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Microwave Assisted Hot Air Ventilation Drying of Tomato Slices

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Abstract: Microwave power densities of 1.13, 2.08 and 3.11 W g^{-1} were combined with air ventilation (50°C) and hot air drying at 40°C, 50°C, 70°C and 80°C. The drying characteristic curve was analysed to determine the drying time. The drying curves were fitted to Lewis, Page and Henderson and Pabis equations. The tomato slice dried faster when subjected to microwave heating coupled with hot air ventilation. The coefficients of determination for all the three equations were found to be high. Microwave drying at 1.13 and 2.08 W g^{-1} maintained superior colour quality.

Keywords: microwave, tomato slice, drying equation, colour, drying rate, moisture content.

1. Introduction

There is sufficient market demand for dehydrated fruits and vegetables worldwide.[1] Dehydration removes the majority of water from fruits and vegetables and highly improves the shelf life of the final dried products resulting from reduced water activity. Drying of fruit and vegetables using high temperature and for long drying time by conventional heating results in the damage of quality of the final dried products. [2] This is partly attributed to the fact that fruits and vegetables are subjected to low drying rate during the falling drying rate period in many of the conventional drying methods such as airflow drying, vacuum drying, and freeze-drying. [3,4,5] The most important fruit and vegetables quality known to be affected by high temperature drying for long time includes nutritional value, structural properties and sensory attributes. In conventional hot air ventilation heating or drying, long exposure time is required to reduce food water content down to lower safe moisture content. The acceptability (visual appeal, taste, aroma, flavour and texture), structural property and nutritional value of fruits and vegetables are also highly affected. [3,4,6,7] Zhang et al. [3,4] reported that hot air ventilation drying of produce at high temperature for long time causes a significant damage to nutritional value as well as sensory quality of fruits and vegetables. However, microwave drying of fruits and vegetables results in high temperature efficiency, shorter drying time and result in better product quality compared to conventional hot air ventilation drying. [2,8,9,10]

In recent years, microwave drying has gained popularity as an alternative drying method for a wide variety of food and agricultural products, although microwave drying research so far focused mainly on the fundamental aspects than industrial application. The idea to combine fast heating of microwave and low temperature convective drying has been investigated by a number of researchers. Zhang et al.[4] reported a review on trends in microwave-related drying of fruits and vegetables indicating the advantages of combining conventional drying methods with microwave heating. The review also clearly indicates that combination of drying methods leads to better drying processes than using microwave or conventional drying methods alone. Microwave heating is based on the transformation of alternating electromagnetic field energy into thermal energy by affecting the polar molecules of a material. Heating of bulk foods can easily be achieved by microwave heating than by conventional heating, which is one of the most important characteristics of this drying technology. [1,9] The convective mode of heat transfer is used in conventional

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heating which is followed by conduction where heat must diffuse in from the surface of the material deep into fruits and vegetables. However, microwave leads to a volumetric heating which means that all the materials can be heated to the desired temperature at the same time. In microwave heating microwave energy is directly absorbed and converts it into heat inside fruits and vegetables. This leads to movement of moisture by diffusion from the deep interior section of fruits and vegetables to the surface.

In microwave heating, heat is generated throughout the material, leading to faster heating rates, compared to conventional heating where heat is usually transferred from the surface to the interior. [11] Microwave drying is caused by water vapour pressure differences between interior and surface regions, which provide a driving force for moisture transfer. As a result, microwave treatment can greatly reduce the drying time of the biological products without quality degradation. Based on this analysis the present study was aimed at the microwave assisted hot air ventilation drying of a fixed thickness tomato slices. The objective of this study is, therefore, to look at the drying characteristics and determination to drying time required to reduce the moisture content of fixed thickness (5 mm) tomato slices to low safe moisture content during drying using hot air ventilation and combined microwave with hot air ventilation drying.

