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Dielectric Properties and Microwave Drying of Tomato Slice

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Abstract

Dielectric properties of tomato slices are highly useful for predicting the heating rates and behaviour of the materials when subjected to high frequency electromagnetic waves. Dielectric properties of tomato slice (6 mm) at different moisture contents such 10, 30, 50 and 70% (w.b) were determined by using microwave spectroscopy. The corresponding dielectric properties like dielectric constant (ε′) and dielectric loss (ε″) were observed. The result showed that both dielectric constant (77 to 7.2) and dielectric loss (48 to 3.4) decreased with increase in frequency from 200 MHz to 200 GHz. Drying of tomato slices were carried out at 50, 60, 70°C by using two methods namely microwave assisted vacuum dryer and microwave assisted hot air dryer at the selected temperatures. From the study, it was found that the time taken for drying of tomato slice in microwave assisted vacuum was lower (150, 100 and 70 min) when compared to microwave assisted hot air drying at 50, 60 and 70°C, respectively.

Dielectric properties and microwave drying of tomato slice

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Introduction

Tomato (*Lycopersicon esculentum*) is an important vegetable used in daily dietary. It is rich in health valued food components such as carotenoids (lycopene), ascorbic acid (vitamin C), vitamin E, folate and dietary fiber (Davies and Hobson, 1981). Drying has been performed in food processing industries in long term preservation of the final products. The basic objective in drying food products is the removal of moisture from the produce to a level at which microbial spoilage can be avoided. Generally, processed food products have been considered to have lower nutritional value than the fresh commodity mainly due to heat treatment during processing. (Drouzas and Schubert, 1996; Lathrop & Leung, 1980).

Dielectric properties can influence the level of interaction between the food material and high frequency electromagnetic energy. Therefore it is becoming popular in the application of microwave energy in food processing industry due to volumetric heating (Mudgett, 1995). Generally the dielectric property of food material varies with composition, moisture, temperature and frequency (Ryynanen, 1995). In drying of food materials, various research works have been carried out to optimize the power requirement to reduce the quality degradation during drying because microwave power level governs the quality of dried product. Shivahare et al. (1992a) reported the good seed quality of corn could be obtained by drying using microwave with 5 min on and 15 min off pulse at 0.5 W/g absorbed power. Burning of carrots was observed at higher microwave power level with a rated power of 600 W (Prabhanjan et al., 1995). The energy consumption may be decreased due to high thermal efficiency of microwaves at low moisture contents in comparison with conventional hot air drying. Though hot air drying has been used for drying of various food materials, due to longer drying time, thermal degradation of food materials can not be avoided. Therefore to reduce the drying time, and to reduce the thermal degradation, microwave assisted hot drying may be used to improve the final product quality (Torringa et al., 1996).

Vacuum drying makes it suitable for materials having anti oxidative and heat sensitivity properties due to the absence of oxygen and produces quality products as compared to other drying methods. Also microwave assisted vacuum drying increases the drying rate, thereby color, texture and flavor of the dried products can be maintained (Gunasekaran, 1999). Microwave assisted vacuum drying was used to dry yoghurt (Kim and Bhowmik, 1995), fruits (Pappas, et al, 1999) and food materials (Gunasekaran, 1999). Based on these observations, a study was undertaken to observe the dielectric properties of tomato slices using microwave spectroscopy and to dry the tomato slice using microwave assisted vacuum drying and hot air drying methods at the selected temperatures of 50, 60 and 70^{o}C.

Materials and Methods

Fresh Olympian gold (#4799) tomatoes were procured from local market. The tomatoes were washed and sliced to 6 mm thickness using a hand operated mechanical slicer. The sliced tomatoes were dried at different moisture levels at 70^{o}C to determine the dielectric properties using microwave spectroscopy. The slices were dehydrated at the selected temperatures of 50, 60 and 70^{o}C using two drying methods namely microwave assisted vacuum Drying (MVD) and microwave assisted hot air drying (MHD).

