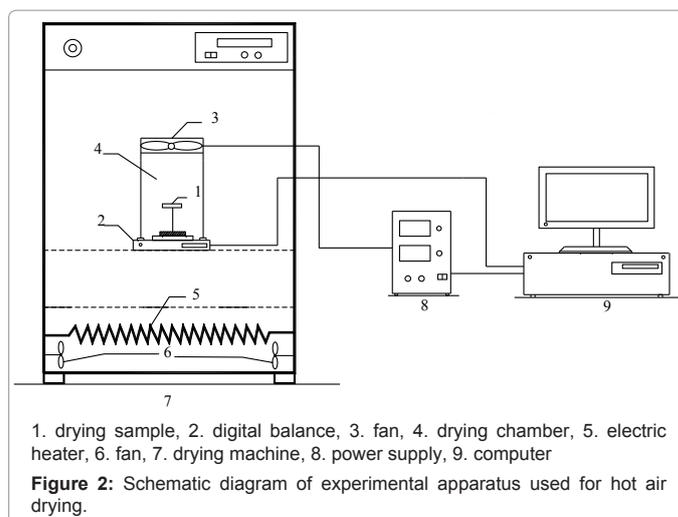
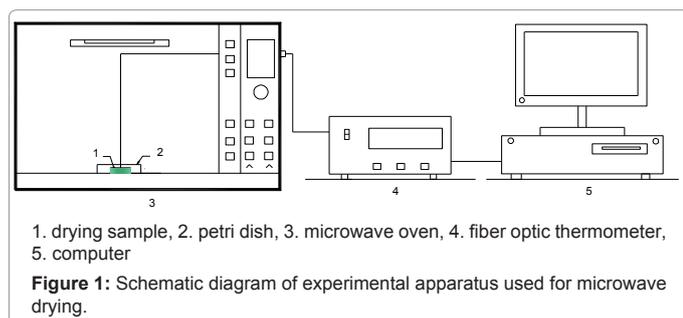
a maximum of five days. The initial moisture content of the fruits was measured by the vacuum oven method (AOAC, 1990) and was determined to be $91.03 \pm 0.1\%$ w.b. (10.14 d.b. decimal). Twenty okra fruits were selected randomly, and their lengths and diameters were measured using a Vernier caliper. The fruits were selected according to a diameter of 16.5 ± 0.2 mm and a length of 91.5 ± 1.6 mm. After being washed and drained, the fruits were cut into pieces of 20 mm in size and were used in either a drying or chemical analysis. The average weight of twenty pieces of sample product was approximately 3.5 ± 0.01 g.

Microwave drying

The microwave drying experiments were carried out using a microwave oven (MRO-DF6, 2008 Hitachi, Thailand) at powers of 500, 600 and 800 W. A schematic diagram of the experimental apparatus used for microwave drying is provided in (Figure 1). A glass petri dish (20 cm in diameter and 2 cm deep) containing between 35 and 40 g of sample was placed at the center of the oven to allow good absorption of the microwave energy. The temperature at the center of an okra sample was measured using a fluorescent typed fiber-optic thermometer with an optical fiber of a 0.1 mm diameter inserted into the okra between 10 s of radiation and 5 min of tempering. The change in mass during the microwave drying was recorded by removing the sample and weighing it with a digital balance (GX-200, A&D Co, Ltd, Japan) at 1 min intervals of drying time until the moisture content reached $14.20 \pm 0.50\%$ w.b. The experiments were replicated three times for each drying condition, and the mean value was used for discussion.

Hot air drying

A schematic diagram of the experimental apparatus used for hot air drying is presented in (Figure 2). The drying system was controlled automatically using RsCom software Ver. 2.40 (A&D Co, Ltd, Japan). The drying chamber fan was stopped 1 min before measuring the sample weight and was turned back on after the measurement. The hot air drying experiments were carried out at temperatures of 40, 50, 60 and 70°C. The weight of each drying sample ranged between approximately 20 and 30 g. Changes in mass during hot air drying were recorded at intervals of 0.5 h until the final moisture content reached $14.20 \pm 0.50\%$ w.b. (0.17 ± 0.002 d.b. decimal). The air velocity during drying was measured using an anemometer (V-01-AND2H, I Denshi Giken Co, Ltd, Japan). The average air velocity was 1.1 ms^{-1} . The temperature at the center of an okra sample was measured using T-type thermocouples of 0.1 mm in diameter inserted into the okra. The relative humidity, which ranged from 2 to 20%, was observed using a midi Logger with a humidity-to-voltage conversion module (GL200, Graphtec Corp, China). The experiments were replicated three times for each drying condition, and the mean value was used for discussion.