NOMENCLATURE

k	drying constant in thin-layer equation	s^{-1}
m	moisture content	$kg.kg^{-1}$ dry tomato slice
m_o	initial moisture content	$kg.kg^{-1}$ dry tomato slice
m_e	equilibrium moisture content	$kg.kg^{-1}$ dry tomato slice
MR	moisture ratio	
n	drying power factor in thin-layer equations	
t	time	s
α, β, γ	drying constants in the thin-layer drying equations	s^{-1}

2. Materials and Methods

2.1. Raw material and drying process

Ripe red and firm tomato (cultivars *Marglobe*) was used for the drying experiment. The drying tests were conducted using 5 mm thickness tomato slices weighing 60 ± 2 g. The 5 mm tomato slices were prepared using kitchen slicer. Firm and ripe red tomatoes were purchased from local farmers market. The fresh ripe tomato samples were stored in a storage room with the inside air temperature of 13°C until drying experiment which was done within 2-3 days period. Before drying trial, the materials were taken out and kept at room temperature for about 12 h over night for thermal equilibrium. The initial moisture content of the tomato samples was determined in an oven at a temperature of 105°C for 24 h. The initial moisture content was 94.01% for tomatoes. A 5 mm thickness tomato slice samples were prepared before each drying runs. All sliced samples were taken from the central region of tomato fruits for uniformity. Each slice of tomato was subjected to drying at a specific temperature (40, 50, 60, 70 and 80°C) and microwave power density (1.13, 2.08 and 3.11 W g^{-1} combined with 50°C). During each run one slice was placed as a single layer on the base of the sample holder. Before starting each run the data acquisition system was switched on and the air temperatures were then set to the experimental desired temperature value. During each run inlet air and modulated air temperature, sample weight and sample temperature were recorded continuously by the data acquisition system. The drying process was finished when the sample reached the moisture content of 10%.

2.2. Tomato slices drying

Series of two different tests under constant drying conditions were performed. All combinations of microwave power density (1.13, 2.08 and 3.11 W g^{-1}) combined with 50°C hot air ventilation and hot air drying without microwave heating at the drying air temperatures of 40, 50, 60, 70 and 80°C with the air velocity of 1.0 m s^{-1}. There were 24 distinct experimental runs with seven duplications. About 60 ± 2 grams of tomato slices were used for each run. From the starting of the drying the change in the sample weight was recorded at the time intervals of 2 minutes. The drying tests were terminated when the moisture content indicated 10%. The final moisture content of each sample was measured in order to calculate the moisture content at each weighing interval. Drying tests were replicated three times at each inlet air temperature and averages are reported.

2.3. Microwave drying system and measurements

The microwave assisted hot air ventilation heating or drying system introduced by Cheng et al [1] was used to dry tomato slices at the power densities of 1.13, 2.08 and 3.11 W g^{-1} and different drying air temperatures. During the drying study, inlet air temperature, modulated air temperature, sample weight, sample temperature, and air velocity resulting from the air ventilation through heating resistance from the bottom of sample holder were monitored through data acquisition systems. Thermocouples were used to record the inlet and modulated air temperatures during the drying period of each runs. To maintain the modulated air temperature at pre-set temperature a proportional, integral and derivative controller was used through controlling the supply power to heating resistance coil. A Strain gauge was used to continuously monitor the sample weight during each run.

2.4. Colour analysis

The tomato slices colour measurement was performed using a chromameter (CR-300X, Minolta Camera Co. Ltd., Japan) and using the procedure as described by Cheng et al. [1]. The calibration of the chromameter was done using a standard white plate. The L* coordinate ranged from 0 (black) to 100 (white), the a* coordinate indicated red-purple colour or bluish green colour and the b* coordinate indicated yellow colour or blue colour.[12,13] The reading was performed on the sliced surface of the pericarp tissue of tomato slices. For statistical purpose the colour reading was done at three randomly selected different locations and the mean of those three readings from the same sample was reported.

2.5. Theory of modelling drying curves

There are two types of thin-layer models in use: diffusion models and empirical models. The accuracy of diffusion models to predict moisture content depends on having good assumptions concerning the geometry, moisture diffusivity and temperature profile of a piece of food. The diffusion models need more computation time and computer memory than the simpler empirical models. According to Bruce [14] the diffusion models are more accurate and allow internal moisture movement to be modelled. However, he noted that in simulations of deep-bed drying the simpler models are expected to be useful where economy of computation is concerned. Parry [15] concluded that empirical models are more applicable for control technology to drying, because less time is required for computation. Therefore, it was decided to look at widely used simpler models.