Measurement of dielectric properties

Dielectric property of tomato slice was performed with an open ended coaxial probe connected with a net work analyzer (Agilent 200 MHz – 20 GHz). The net work analyzer gives a microwave signal through the high temperature probe. The signal is reflected from the interface between probe end and sample as a function of microwave dielectric constant (ε′) and loss factor (ε″). The network analyzer detects the dielectric property as a function of frequency. The instrument was calibrated using air and distilled water at 23^{o}C. Tomato slices were dried at 70^{o}C to the moisture content level of 70, 50, 30 and 10% (w.b.) and correspondingly at each moisture level, the dielectric measurements were carried out.

Microwave drying set up

A laboratory scale microwave oven was modified and used to perform the drying study. The microwave dryer is equipped with hot air and vacuum set up. The microwave dryer consists of a magnetron, a wave guide, a drying unit, an air inlet, an air out let, a vacuum pump, an automatic weighing platform and a panel board for controlling the temperature, microwave power input (Fig.1). Microwaves were generated by a 750 W, 2450 MHz microwave power generator. The power can be modulated and passed through the rectangular wave guide to the microwave cavity. A circulator was used to absorb the reflected microwaves within the cavity and the tuning screws were used to adjust the reflecting power during the process. The same microwave drying set up was used for both microwave assisted vacuum and hot air drying methods of tomato slices.

Microwave assisted vacuum drying

The microwave assisted vacuum drying unit consists of a drying chamber made of a flat acrylic plate and a thick wall glass jar. The jar could be fitted tightly with the plate without any air leakage. The entire unit was attached to the weighing platform to measure the mass reduction during drying. The drying chamber was connected to a vacuum pump (John Scientific Inc., Canada) through a flexible pipe passing from the flat plate, and the vacuum pressure inside the chamber was maintained at 25 mm of Hg by adjusting the vacuum valve. The real time - temperature was measured using optical fibre. Microwave input power level was kept as 1W/g. Tomato samples (sliced 6 mm) of 100 g were kept in the drying chamber, attached to a digital electronic weighing platform (5 kg capacity) with an accuracy of ± 0.01g. The slices were dried at three different temperatures namely, 50, 60 and 70^{o}C with three replications.

Microwave assisted hot air drying

The microwave assisted hot drying unit consists of a drying chamber with a hot air inlet and exhaust. A circular perforated disc of size (25 cm diameter) was used to dry the tomato slices. The disc was attached to the weighing platform to measure the reduction in mass during drying. Microwave power level was kept as 1W/g. Tomato samples (sliced 6 mm) of 100 g were kept in the drying chamber, attached to a digital electronic weighing platform. The slices were dried at three different temperatures namely, 50, 60 and 70^{o}C with three replications.

Moisture diffusivity

Fick's second law was used to describe the diffusion of moisture during drying of tomato slices spread in the form of a thin slab (Crank, 1975). The equation is:

$$\frac{M_t}{M_\infty} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2 \pi^2} e^{\left(-\frac{D(2n+1)^2 \pi^2 \theta}{4L^2}\right)} \qquad (1)$$

Equilibrium at the interphase as a boundary condition is a key factor for using equation (1). For long drying periods (t > 5 min), Eq. (1) can be simplified ($M_t = M_I - M_\theta$ and $M_\infty = M_I - M_e$) to the following form by taking n = 0:

$$\text{Moisture ratio (MR)} = \frac{M_\theta - M_e}{M_I - M_e} = \frac{8}{\pi^2} e^{\left(-\frac{D\pi^2\theta}{4L^2}\right)} = A \; e^{\left(-\frac{D_{eff}\theta}{4L^2}\right)} \qquad (2)$$

Where A = $(8/\pi^2)$. Equation (2) can be linearized:

$$ln \text{ (MR)} = ln \left(\frac{M_\theta - M_e}{M_I - M_e}\right) = \ln A - \left(\frac{D_{eff}\theta}{4L^2}\right) \qquad (3)$$

From Eq. (3), a plot of *ln* (MR) versus drying time should give a straight line with a slope *S*:

$$S = \frac{D_{eff}}{4L^2} \qquad (4)$$

The moisture diffusivity (D_{eff}) can therefore be determined from the value of the slope.