Mathematical modeling

Many researchers have utilized an exponential or diffusion model as the mathematical model to analyze the data obtained from drying fruits and vegetables [4,6,15-18]. Therefore, in this study, the Lewis (exponential) equation and the diffusion equation were postulated to describe the drying kinetics of okra during microwave and hot air drying.

The Lewis equation:

$$\frac{dM}{dt} = -k_1(M - M_e) \quad (1)$$

where M is the moisture content (d.b. decimal), M_e is the equilibrium moisture content (d.b. decimal), k_1 is the drying constant during the falling rate period (h⁻¹), and t is the drying time (h).

Under the initial condition $t = 0, M = M_o$, Eq. (1) can be written as follows:

$$\ln \frac{M - M_e}{M_o - M_e} = -k_1 t$$

or:

$$MR = \frac{M - M_e}{M_o - M_e} = \exp(-k_1 t) \quad (2)$$

The k^1 value and M_e were determined by means of the non-linear least squares method.

The diffusion equation: The solution of the diffusion equation is an infinite series [19], and it can be expressed as follows:

$$MR = \frac{M - M_e}{M_o - M_e} = \sum_{i=1}^{\infty} B_i \exp(-D\lambda_i^2 t) \quad (3)$$

where B_i is a constant for a given solid shape. The infinite series on the right side of Eq. (3) converges rapidly to the first term when the Fourier number $F_0 = Dt/l^2$ becomes large, and it can be expressed as follows:

$$MR = B_1 \exp(-D\lambda_1^2 t) = B_1 \exp(-K_1 t) \quad (4)$$

where K_1 is a drying constant. If B_1 is equal to unity, then Eq. (4) is none other than the expression from the exponential model. The values B_1 and K_1 are estimated by applying the experimental data to Eq. (4) by means of a non-linear least squares method. When the value of B_1

is close to 1, Eq. (4) corresponds to Eq. (2). In this study, all values of B_1 were 0.95 for hot air drying and 1 for microwave drying. Therefore, an exponential model is the most suitable method of describing the drying characteristics of okra during hot air drying and microwave drying [15].

The goodness of fit of the tested mathematical models to the experimental data was evaluated with the coefficient of determination (R_2) and the root mean square error (RMSE). The goodness of fit was that which resulted in high R_2 and low RMSE [4,20]. The RMSE was calculated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (M_{exp,i} - M_{pre,i})^2}{N-1}} \quad (5)$$

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.

Ascorbic acid content

The ascorbic acid content was determined using a reflectometer (RQ-flex-plus, Merck, Japan), as described by Merck KGaA. A weight of 5 g of okra fruit was placed in a beaker, and approximately 50 mL of oxalic acid solution 1% was added. The mixture was homogenized for 1 min and then centrifuged at 8000 rpm for 10 min. The supernatant solution was used to analyze the ascorbic acid. The ascorbic acid content was calculated using the following equation:

$$C = \frac{m_a \cdot V_{ox}}{W} \quad (6)$$

where C is the ascorbic acid content (mg/kg), m_a is the measured value of ascorbic acid (mg.L⁻¹), V_{ox} is the volume of oxalic acid (mL) and W is the weight of sample (g).

Total color difference (TCD)

The L^* (lightness: $L^*=0$ for black, $L^*=100$ for white), a^* (redness-greenness: $a^*<0$ for green, $a^*>0$ for red) and b^* (yellowness-blueness: $b^*<0$ for blue, $b^*>0$ for yellow) indexes of the CIELAB (Commission Internationale de l'éclairage, L^* , a^* , b^*) colorimetric system were used to evaluate the color change of the okra during drying. The L^* , a^* and b^* values were measured using a chroma meter (CR-200b Minolta, Japan) with a D65 light source at four different points on the okra's surface at each predetermined level of moisture content during drying. The average color parameters of fresh okra were used as a reference ($L^* = 48.5$, $a^* = -16.4$, $b^* = 26.0$). The change in the surface color of the sample, which was referred to as the total color difference (TCD), was calculated according to the following equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (7)$$

where $\Delta L^* = L^*_{sample} - L^*_{standard}$; $\Delta a^* = a^*_{sample} - a^*_{standard}$; $\Delta b^* = b^*_{sample} - b^*_{standard}$