2.6. Diffusion drying models

Marchant [16] assumed the moisture diffusivity D to be a function of concentration of moisture at any point in the individual grain kernel. As a result he proposed the following diffusion equation:

$$\frac{\partial m}{\partial t} = D\left[\frac{\partial^2 m}{\partial r^2} + \frac{2}{r}\frac{\partial m}{\partial r}\right] + \left[\frac{\partial m}{\partial r}\right]^2 \frac{\partial D}{\partial m} \tag{1}$$

He also developed a finite difference solution to this equation (1) with 10 concentric shells. Bruce [14] applied this model to drying of barley in a temperature range of 50°C to 100°C with boundary conditions:

$$m(r,0) = m_o \text{ and } m(r_o,t) = m_e + (m_o - m_e)\exp(-\gamma\, t) \tag{2}$$

The second boundary condition assumes that the surface moisture content approaches the equilibrium moisture content exponentially as the drying time advances. Bruce used equation (1) at constant temperature, with moisture- dependant diffusivity, which was proposed by Chu and Hustrulid [17], of the form:

$$D = \alpha \exp(\beta m) \tag{3}$$

where α and β are dependent on the drying air temperature.

By assuming that diffusion only takes place at the surface Lewis [18] developed an equation, analogous to Newton`s law of cooling, of the form:

$$\frac{dm}{dt} = -k(m - m_e) \tag{4}$$

Integrating equation (3) gives the following equation:

$$MR = \frac{m - m_e}{m_o - m_e} = \exp(-kt) \tag{5}$$

Several research report that the values of the equilibrium moisture content (m_e) are relatively small when compared to the instantaneous moisture content (m) and initial moisture content (m_o) [19]. Thus, the Lewis model can be written as follows:

$$MR = \frac{m}{m_o} = \exp(-kt) \tag{6}$$

In both equations (5) and (6) k is a temperature dependent drying constant.

3.2. Empirical drying Models

For foods several empirical drying equations have been developed by adding some factors to the Lewis model. Page [20] proposed an equation similar to the Lewis model with the addition of the power factor *n* to the time variable to improve prediction of the drying characteristics:

$$MR = \exp\left(-kt^n\right) \tag{7}$$

Page's model has been widely used to describe drying behaviour of a variety of biological materials. [19,21,22] Similarly, the values of the equilibrium moisture content are relatively small compared to instantaneous moisture content and initial moisture content and the moisture ratio can be simplified to m/m_o:

$$MR = \frac{m}{m_o} = \exp\left(-kt^n\right) \tag{8}$$

Henderson and Pabis [23](1961), as presented in Akpinar et al. [24], proposed a two term equation:

$$MR = a\exp\left(-kt\right) \tag{9}$$

This equation was used to predict sun drying moisture loss kinetic of figs and found to be one of the best models which predict the moisture loss with small standard error and high correlation coefficient. [25]

3. Results and Discussion

3.1. Drying curves

The relationship between dimensionless moisture content and drying time of tomato slices subjected to microwave assisted hot air drying and hot air ventilation drying alone is given in Fig. 1 and 2. In this case microwave assisted hot air ventilation drying during the whole drying period was applied. It is apparent that dimensionless moisture content decreases continuously with drying time. As can be seen from the data presented, the time required to dry tomato slice to 10% moisture content decreased with an increasing in microwave power density from 1.13 to 3.12 W g^{-1} combined with hot air at 50°C air ventilation. The drying time varied between 1.1 and 3.3 h as the microwave power density increased from 1.13 to 3.12 W g^{-1}. A rapid drying was observed in dimensionless moisture content in this study which is in agreement with the previous findings. [8,26,27,22] The instantaneous moisture content rapidly decreases as the microwave power density increases which is due to faster of moisture diffusion from the centre of tomato slices to the surface.

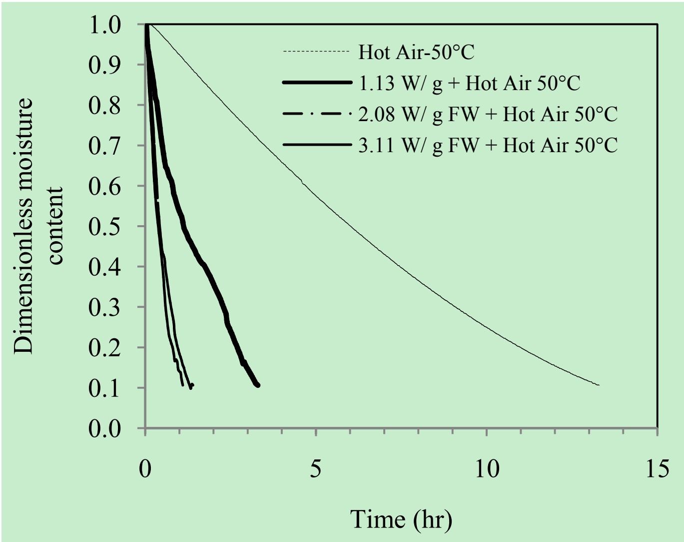


Fig. 1. Moisture content of tomato slices changes with microwave power density and time