Also the drying rate constant '*k*' was determined by using the single exponential relationship:

$$\text{Moisture ratio (MR)} = \frac{M_\theta - M_e}{M_I - M_e} = ae^{-k\theta} \qquad (5)$$

By linearising the equation (5)

$$ln\text{(MR)} = ln\left(\frac{M_\theta - M_e}{M_I - M_e}\right) = Ina - k\theta \qquad (6)$$

Where M_I, M_e and M_θ are the initial, equilibrium and moisture content at any time θ, % (d.b.), respectively. The drying rate constant '*k*' (min^{-1}) value was determined from the slope values obtained by plotting *ln* (MR) vs drying time (θ) of tomato slice.

Moisture content

The moisture content of the tomato samples was determined by using vacuum oven at 70°C for 24 h (AOAC, 1980). Triplicate samples were used for the determination of moisture content and the average values were reported.

Colour

The colour parameter for fresh and dried tomato slices was determined using a tritimulus colorimeter (Minolta CR-300 series chromameter). The equipment was calibrated against a white Minolta calibration plate with 2° observer values in terms of L, a & b. Where, luminance (L) forms the vertical axis, which indicates whiteness to darkness. Chromatic portion of the solids is defined by: a (+) redness, a (-) greenness, b (+) yellowness, and b (-) blueness.

Results and Discussions

Effect of frequency and moisture

The dielectric constant ε′ and loss factor ε″ decreased with increase in frequency from 200 MHz to 20 GHz as shown in Figure 2. The dielectric constant decreased linearly with increase in frequency, but the loss factor ε″ decreased inversely proportional to the frequency. The study showed that the penetration depth was lower at higher frequencies. Wang et al., (2003) reported that the penetration depth was increased about four times at lower frequencies (27 – 40 MHz) than at higher frequencies (915 – 1800 MHz). As the moisture content decreased from 94 to 10%, the dielectric constant (ε′) changed from linear reduction to non-linear reduction (77 to 7.2). The variation in the loss factor (ε″) was decreased (48 to 3.4) towards 10% moisture content of the slice (Fig. 3). The dielectric constant (ε′) at 2450 MHz was determined to be 73.91, 64.17, 46.59, 37.06, 12.38 and loss factor (ε″) at 2450 MHz was determined to be 16.24, 16.11, 17.47, 16.84, and 6.11, respectively for fresh, 70, 50, 30 and 10% moisture content (w.b.) of tomato slices. The result showed that there was a reduction in both the ε′ and ε″ factors at 2450 MHz when the moisture content of the tomato slices were reduced from 94.0 to 10% (w.b.).

Microwave assisted vacuum drying

The effect of temperature on the moisture reduction of tomato slice is shown in Fig. 4. From the figure, it was observed that the time taken for drying a 6 mm thick slice from 94.1 to 10 ± 0.3% (w.b.) moisture content at 50^oC was 150 min. The time taken for the same level of moisture reduction at 60^oC, it was 110 min and at 70^oC, it was 70 min. In the case of micro wave assisted hot air drying, (Fig.6), the time taken for drying from 94.1 to 10 ± 0.5% (w.b) moisture content at 50^oC was 200 minute, at 60^oC, it was 150 min and at 70^oC, it was 130 min. Thus, the reduction in the moisture content of microwave assisted vacuum dried tomato slice at any point of time during drying was lower when compared to the microwave assisted hot air dried tomato slice at the selected temperatures of 50, 60 and 70^oC.

The decrease in drying time was mainly due to the higher vapour pressure gradient created in the vacuum due to higher temperature, lower relative humidity with microwave energy, which helped in faster removal of moisture from the tomato slices. From the drying curves, it is also observed that the difference in the temperature greatly affects the drying time in both the drying methods. A constant rate drying period was not observed in both the drying methods but only a long falling rate drying period was observed. The results are similar to the previous works on onion slices by Praveen kumar et al. (2006); Torringa et al., (2001) and Prabhanjan, et al., (1995).