Rehydration

Rehydration tests of the dry samples were performed by soaking the samples in distilled water at 100°C. A sample of 10 g was weighed into a 500 mL beaker containing 200 mL of distilled water. The beaker was placed on a hot plate and covered with a watch glass. The water was brought to the boiling point within 3 min and maintained at boiling for an additional 5 min. The sample was transferred to a 10 cm Buchner funnel covered with Whatman No. 4 filter paper. The water was drained until no more drops came from the funnel. The sample

was then weighed. The rehydration ratio was calculated as the ratio of the water absorbed (g) divided by the weight of the dried sample (g).

Statistical analysis

A one-way analysis of variance (ANOVA) was performed using R software Ver. 2.13.1. Comparisons between the means were examined using Tukey's test at a $P<0.05$ significance level.

Results and Discussion

The temperature at the center of the okra, which was measured by a fluorescent typed fiber-optic thermometer with an optical fiber of 0.1 mm in diameter inserted into the okra, ranged from 40 to 100°C between 10 s of radiation and 5 min of tempering during the process of microwave drying. In addition, the temperature in the center of the okra, which was measured by T-type thermocouples of 0.1 mm in diameter inserted into the okra, asymptotically approached the dry bulb temperatures of the drying air during the first 40-60 min from the initiation of the hot air drying tests.

The changes in the moisture content of okra during microwave and hot air drying are presented in (Figures 3 and 4). The moisture content decreases gradually with increases in drying time, exhibiting a gentle downward curve. The data also indicate that the drying time of the microwave drying was much shorter than that of the hot air drying. The time required to reduce the moisture content from 10.14

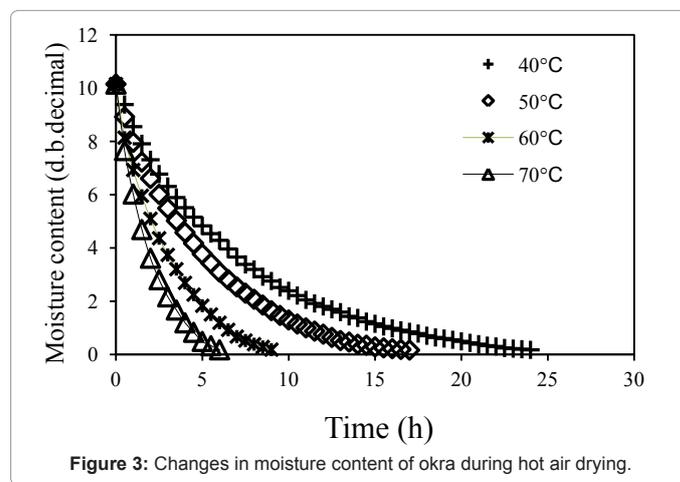


Figure 3: Changes in moisture content of okra during hot air drying.

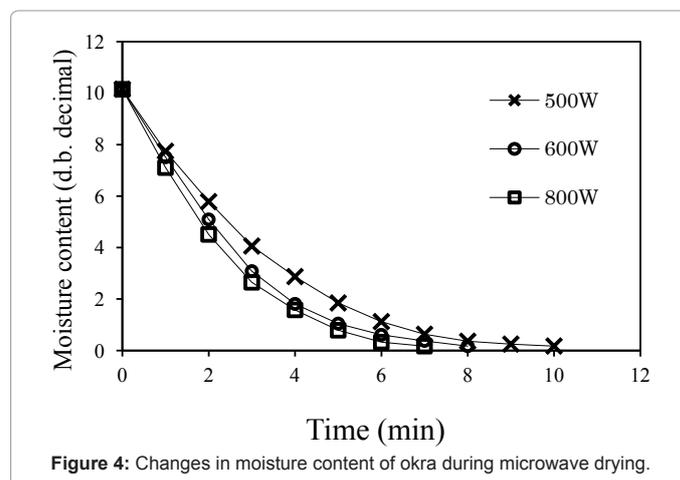


Figure 4: Changes in moisture content of okra during microwave drying.