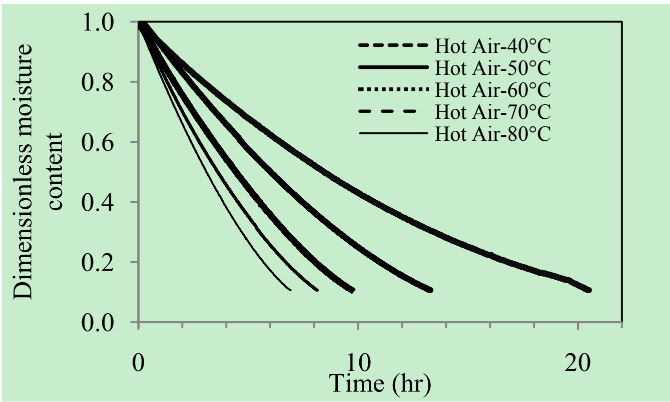


Fig. 2. Moisture content of tomato slices changes with drying air temperature and time

The tomato slices experienced both constant and falling drying rate period (Fig. 3 and 4). The constant rate drying period was found to be for very short period of about 2.5 minutes when microwave power density of 1.13 W g^{-1} is used to assist heating tomato slices with air at 50°C temperature which significantly increased the drying rate. Internal heating using microwave was found to be an effective method for drying enhancement which is in agreement with the previous report. [28] Heat is generated when microwave interacts with the polar water molecules in fruits and vegetables and significantly high drying rate was achieved when compared to air drying alone. [29] Heating is immediate due to radiative energy transfer; hence the surface-to-centre conduction stage is largely eliminated due to gradual vapour pressure differences. During conventional drying, moisture is initially evaporated from the surface while the internal tomato slices water diffuses to the surface slowly. Under microwave drying, internal heat generation leads to an increase in internal temperature and vapour pressure, both of which help liquid flow towards the surface, thus increasing the drying rate. More of the applied energy is converted to heat within the tomato slice.

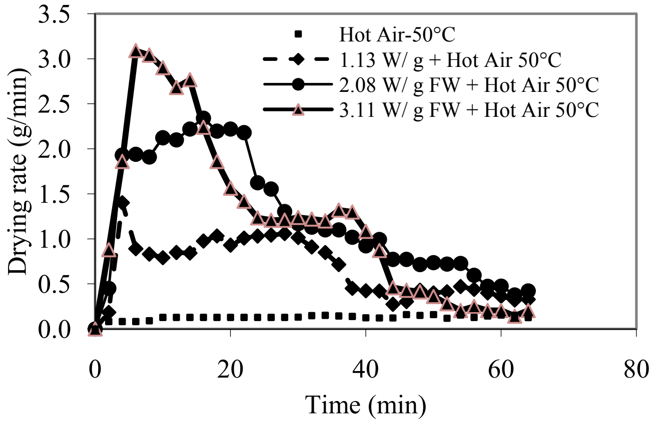


Fig. 3. Drying rate of tomato slices changes with drying time (similar trends).

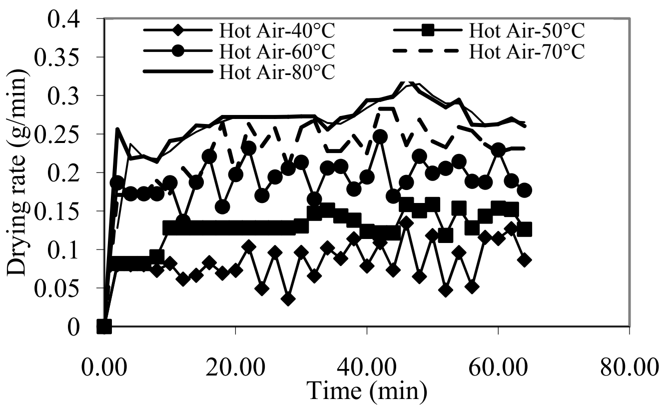


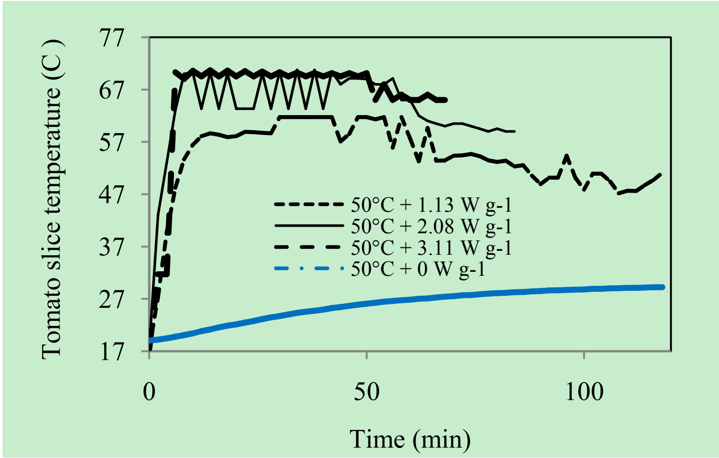
Fig. 4. Drying rate of tomato slices changes with drying time