The calculated drying rates for the microwave assisted vacuum dried tomato slices were 1.38, 1.87 and 2.51g/min during the first 10 minutes and 0.01, 0.02 and 0.03 g/min during the final stage of drying for 50, 60 and 70^oC, respectively (Fig.5). For the microwave assisted hot air dried tomato slice, the drying rates were 1.88, 1.52 and 1.09, g/min during the first 10 minutes and 0.01, 0.02 and 0.02 g/min in the final stage of drying at 50, 60 and 70^oC, respectively(Fig.7). This clearly indicates that, the microwave assisted vacuum drying was faster than microwave assisted hot air drying as the drying rate of tomato slices were higher during the initial stage as compared to the final stage of drying. These drying results are in agreement with the results recorded in high moisture foods like tomato (Jayaraman et al., 1975) and papaya (Levi et al., 1983).

Moisture diffusion in tomato slice

The moisture diffusivity in tomato slices, dried by using two methods was calculated based on the relationship obtained by plotting *ln* (MR) *vs* time and the results are shown in the Table 1. The moisture diffusion values of microwave assisted vacuum dried tomato slice were ranged from 3.55 to 8.54 x 10^{-8} m^2/s and for microwave assisted hot air drying, it ranged from 2.06 to 4.64 x 10^{-8} m^2/s, respectively at 50, 60 and 70°C. Also the drying rate constant '*k*' increased with increase in the drying temperature from 50 to 70°C. Between the drying methods, the drying rate constant was higher in microwave assisted vacuum dried tomato slice when compared to microwave assisted hot air dried tomato slice. Due to vacuum with microwave power, the moisture diffusion and drying rate constant were higher than microwave assisted hot air drying method.

Colour

The change in color of tomato slices dried under microwave assisted vacuum dryer and microwave assisted hot air dryer at 50, 60 and 70°C, are shown in Table 2. From the table, it was observed that there was a significant change in colour (L, a, & b) of microwave assisted hot air dryer when compared to microwave assisted vacuum dried samples. This may be due to longer drying time with air, which induced the non-enzymatic browning or Maillard reaction for the oxidative colour change. In microwave assisted vacuum drying, the colour change 'a' was not significant due to the exclusion of air and in turn without oxidation (Porretta and Sandei, 1991). In both the methods, the colour change was significant at 70°C, when compared to 50 and 60°C.

Conclusion

The dielectric property study demonstrated that the depth of penetration decrease with increase in frequency. Both ε′ and ε″ were decreased when the moisture content of the slice was reduced from 94 to 10% (w.b.) at 2450 MHz. The time taken for drying of microwave assisted vacuum drying was lower when compared to microwave assisted hot air drying at 50, 60 and 70°C, respectively, From the moisture diffusion study, it was observed that the moisture diffusion was higher in microwave assisted vacuum drying than in microwave assisted hot air drying method. The study also showed that the tomato slices retained better colour in microwave assisted vacuum drying than in microwave assisted hot air drying method.

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References

Association of Official Analytical Chemists (AOAC). 1980. Official methods of analysis. 13th edn., Washington DC, pp130-143.

Crank, J. 1975. The mathematics of diffusion. Oxford University Press, London.

Davies, J.N. and G.E. Hobson. 1981. The constituents of tomato fruit: The influence of environment, nutrition, and genotype. *CRC critical Reviews in Food Science and Nutrition*. 15: 205 -280.

Drouzas, A.E.and H.Schubert. 1996. Microwave application in vacuum drying of fruits. *Journal of Food Engineering*. 28:203-209.

Gunasekaran, S. 1999. Pulsed Microwave-Vacuum Drying of Food Materials. *Drying Technology.*17: 395-412.

Jayaraman, K.S., T.Goverdhanan, R.Sankaran, B.S.Batia and H.Nath. 1975. Studies on the development of some dehydrated instant soup cubes for use in emergency rations. *Journal of Food Science and Technology*. 13: 29-34.

Kim, S.S. and S.R. Bhowmik. 1995. Effective Moisture Diffusivity of Plain Yoghurt Undergoing Microwave Vacuum Drying. *Journal of Food Engineering* 24:137-148.

