Studies on microwave energy absorption of fresh green bell pepper (Capsicum)

Ahmad Kouchakzadeh*, Aref Safari

(*Department of Biosystem Engineering, Ilam University, Ilam, Iran*)

Abstract: Electromagnetic wave of extremely high frequency caused non-uniform absorption in foodstuffs. To measure the ability of fresh green bell pepper in absorbing microwave energy, the water as the medium absorption radiation was used and by determining the water temperature and then calculating its absorbed microwave energy, the microwave energy absorbed by the fresh green bell peppers were acquired. The results showed that absorb energy is proportional to the square of irradiated powers.

Keywords: microwave, energy absorption, green bell pepper

Citation: Kouchakzadeh, A., and A. Safari. 2015. Studies on microwave energy absorption of fresh green bell pepper (Capsicum). AgricEngInt: CIGR Journal, 17(2):105-111.

1 Introduction

The microwaves are the part of electromagnetic waves with the frequency about 0.3-300 GHz and wavelength of 0.001-1 m (Jones et al., 2002). They are reflected by metals, effluence by material such as plastic, glass, paper and ceramic, and absorbed by material with bipolar molecules such as foodstuffs. Highly specific in heating effect in foods are the characteristic of microwave energy (Buffler, 1993). As the water molecules are bipolar and revolve in the quickly altering electromagnetic field (billion times a second), heat is developed in the foodstuff because of discord between the water molecules. Because the waves can penetrate directly into the material, heating is volumetric (from inside out) and supplies rapid and constant heating in every part of product. The fast absorption of energy by water molecules causes rapid evaporation that improves drying, which succeeds in most convective drying techniques. The most widely commercially used frequency is 2.450 GHz (Kouchakzadeh and Shafeei, 2010). In microwave heating, the power absorbed at a location x inside a food is related to the electric field, E, at that location by the Equation 1 (Metaxas, 1983):

$$p(x) = \frac{1}{2}\omega\varepsilon'\varepsilon''E^2 \qquad (1)$$

where *p(x)* is power, W; ω is angular frequency, rad/s; $\varepsilon', \varepsilon''$ are the dielectric constant and dielectric loss factor of the material, and *E* is the electric filed, V/m. In microwave oven, E is proportionate of oven's magnetron length like an antenna in the waveguide and current excitation, I; thus, the total power absorbed by the load can be written as Equation 2 (Collin, 2007):

$$p_{total} \propto I^2 \qquad (2)$$

Some factors that may affect the microwave heating process are mostly included as foodstuff geometry, thermal, physical and dielectric properties, and parameters such as frequency, temperature, power applied and radiation period. The dielectric constant and dielectric loss factor describe the behavior of a material under the electromagnetic field. The dielectric constant is a relative measurement of polarization that occurs when a material is placed in an electric field. The

Received date: 2014-05-10 **Accepted date:** 2015-04-12

***Corresponding author: Ahmad Kouchakzadeh,** Department of Biosystem Engineering, Ilam University, Ilam, Iran. Phone: 00989124532128. Fax: 00988412227015. Email: akouchakzadeh@mail.ilam.ac.ir.

dielectric loss factor is a measure of a material's ability to convert electrical energy to heat. The extent of these properties is significant in microwave absorption that resulting heating (Kouchakzadeh, 2013). These properties are responsible for water, salt, fat, carbohydrate and protein levels. The dielectric properties for a wide range of food and agriculture commodities have been recorded; the dielectric properties of foods are temperature dependent (Nelson, 2008; Jones et al., 2002), studies must be conducted over the wide range of temperatures experienced by the product during thermal processing if dielectric heating behavior is to be precisely predicted. Sun et al. (1994) developed equations for a series of foods as a function of temperature, moisture and ash content up to 70 ℃. Uan et al. (2004) studied the dielectric conduct of mashed potatoes at temperature from 20 ℃ to 120 ℃ n microwave and RF range. Tulasidas et al. (1995) researched about dielectric properties of grapes and sugar solution. Dielectric properties of four apple cultivars were also measured about codling moth control studies (Sun et al., 1994). The research has been reported for dry agricultural commodities, such as alfalfa seeds (Yang et al., 2003), walnuts (Wang et al., 2007), legumes (Wang et al., 2010), pistachio nuts (Kouchakzadeh, 2013), and some fruits and vegetables (Sagar et al., 2010).