The time was reduced from 13.3 to 3.3 h during drying of tomato slices using 50°C hot air ventilation coupled with 1.13 W g^{-1} microwave power densities (Table 1). Increasing the microwave density to 2.08 and 3.11 W g^{-1} further decreased the required drying time to 1.4 and 1.1 h, respectively. In general, the time required to reduce the dimensionless moisture content to any given level was highly dependent on the drying conditions being the highest at 50°C and the lowest at microwave power density of 3.11 W g^{-1} coupled with hot air ventilation drying at 50°C drying air temperature.

The drying time for tomato slices at 40, 60, 70, 80°C were 20.5, 9.70, 8.13 and 6.93 h, respectively. Consequently, the effect of hot air temperature in forced air ventilation drying has been reflected in drying rate. However, the drying air temperature increased the dried product freshness quality characteristics losses. [19,30,31,32] Several research reports also showed that quality deterioration as the drying air temperature increases during drying of tomato slices or pulp. [31]

As the drying temperature increases the quality attributed of dried products deteriorates which is one of the most important disadvantages of hot air ventilation drying system. [8,33] In general, increasing air temperature by 10°C starting from 40 to 50, 60, 70 or 80°C reduced the drying time by 35, 53, 60 and 66%, respectively, compared to the drying time required to reduce moisture content to 10% at 40°C drying air temperature (Table 1).

Microwave assisted hot air (50°C) ventilation drying of tomato slices reduced drying times by 84, 93 and 95 % at the microwave power density of 1.13, 2.08 and 3.11 W g^{-1}, respectively. However, the changes in the overall appearance quality of drying tomato slices remain smaller for all the power density used in this study.



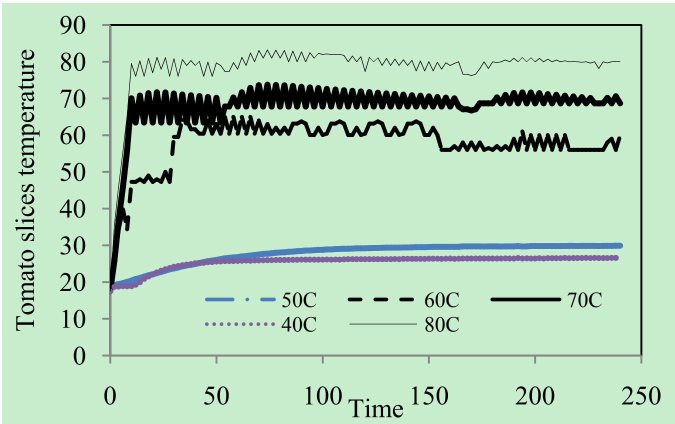


Fig. 5a,b. Tomato slice temperature during drying with air velocity at 1.0 m/s, air temperature at 40, 50, 60, 70 and 80°C, and power density at 1.13, 2.08 and 3.11 W g^{-1}.

Table 1. Effects of different drying air temperature and power densities on drying time of tomato slices.

Hot Air Ventilation Drying		
Temperature	Time (hrs)	Percent reduction in drying time
40°C	20.5	0
50°C	13.3	35
60°C	9.70	53
70°C	8.13	60
80°C	6.93	66
Microwave assisted hot air ventilation drying		
Drying treatment	Time (hrs)	Percent reduction in drying time
50°C + 0 W g^{-1}	13.3	35
50°C + 1.13 W g^{-1}	3.3	84
50°C + 2.08 W g^{-1}	1.4	93
50°C + 3.11 W g^{-1}	1.1	95

3.2. Material temperature

Fig. 5a and b shows the internal tomato slices temperature for drying at microwave power densities of 1.13, 2.08 and 3.11 Wg-1 combined with 50°C drying air temperature during ventilation as well as hot air temperature of 40, 60, 70, 80°C. The internal tomato slice temperature changes with levels of power density and drying air temperature. The internal material air temperature rapidly increased during the first few minutes and seemed to remain almost constant. The temperature curve during microwave assisted hot air ventilation drying categorized into three different zones. The material temperature dropped slowly after reaching the maximum value followed by a steady temperature period. As shown in drying rate curves (Fig. 5a), the first and second temperature zones approximately corresponded to the constant drying rate region where most moisture loss occurred. On the other hand, two distinct zones were observed in temperature curve during phase-controlled MW drying, a gradual temperature rising zone followed by a stable temperature zone, the first zone nearly matches the constant drying rate region.