to 0.17 (d.b. decimal) ranged between 390 and 600 s at three radiation powers with microwave drying, while it required between 6 and 24 h at four temperatures with hot air drying. These data are comparable to those found in previous studies [21,5,22]. Ertekin and Yaldiz [16] determined that the drying time necessary to reach a safe final moisture content of eggplant was 4.4 h at a drying air temperature of 70°C; 38.4 h, at 30°C. Ozkan et al. [23] reported that the time required to reduce the moisture content of spinach from 9.01 to 0.1 d.b. decimal ranged from 290 to 4005s, depending on the power level of the microwave. The drying rates of the microwave and hot air drying method were calculated using the data describing the changes in moisture content. (Figures 4 and 5) present the relationship between the drying rate and the moisture content of the okra. In both microwave drying and hot air drying, the drying rate increased with increases in the microwave energy or hot air temperature. The figures show that the drying process of okra took place only in the falling rate period, not in the constant rate period. These results concur with those previously reported for the drying curves of fruits and vegetables [6,17,4].

Drying model for okra fruit

As previously discussed, in this study, all the values of B_1 were about 1 for microwave drying and approximately 0.95 for hot air drying. Therefore, we attempted to utilize an exponential model to describe the drying characteristics of okra during microwave and hot air drying. A non-linear least squares method was applied to Eq. (2) using the measured changes of the moisture content of okra under seven drying conditions. The determined values of the drying constant k_1 are presented in (Table 1). The drying constant k_1 ranged from 0.27 to 0.36 min^{-1} for microwave drying and from 0.15 to 0.49 h^{-1} for hot air drying (RMSE=0.017-0.097). They increased with increases in the drying temperature or microwave energy. (Figures 3 and 4) present a comparison of the measured results with the results calculated with Eq. (2), using the values of parameters k_1 from (Table 1) and M_e , which is assumed to be zero. As (Figures 3 and 4) demonstrate, the measured results were in accord with the calculated results. These values are comparable to those previously reported for the drying constant of kiwifruit dried at temperatures from 40 to 70°C ranged from 0.478 to 2.56 h^{-1} . Studied the drying kinetics of pumpkin using different methods and found that the drying constants of different cultivars of

Temp. (°C)/ Power (W)	k_1	RMSE (d.b. decimal)	R^2
40°C	0.15 ± 0.001 h^{-1}	0.067	0.98
50°C	0.20 ± 0.002 h^{-1}	0.071	0.97
60°C	0.33 ± 0.006 h^{-1}	0.083	0.97
70°C	0.45 ± 0.008 h^{-1}	0.064	0.98
500 W	0.27 ± 0.001 min^{-1}	0.016	0.99
600 W	0.33 ± 0.002 min^{-1}	0.024	0.98
800 W	0.36 ± 0.005 min^{-1}	0.017	0.99

Values: mean calculation ± SD (Standard Deviation)

Table 1: Drying constant k_1 for hot air and microwave drying.

pumpkin ranged from 0.033 to 0.072 h^{-1} for the convective method and 0.087 to 0.107 min^{-1} for the vacuum-microwave method.

The temperature dependency of the hot air drying was calculated using an Arrhenius type equation [4,15]:

$$k_1 = d \cdot \exp\left(-\frac{E}{RT}\right) \quad (8)$$

where d is a constant (h^{-1}), R is a gas constant (8.314 J/mol/K), E is the activation energy (kJ/mol), and T is the absolute temperature (K). The constant d and the activation energy E in Eq. 8 were determined by the least squares method using the drying constant k_1 and T in (Table 1); these values were $d = 2.5 \text{h}^{-1}$ and $E = 36.7 \text{ kJ/mol}$.

Degradation of ascorbic acid

Figures 7 and 8 describe the relationship between the residual ratios of the ascorbic acid content and moisture content of okra during hot air and microwave drying, respectively. The residual ratio of the ascorbic acid content decreased as the moisture content dropped.