Prediction of absorption microwave energy for heat treatments as they relate to the dielectric properties of a foodstuff has been fully known. However, it is practically difficult to acquire the microwave energy absorbed by foods based on theoretical calculation. There are some methods for directly measuring a foodstuff temperature to get the absorbed microwave energy. Many methods have been reported. For example, the temperature of a microwave-irradiated sample can be evaluated by inserting a measuring device into the hot food shortly after turning off microwave power. The measuring apparatus maybe fail in execution when contacted with some heated materials that were sensitive to microwave absorption and fast reached high temperature. The temperature measurement was limited to some points, so that the mean values could not show the accurately temperature of the bulk, particularly for merged foodstuffs. Thus, it is important to get a simply faceable method to check it out the characteristic of foodstuffs in microwave absorption to predict the heating conduct of foods when heated by microwave irradiation. Ma et al. (2009) used an easy method to determine the ability of microwave energy absorption by using water as the medium matter to circuitously reflect microwave of the tested materials. The consequences showed that it is not proper to use the rate of surface heating to infer the microwave absorption conduct. Housova and Hoke (2002) studied about microwave cavity (oven) volume and food density. They showed that the ability of microwave absorption in dense foodstuffs decreased in oven with the smaller volume capacity. Hossan et al. (2010) examined the effects of microwave irradiation in different length of the cylindrical foodstuff. They found that the temperature within the body is very sensitive to cylinder length and time. Zhang and Datta (2003) tested about power absorption in single and complex foods that are radiated in a microwave field. They showed that some trends in power absorption as influenced by the dimensions and dielectric properties so foods with small loss factor may not absorb less power if their size is enough large, while high loss foods usually absorb more power at small sizes.

In this paper, a method for measuring absorbed microwave energy in green bell pepper (Capsicum) has been introduced, in which water, because of its responsiveness to microwave energy, was used as the medium material to absorb circuitously reflected microwave radiation of the tested peppers. The method would be suitable for use as a simple alternate method to the other foods as well. Pepper has high moisture content that increase bacterial activity in them so make pepper to be readily subjected to decline and post-harvest losses. One of the best ways of remove the bacterial activity in pepper because of their high moisture content is by drying to a safe moisture level that will not permit bacterial activity to preserve the perishable and extend the shelf-life beyond few weeks when they are in seasons (Tunde-Akintunde et al., 2005). Microwave irradiation is an addition in the drying techniques, relative to convective air drying, vacuum and freeze-drying in pepper industry.

2 Materials and methods

2.1 Experimental procedure

As shown in Figure 1, the tests device consisted of a microwave oven 2.45 GHz (CH-3071, 900 W LG Electronics, Korea), a Pyrex beaker for containing water, and a glass pan to have within pepper for tests. The temperatures of water were measured by a digital thermometer (TM-917 Lutron, Taiwan) with thermocouple (type K) as the probe with the accuracy of 0.1 ℃ when the oven was switched off.

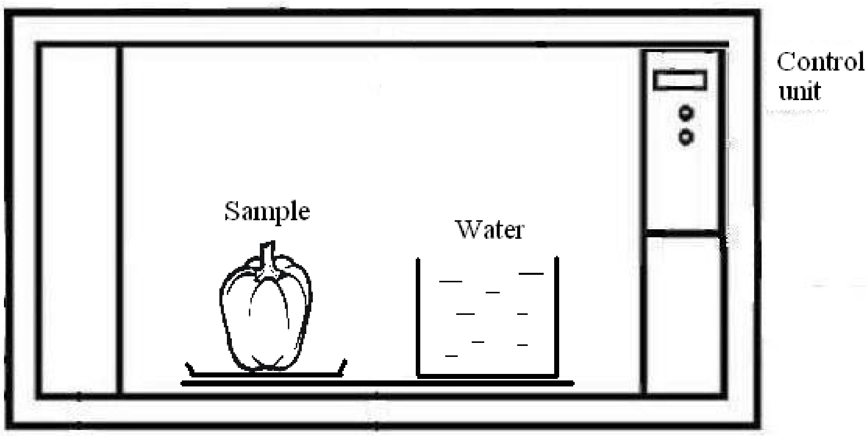

Figure 1 Schematic of microwave oven tests device

2.2 Sample preparation

The green bell peppers got from a field in Iran, Ilam province during harvesting season in September 2013. The samples were first washed and then were put in plastic bags, and placed in a refrigerator before conducting experiments. The initial moisture content of samples were determined by oven drying at temperature of 105 ℃ for 24 h according to a standard method ASABE (2006). About 50 g of grind peppers were placed in an oven, its final weight was taken, and the difference in weight was taken as water loss and expressed as grams water per grams dry matter. The initial moisture content for peppers was 93% (wb).

2.3 The tests

In initially tests, 100 g of distilled water in Pyrex beaker was weighing on a laboratory-weighing platform (Model AB204, Mettler-Toledo AG, Switzerland) with readability of 0.01 g and was taking in microwave oven for the 20, 25, 30 and 35 s microwave heating time at 180, 360, 540, 720 and 900 W power irradiation. The water temperature was measured before and after radiation.