However, in the case of hot air ventilation drying the temperature sharply increased to the peak value depending on the set temperature and remained almost constant with small variations thereafter during the first 4 to 5 hours (Fig. 5b). In this case, where the drying air temperature was set to 40 and 50°C, the material internal temperature showed a slight increase and remained to be below 30°C. Whereas for 60, 70 and 80°C drying air temperature for hot air ventilation heating alone the internal tomato slice temperature sharply increased to a maximum temperatures of about 60, 69 and 79°C and remained constant thereafter.

3.3. Modelling of the drying curves

Evaluation of the models in order to determines moisture content as the function of drying time, the simple diffusion Lewis (Eg. 6), empirical Page (Eg 8) and Henderson and Pabis (Eg. 9) equations were fitted and correlation coefficients (R^2) were calculated. The estimated model parameters and correlation coefficients for the three models are presented in Table 2. Overall the value of R^2 (0.996) obtained from empirical Page equation are higher than those overall correlation coefficient that was found for Lewis (0.987) and Henderson and Pabis equations (0.989). The R^2 for Lewis equation varied between 0.976 and 0.994 while for Page equation R^2 values vary between 0.986 and 0.999. Similarly, the R^2 values for Henderson and Pabis equation vary between 0.983 and 0.997 (Table 2). In general, the Page equation best fitted to the experimental dimensionless moisture content data followed by the Henderson and Pabis equation. Queiroz *et al.* [27] reported that drying curves could be well adjusted by the Page model and the model parameters were correlated as functions of drying conditions. Statistical analysis of experimental data showed that temperature was the main factor affecting drying rate. However, Henderson and Pabis equation seems to over predict the initial dimensions less moisture content while the Lewis equation over predicts the dimensions less moistures content towards the end of drying period although the other two also seemed to slightly over predict the dimensionless moisture content in this study. According to R^2 values, all the three drying models were the best in predicting the dimensionless moisture content of tomato slices during drying under different conditions and drying systems which is in agreement with several findings. [6,34,35]

Figures 6 to 9 display the calculated versus the experimental dimensions on less moisture content data. As can be observed good agreement between the variables was found which is in agreement with previous findings by Madamba et al. [32] for drying garlic slices, by Doymaz and Pala [36] for grape drying and by Doymaz [19] for carrots drying.

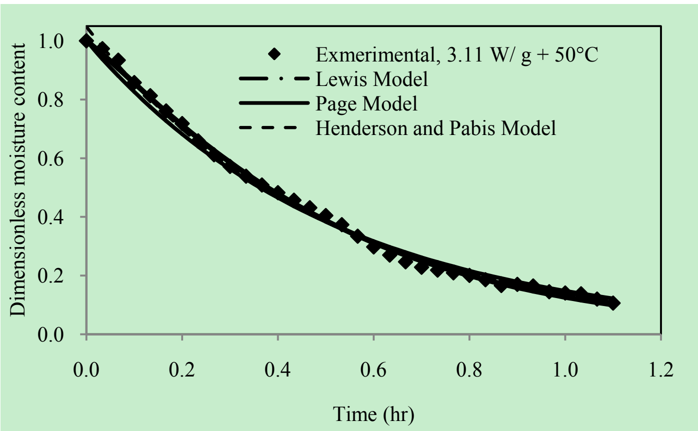


Fig. 6. Comparison of experimental and calculated dimensionless moisture content of tomato slices as a function of drying time (T = 50°C and microwave power density of 3.11 W g-1)

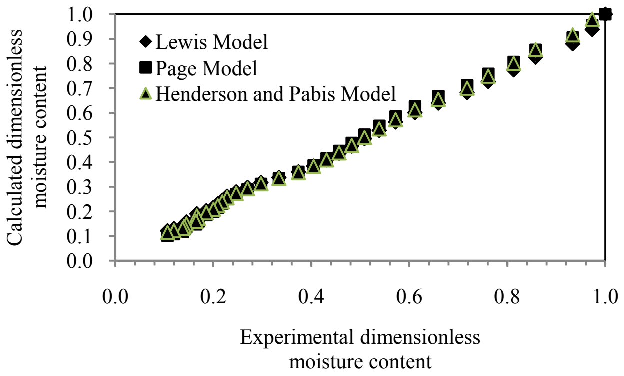


Fig. 7. Comparison of experimental and calculated dimensionless moisture content of tomato slices (T = 50°C and microwave power density of 3.11 W g^{-1}).