Lathrop, P. J., & H. K. Leung, 1980. Rates of ascorbic-acid degradation during thermal-processing of canned peas. *Journal of Food Science.* 45: 152–153.

Levi, A., S.Gagel and B.Juven. 1983. Intermediate moisture tropical fruit products for developing countries. Technological data on papaya. Journal of Food Technology. 18: 667-685.

Mudgett, R.E. 1995. Electrical properties of foods. In M.A. Rao & S.S.H.Rizvi (Eds). Engineering properties of foods. New York, Marcel Dekker, Inc. pp: 389-455.

Pappas, C., E. Tsami and D. Marimos-Kouris. 1999. The Effect of Process Conditions on the drying Kinetics and Rehydration Characteristics of some MW-Vacuum Dehydrated fruits. *Drying Technology.* 17: 157-174.

Porretta, S. and L. Sandai 1991. Determination of 5-Hydroximethyl, 2-furfural in tomato products: Proposal of a rapid HPLC method and its comparison with the calorimetric method. *Food Chemistry*. 39: 51-57.

Prabhanjan, D.G., H.S. Ramaswamy, and G.S.V. Raghavan. 1995. Microwave assisted air drying of thin layer carrots. *Journal of Food Engineering.* 25: 283-293.

Praveen kumar, D.G., H. Umesh Hebber and M.N.Ramesh .2006. Suitability of thin layer models for infrared –hot air drying of onion slices. LWT. Vol. 39, pp. 700-705.

Ryynanen, S. 1995. The electromagnetic properties of food materials: A review of the basic principles. *Journal of Food Engineering,* 26: 409-429.

Shivhare, U. S., G. S. V.Raghavan, R. G. Bosisio, and A. S. Mujumdar. 1992a. Microwave drying of corn III: constant power, intermittent operation. *Transactions of the ASAE*. 35: 959–962.

Torringa, E., E. Esveld, I.Scheewe, R.V.N.Berg and P.Bartels. 2001. Osmotic dehydration as a pretreatment before combined microwave – hot air drying of mushrooms. *Journal of Food Engineering*. 49: 185-191.

Wang, Y., T.D.Wig, J. Tang and L.M.Hallberg. 2003. Dielectric properties of foods relevant to RF and microwave pasteurization and sterilization. *Journal of Food Engineering.* 57: 257-268.