The kinetic of the ascorbic acid decomposition in a first-order reaction was expressed as follows [24]:

$$\frac{dx}{dt} = k'(1-x) \quad (9)$$

where k' is a coefficient of the decomposition rate of the ascorbic acid content (h^{-1}) and x is the residual ratio of ascorbic acid after t h (decimal). The residual ratio of ascorbic acid was defined as the total ascorbic acid content in the dry sample divided by the total ascorbic acid content in the initial sample. Eq. (9) is integrated under the initial condition of $x = 0$ to $t = 0$ and Eq. (10) can be expressed as follows:

$$\ln \frac{1}{1-x} = k't \quad (10)$$

Plotting vs. time (t) and the rate constant k' were determined to be the slopes of the curves. The values of k' under seven drying conditions are provided in (Table 2). The values of k' ranged from 0.40 to 0.46 min^{-1} for microwave drying and from 0.15 to 0.35 h^{-1} for hot air drying. The temperature dependency of the value k' during hot air drying was estimated using the following equation:

$$k'' = d'' \exp\left(-\frac{E'}{RT}\right) \quad (11)$$

where d'' is a constant (h^{-1}). The constant d'' and the activation energy E' in Eq. (11) were determined by a least squares method, using the coefficient of decomposition rate k' shown in (Table 2). The constant d' for hot air drying was 2.2 h^{-1} and the activation energy E' was 28.5 kJ/mol. These data are comparable to those found in previous studies.

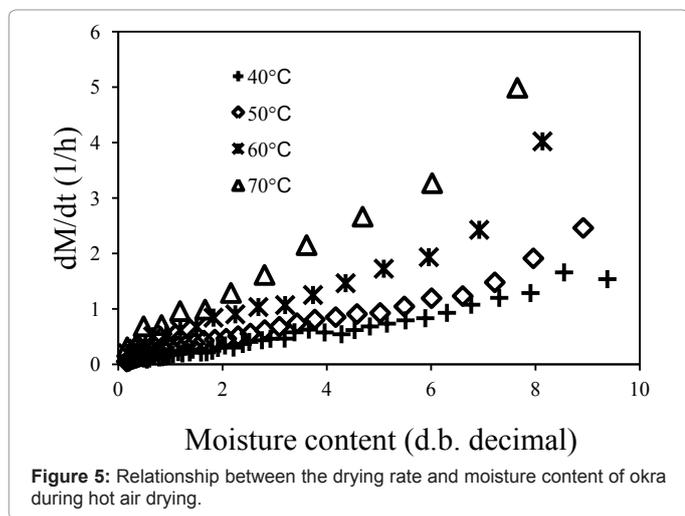


Figure 5: Relationship between the drying rate and moisture content of okra during hot air drying.

Hosaka H [24], reported that the activation of the ascorbic acid decomposition of red pepper dried at temperatures ranging from 50 to 70°C was 26.9 kJ/mol. Orikasa et al. [8], reported that the activation energy of the ascorbic acid decomposition of kiwifruit was 38.6 kJ/mol.

The ascorbic acid content of okra before and after drying is presented in (Table 2). The average ascorbic acid content of fresh okra was 673.4 mg/100 g of dry matter, which corresponds to 60.6 mg/100 g fresh matter. The microwave energy and hot air temperature caused the losses of ascorbic acid. The ascorbic acid content of okra after drying ranged from 248.1 to 381.76 mg/100 g of dry matter. The ascorbic acid content was highest in the sample dried at a power of 800 W. The lowest ascorbic acid content was found in the sample dried at 40°C, possibly because the long drying time caused a higher loss of ascorbic acid. Statistically significant differences were found among these values.

According to Sokhansanj and Jayas [25], the loss of ascorbic acid content during drying was between 10% and 50%. Daood et al. [26] found that 63% of the original ascorbic acid content was lost during the drying process of red peppers at ambient temperatures. Karina and Guillermo [27] reported that the ascorbic acid retention of red peppers after drying ranged from 12 to 18% at temperatures from 50 to 70°C. In this study, the loss of the ascorbic acid content of okra was between

	k'	Ascorbic acid content (mg/100 g dry matter)	Moisture content after rehydration (d.b. decimal)
Fresh sample	-	673.4 ± 7.14	10.14 ± 0.05
40°C	0.145 ± 0.004 h ⁻¹	248.2 ± 5.17	6.18 ± 0.10
50°C	0.227 ± 0.031 h ⁻¹	263.6 ± 6.20	6.61 ± 0.19
60°C	0.40 ± 0.014 h ⁻¹	345.5 ± 8.44	6.92 ± 0.07
70°C	0.345 ± 0.011 h ⁻¹	325.8 ± 7.14	6.36 ± 0.10
500 W	0.40 ± 0.014 min ⁻¹	281.5 ± 8.15	6.62 ± 0.10
600 W	0.40 ± 0.028 min ⁻¹	313.7 ± 9.28	6.90 ± 0.12
800 W	0.46 ± 0.014 min ⁻¹	381.8 ± 8.08	7.75 ± 0.11

Values' mean calculation ± SD

Table 2: Coefficient of the decomposition rate of ascorbic acid (k'), ascorbic acid content before and after drying, and moisture content of okra after rehydration.