Table 2**.** Non-linear regression analysis results of semi-empirical Page's, Henderson and Pabis's, and Lewis's equations for microwave assisted hot air ventilation drying and hot air ventilation drying of tomato slices; k, drying rate constant, min^{-1}; n, exponent; R^2, coefficient of determination.

Model	Drying treatment	Coefficient ***(a)***	Drying coefficient ***(k)***, min^{-1}	Exponent ***(n)***	Modelling efficiency ***(R^2)***
Lewis	1.13 W g^{-1} + 50°C	-	1.592	-	0.991
	2.08 W g^{-1} + 50°C	-	1.914	-	0.993
	3.11 W g^{-1} + 50°C	-	0.584	-	0.984
	0 W g^{-1} + 50°C	-	0.124	-	0.991
	60°C	-	0.172	-	0.994
	70°C	-	0.210	-	0.978
	80°C	-	0.246	-	0.976
	40°C	-	0.086	-	0.989
Page	1.13 W g^{-1} + 50°C	-	0.606	0.930	0.986
	2.08 W g^{-1} + 50°C	-	1.668	1.140	0.997
	3.11 W g^{-1} + 50°C	-	2.066	1.122	0.998
	50°C	-	0.067	1.321	0.998
	60°C	-	0.106	1.289	0.997
	70°C	-	0.144	1.256	0.997
	80°C	-	0.171	1.275	0.997
	40°C	-	0.059	1.167	0.999
Henderson & Pabis	1.13 W g^{-1} + 50°C	0.967	0.560	-	0.986
	2.08 W g^{-1} + 50°C	1.057	1.692	-	0.996
	3.11 W g^{-1} + 50°C	1.048	2.019	-	0.997
	40°C	1.092	2.092	-	0.993
	50°C	1.089	0.140	-	0.985
	60°C	0.072	0.187	-	0.983
	70°C	1.066	0.227	-	0.986
	80°C	1.066	0.266	-	0.984

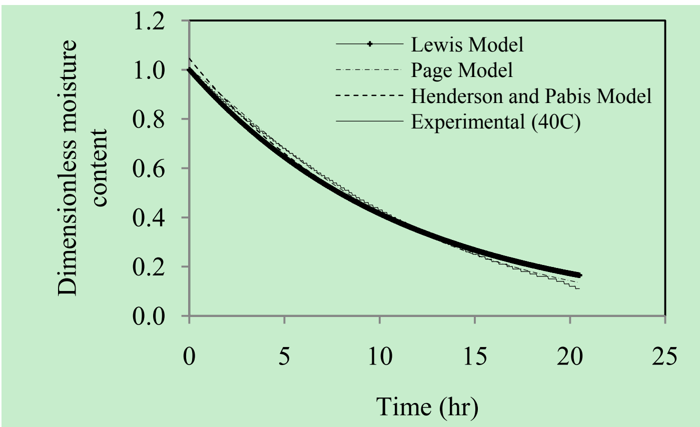


Fig. 8. Comparison of experimental and calculated dimensionless moisture content of tomato slices (T = 40°C)

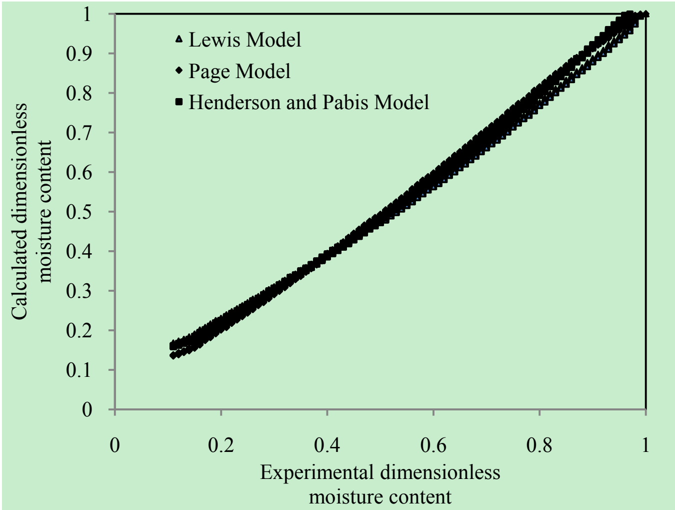


Fig. 9. Comparison of experimental and calculated dimensionless moisture content of tomato slices (T = 40°C)