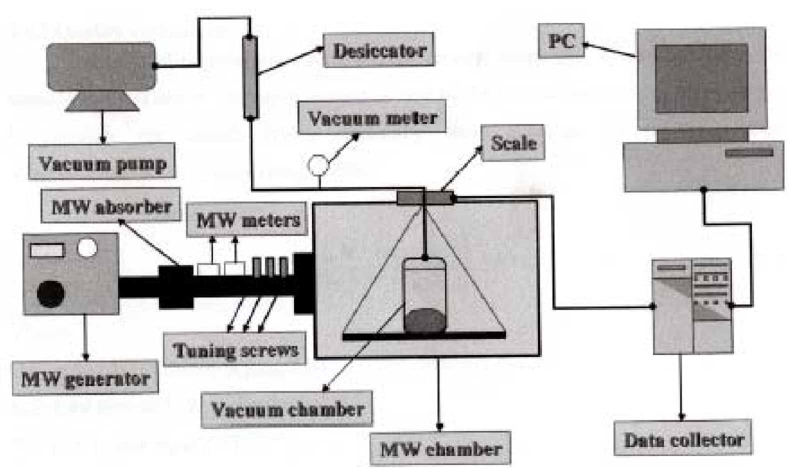


Figure 1. Schematic view of microwave drier set up

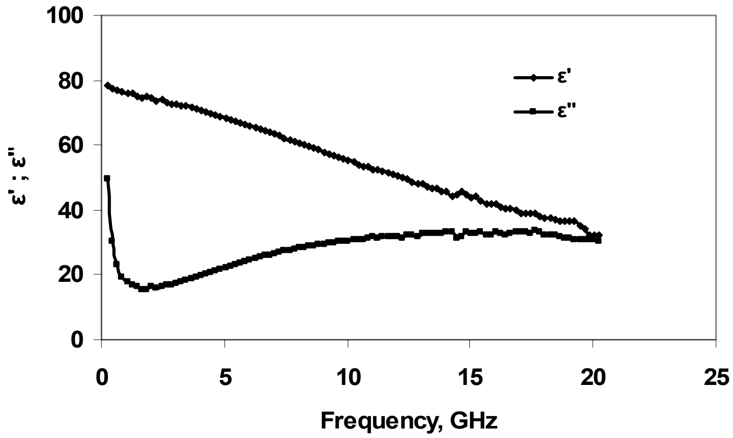
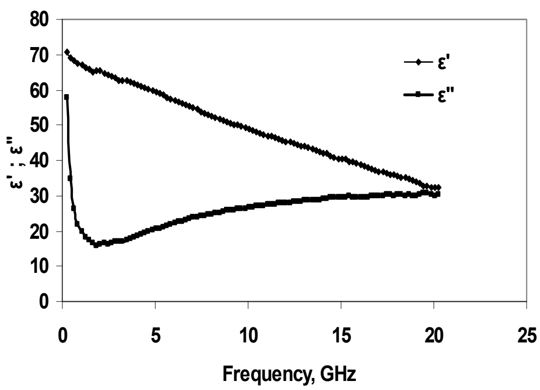
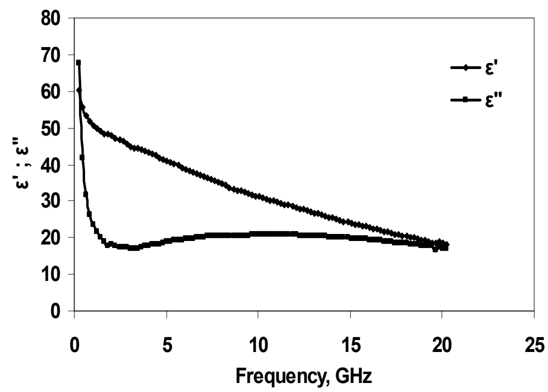


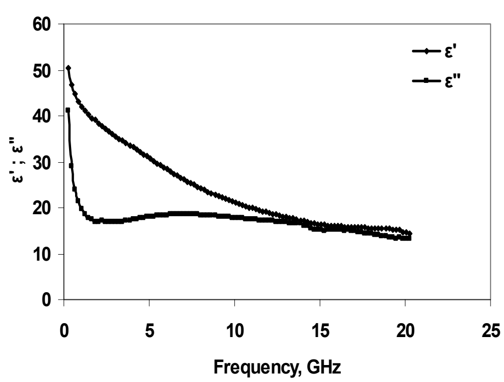
Figure 2. Dielectric behaviour of fresh tomato slices