43% and 63%, and that of okra dried at a power of 800 W was the lowest, approximately 43%.

Total color difference (TCD- ΔE)

The changes in the surface color of the okra during drying were examined at six drying conditions (three levels of radiation power for microwave drying and three temperatures for hot air drying). The ΔE was calculated according to Eq. (7) using the measured L^* , a^* and b^* values. A larger ΔE value represents a greater change in color. Using the ΔE value, we quantified the color change of the okra's surface with the progress of the drying process. Uno et al. studied the color changes in the juices of several types of apple and suggested the following equation to examine the kinetic of TCD:

$$\Delta E = B (1 - \exp(-k_2 t)) \quad (12)$$

where B is the extent of browning and k_2 is the coefficient of the browning rate (h⁻¹).

In this study, we also evaluated the kinetic of the color change of okra during hot air and microwave drying using the same equation (12). The values of B and k_2 were estimated using a non-linear least squares method, and the determined values are provided in (Table 3). (Table 3) represents the relationship between ΔE , B and k_2 . The higher ΔE caused the higher B and k_2 values. The B values ranged from 12.3 to 18.4 for microwave drying and from 25.3 to 29.1 for hot air.

The color of okra was affected by microwave energy and high temperature. The effects of microwave energy and hot air temperature on TCD during drying are provided in (Figures 9 and 10) and (Table 3). The figures show that both microwave and hot air drying cause increases in the TCD of the dried sample. (Table 3) also presents the TCD of the sample dried at six drying conditions. The TCD ranged from 10.3 to 16.5 for microwave drying and from 21.4 to 26.1 for hot air. The data also indicated that the color of the sample dried by the microwave oven method exhibited less change than the sample subjected to hot air drying. In particular the sample dried at the radiation power of 800 W showed the least color change compared to the fresh sample. According to [28], microwave energy transfers liquid from the interior of the material to its surface, and this liquid is quickly converted into vapor. Therefore, the microwave drying process does not cause the phenomenon of surface overheating, resulting in less change in the surface color. Ozkan et al. [23] reported that spinach

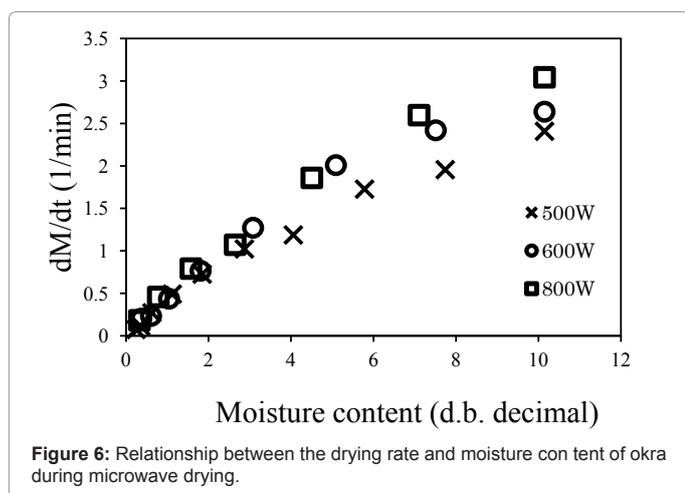


Figure 6: Relationship between the drying rate and moisture content of okra during microwave drying.

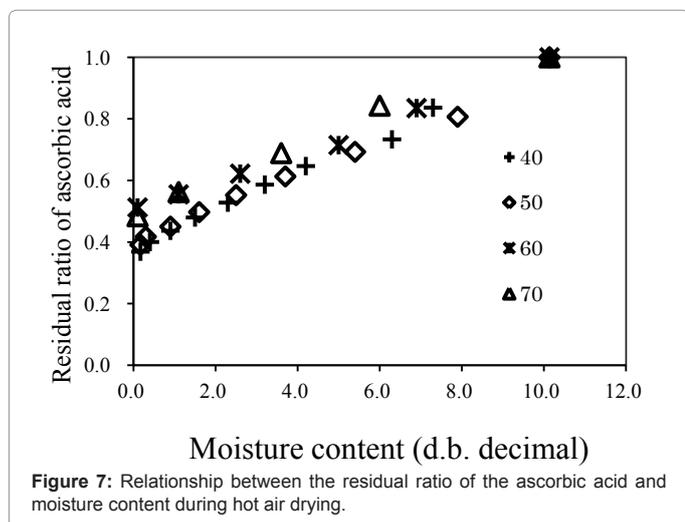


Figure 7: Relationship between the residual ratio of the ascorbic acid and moisture content during hot air drying.