3.4. Colour of fresh and dries tomato slices

Among several subjective quality attributes of dried tomato slices the colour is an important one which indicates the level of effects of different drying methods or conditions. The colour plays a crucial role especially when it comes to consumer's preference. Table 3 displays the change in colour of fresh and dried tomato slices that were subjected to different levels of microwave power density and drying air temperature during hot air ventilation drying. The data clearly showed that the dried tomato slices were found to be relatively darker than fresh ones as the result 'L*' value decreased for all dried samples when compared to 'L*' values for fresh tomato slices. The drying conditions had highly significant ($P \leq 0.0001$) effects on the changes in colour of tomato slices. However, the colour of tomato slices subjected to 60, 70, 80 and 3.11 W g^{-1} microwave power density coupled with 50°C air temperature drying were found to be significantly ($P \leq 0.0001$) darker than the others. Drying using 1.13 and 2.08 W g^{-1} microwave power densities coupled with 50°C hot air ventilation produced brighter and less dark tomato products. Similarly, drying using hot air at 40°C and 50°C produced same standard quality in terms of colour after drying which was found to be brighter and less dark when compared to dried tomato slices subjected to 60, 70 and 80°C temperatures.

Drying using 1.13 W g^{-1} coupled with 50°C hot air ventilation and by hot air ventilation at the temperatures of 40 and 50°C without microwave heating was found to be the best in terms of maintaining the colour quality of the tomato slices. Drying treatments had significant ($P \leq 0.0001$) effect on the 'a*' values of the slices. In this case also the higher 'a*' values of slices were maintained in tomato samples subjected to 1.13 and 2.08 W g^{-1} coupled with 50°C hot air ventilation as well as very low temperature drying at 40°C and 50°C. But the 'b*' value increased after drying compared to the 'b*' values for fresh slices. The reduction in 'b*' values were saviour in tomato slices subjected to high temperature and high microwave power density treatments which is in agreement with the findings of Sacilik et al. [37]

Table 3. Colour changes during drying of tomato slices using different microwave power density and drying air temperature.

Drying Treatment	L*	±SD	a*	±SD	b*	±SD
Fresh	52.78^{a}	1.27	14.15^{a}	0.28	12.68^{f}	0.52
3.11 W g^{-1} + 50°C	43.11^{e}	1.05	10.96^{d}	0.93	17.80^{c}	0.37
2.08 W g^{-1} + 50°C	45.00^{d}	0.13	13.01^{b}	0.12	13.45^{edf}	0.03
1.13 W g^{-1} + 50°C	47.89^{b}	0.63	12.76^{cb}	0.60	13.04^{ef}	0.06
0 W g^{-1} + 50°C	48.07^{b}	1.10	12.85^{b}	0.16	13.96^{ed}	0.07
60°C	46.02^{cd}	0.94	12.06^{c}	0.02	14.18^{d}	0.17
70°C	45.06^{d}	0.95	10.29^{ed}	0.52	20.21^{b}	1.12
80°C	39.09^{f}	1.01	9.70^{e}	0.17	21.71^{a}	1.35

40°C	47.57[cb]	1.74	12.79[b]	0.10	13.95[ed]	0.08
Significance						
P		< 0.0001		< 0.0001		< 0.0001
R^2		0.944		0.938		0.975
CV		2.308		3.559		3.985
RMSE		1.063		0.429		0.624
$LSD_{0.05}$		1.824		0.737		1.070
EMS		1.130		0.184		0.389

4. Conclusions

Drying kinetic of tomato slices was investigated at various microwave output powers and air temperature. Drying time decreased considerably with increase in microwave power density and with increase in hot air temperature. Drying took place in a constant rate period followed by the falling rate period after a short heating period. Hot air ventilation drying relatively involved exposure of the tomato slices to long drying times. In this drying study, microwave assisted hot air drying treatment greatly reduce the drying time of the tomato slices by greater than 84% when compared to drying at 50C drying air temperature. Microwave assisted low temperature air ventilation drying could be considered as an alternative drying method for tomato slices as it also maintains the superior quality in terms of colour.

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