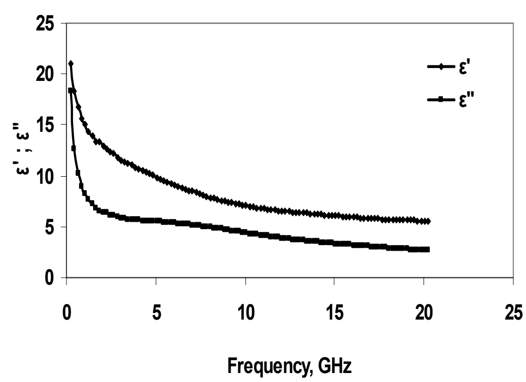
70% moisture content



50% moisture content



30% moisture content



10% moisture content

Figure 3. Dielectric behaviour of tomato slices at different moisture contents

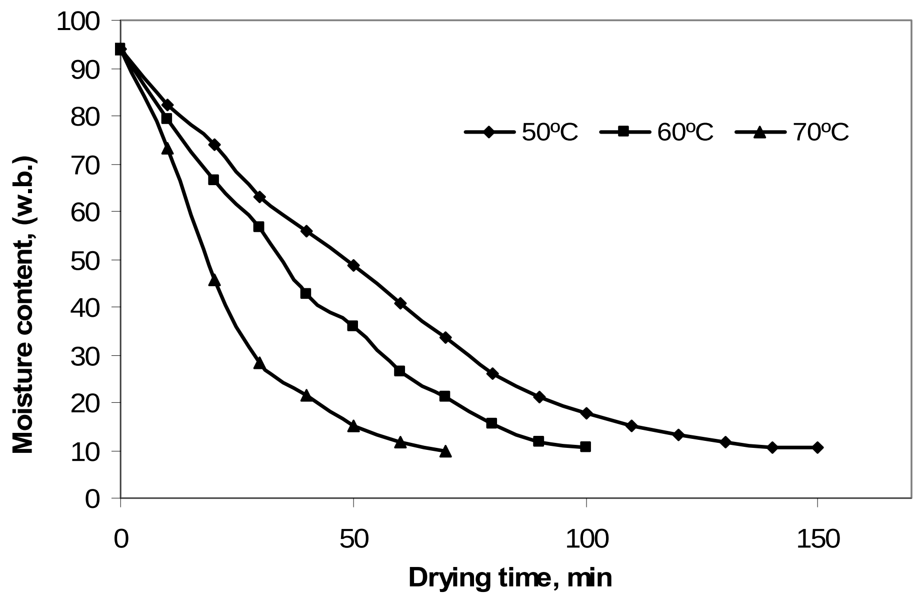


Figure 4. Relationship between moisture content and drying time of microwave assisted vacuum drying of tomato slices

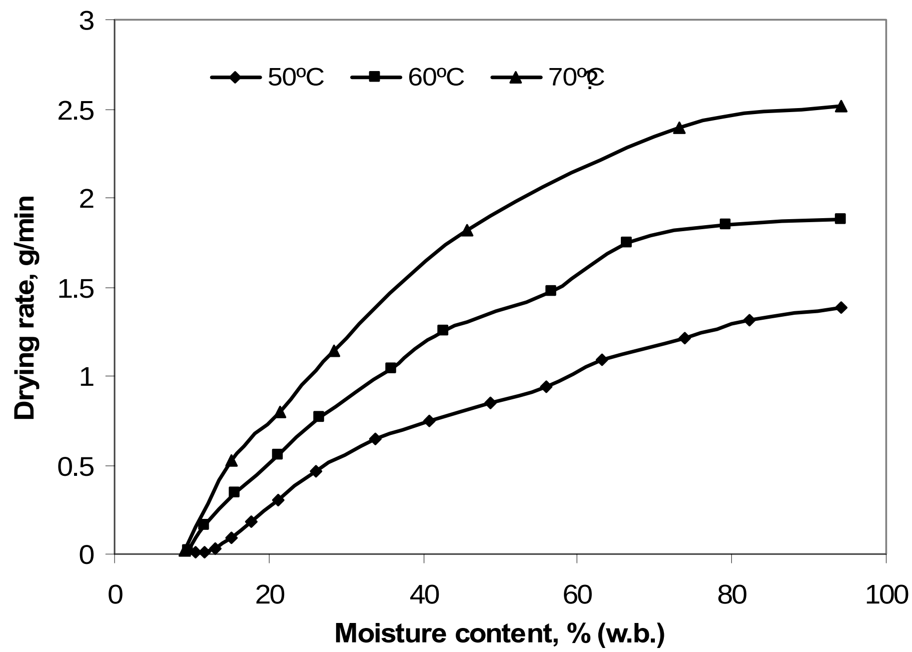


Figure 5. Relationship between drying rate and moisture content of microwave assisted vacuum drying of tomato slices