dried at the radiation power of 750 W presented the best TCD when compared with 1000, 850, 650, 500, 350, 160 and 90 W.

Rehydration

Indicated that carrot slices dried by vacuum microwave had higher rehydration ratios and a softer texture than air-dried slices, Moreira et al. [29] found that samples dried over longer periods demonstrated lower rehydration ratios. Krokida et al. [14] reported that the rehydration ratios of apple, potato, carrot, banana, pepper, garlic and mushroom range between 1 and 4, depending on the absorbed water's temperature. In this study, dry okra with an average moisture content of 0.17 (d.b. decimal) was used to determine the rehydration ratio. The moisture content of okra after rehydration is described in (Table 2). The moisture content ranged from 6.18 to 7.75 (d.b. decimal) (moisture content of fresh sample: 10.14 (d.b. decimal)). The data indicated that the samples were not all able to absorb the same amount of water that they lost during the drying process. According to Sumnu et al. [30], the high internal pressure produced by microwave drying can cause the structure of material to expand and puff, resulting in a decrease in the density of the structure. This less dense structure has a higher capacity to absorb water and reconstitute. The effects of microwave energy and hot air temperature on the rehydration ratio of okra are presented in Fig. 11. The rehydration ratios ranged from 5.2 to 6.5. Microwave drying at a radiation power of 800 W resulted in the highest rehydration capacity compared with those dried at 500 W and 600 W or by hot air drying, and the sample dried at 40°C had the lowest rehydration ratio. The statistical analysis demonstrated the significant influence of the microwave energy and hot air temperature on the rehydration of okra (Figure 11).

	<i>B</i>	<i>k</i> ₂	ΔE
50°C	25.3 ± 0.63	0.11 ± 0.005 h ⁻¹	21.4 ± 0.15
60°C	26.7 ± 1.86	0.13 ± 0.009 h ⁻¹	24.5 ± 0.20
70°C	29.1 ± 1.70	0.40 ± 0.076 h ⁻¹	26.1 ± 0.17
500 W	18.4 ± 0.75	0.37 ± 0.026 min ⁻¹	16.5 ± 0.26
600 W	15.1 ± 0.94	0.29 ± 0.018 min ⁻¹	13.0 ± 0.25
800 W	12.3 ± 0.70	0.23 ± 0.025 min ⁻¹	10.3 ± 0.36

Values' mean calculation ± SD

Table 3: Extent of browning *B*, rate of browning *k*₂, and total color difference.

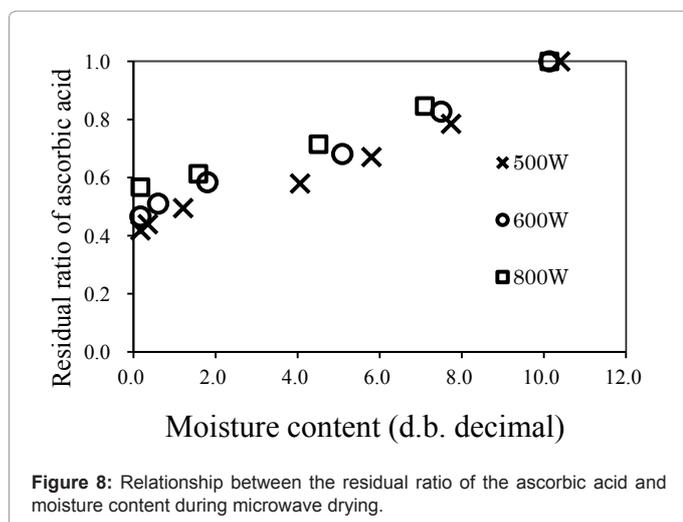


Figure 8: Relationship between the residual ratio of the ascorbic acid and moisture content during microwave drying.

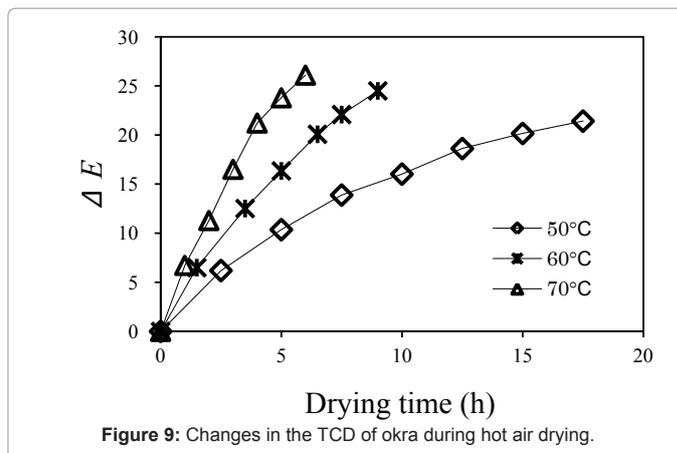


Figure 9: Changes in the TCD of okra during hot air drying.

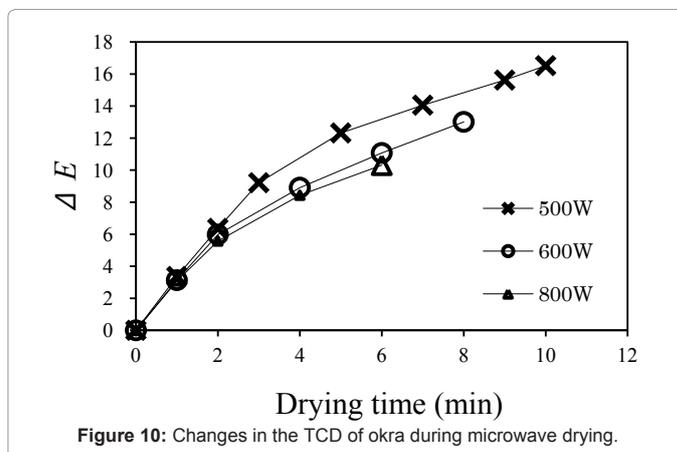


Figure 10: Changes in the TCD of okra during microwave drying.

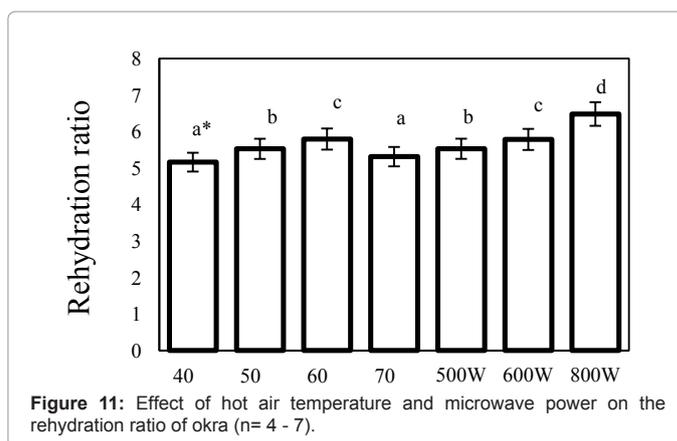


Figure 11: Effect of hot air temperature and microwave power on the rehydration ratio of okra (n= 4 - 7).

Conclusion

The drying characteristics and quality of okra during microwave and hot air drying were recorded at four temperatures between three levels of power from 500 to 800 W for microwave drying and 40 and 70°C for hot air drying. The drying process of okra took place only in the falling rate period. The time required to reduce the moisture content from 10.14 to 0.17 (d.b. decimal) varied between 390 and 600 s for microwave drying and 6 to 24 h for hot air drying. The drying constant *k*₁ increased as microwave power or the drying temperature

rose and ranged from 0.272 to 0.361 min⁻¹ for microwave drying and from 0.147 to 0.489 h⁻¹ for hot air drying. The activation energy of drying and decomposition of ascorbic acid in hot air drying were 36.65 and 28.54 kJ/mol, respectively. In this study, microwave drying at 800 W presented the shortest drying time, the least change in ascorbic acid and the total color change, and the sample dried under this condition exhibited the highest rehydration ratio. Thus, high-power microwave drying is available to minimize the changes in the ascorbic acid content and TCD and increase the rehydration ratios.

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