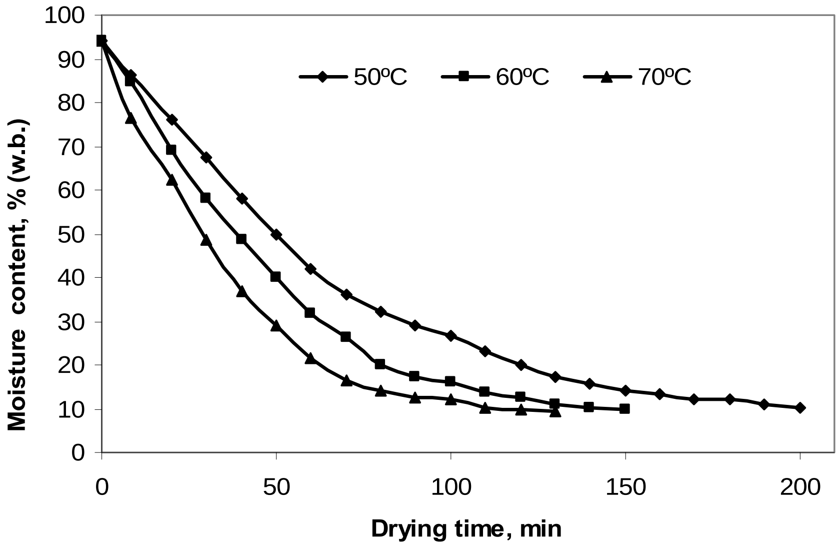


Figure 6. Relationship between moisture content and drying time of microwave assisted hot air drying of tomato slices

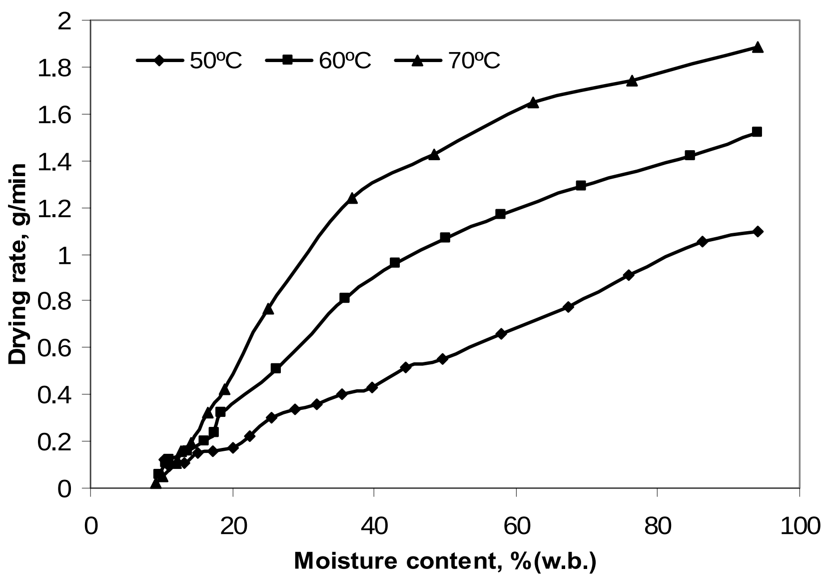


Figure 7. Relationship between drying rate and moisture content of microwave assisted hot air drying of tomato slices

Table 1 . Drying parameters of tomato slice

Drying methods	Regression equation	Drying rate constant '*k*' min^{-1}	Moisture diffusion, D_{eff} x 10^{-8} m^2/s	R^2
MVD at 50°C	y =-0.0333x + 0.6003	0.033	3.55	0.92
60°C	y = -0.0418x + 0.5173	0.041	4.45	0.90
70°C	y = -0.0801x + 0.5732	0.080	8.54	0.90
MHD at 50°C	y = -0.0194x + 0.2519	0.019	2.06	0.96
60°C	y = -0.0306x + 0.3881	0.030	3.26	0.94
70°C	y = -0.0435x + 0.4309	0.043	4.64	0.92

Table 2. Colour values of Microwave assisted vacuum and hot air dried tomato slices

Thickness, mm	Microwave assisted vacuum dryer			Microwave assisted hot air dryer		
	'L'	'a'	'b'	'L'	'a'	'b'
Fresh	38.54	12.32	12.08	38.54	12.32	12.08
50°C	40.13	12.51	13.21	42.66	11.83	17.26
60°C	40.69	12.55	13.15	46.52	10.93	18.13
70°C	41.15	12.76	14.29	49.29	10.18	19.15
Critical difference CD(5%)	1.31	0.19	0.79	1.12	0.22	0.63