The energy absorbed by the water is calculated by Equation 3 as follow:

$$Q_w = m_w C_w \Delta T \quad (3)$$

where Q_w is the absorbed energy, J; m_w is the water mass, kg; C_w is the specific heat of water, 4184 J/kg ℃; ΔT is the temperature rising $(T_{final} - T_{initial})$, ℃.

The dependence between the microwave power applied in water heating and the increase of temperature can be described by the Equation 4 (Ma et al., 2009):

$$\Delta T = k \frac{pt}{m_w C_w} \quad (4)$$

where p is the microwave power used for heating, W; t is the time of heating, s; and k is the utilization efficiency of the output microwave energy.

In finally tests, green bell peppers were weighed and added in microwave oven, so that both of 100 g water and quantity of 30, 40 and 50 g grind pepper were irradiated as similar as time and power in initially tests. The water temperature was measured before and after radiation. Each test was repeated three times and the results were averaged.

In order to discussion; indicate Q_2 as the absorbed microwave energy in the cavity for heating the pepper and the water medium, J; and Q_1 as the absorbed microwave energy in the cavity for heating only the water, J; then the following Equation 5 and Equation 6 can be derived:

$$Q_1 = Q_w = m_w C_w \Delta T_1 = kpt \quad (5)$$

$$Q_2 = Q_w + Q_p = m_w C_w \Delta T_2 + Q_p \quad (6)$$

where Q_p is the absorbed microwave energy by pepper, J; ΔT_1 is the temperature rising in initial tests, ℃; ΔT_2 is the temperature rising in finally tests, ℃.

By equalizing Equation 3 and Equation 4 the required equilibrium condition is written as following Equation 7:

$$Q_p = kpt - m_w C_w \Delta T_2 \quad (7)$$

So by finding utilization efficiency of the output microwave energy, k; from Equation 2 in initial tests and measuring temperature rising of water in final tests, ΔT_2; the energy absorbed by pepper were determined.

3 Results and discussion

It can be seen from Table 1 that the utilization efficiency of the output microwave energy rises from 0.38 to 0.62 and in all microwave powers the efficiency is ascending by irradiation times. This suggests that radiation with lower microwave power and longer times have more efficient for heating.

Table 1 the microwave irradiation test results

P, W	T, s	ΔT_1, ℃	k	ΔT_2, ℃			Q_p, J/g				
				+30g pepper	+40g pepper	+50g pepper	+30g pepper	+40g pepper	+50g pepper	average	standard deviation
180	20	4.55	0.53	3.56	3.31	2.92	13.8	13.0	13.6	13.5	0.4
	25	5.62	0.52	4.48	4.12	3.83	15.9	15.7	15.0	15.5	0.5
	30	7.33	0.57	5.86	5.40	5.00	20.5	20.2	19.5	20.1	0.5
	35	9.41	0.62	7.46	6.81	6.32	27.2	27.2	25.9	26.7	0.8
360	20	6.54	0.38	5.04	4.60	4.18	20.9	20.3	19.7	20.3	0.6
	25	8.23	0.38	6.45	5.93	5.40	24.8	24.1	23.7	24.2	0.6
	30	10.42	0.40	8.32	7.56	6.93	29.3	29.9	29.2	29.5	0.4
	35	12.50	0.42	10.68	9.78	9.00	34.5	35.8	33.9	34.7	1.0
540	20	10.16	0.39	7.83	7.06	6.38	32.5	32.4	31.6	32.2	0.5
	25	12.73	0.39	9.89	8.97	8.18	39.6	39.3	38.1	39.0	0.8
	30	16.27	0.42	12.9	11.79	10.72	47.0	46.9	46.4	46.8	0.3
	35	20.24	0.45	16.10	14.70	13.57	57.7	57.9	55.8	57.2	1.2
720	20	15.6	0.45	11.88	10.64	9.53	51.9	51.9	50.8	51.5	0.6
	25	18.9	0.44	14.5	13.03	11.71	61.4	61.4	60.2	61.0	0.7
	30	23.83	0.46	18.56	16.83	15.20	73.5	73.2	72.2	73.0	0.7
	35	30.44	0.51	23.94	21.79	19.80	90.7	90.5	89.0	90.1	0.9
900	20	22.71	0.53	16.86	14.96	13.14	81.6	81.1	80.1	80.9	0.8
	25	27.92	0.52	21.14	18.92	16.82	94.6	94.1	92.9	93.9	0.9
	30	34.54	0.54	26.49	23.85	21.37	112.3	111.8	110.2	111.4	1.1
	35	42.72	0.57	32.87	29.57	26.57	137.4	137.5	135.1	136.7	1.3

Figure 2 shows the variation of absorbed energy vs. time. As shown in Figure the elevation in microwave power caused increase progressive ratio in absorbed heats by peppers at each times.

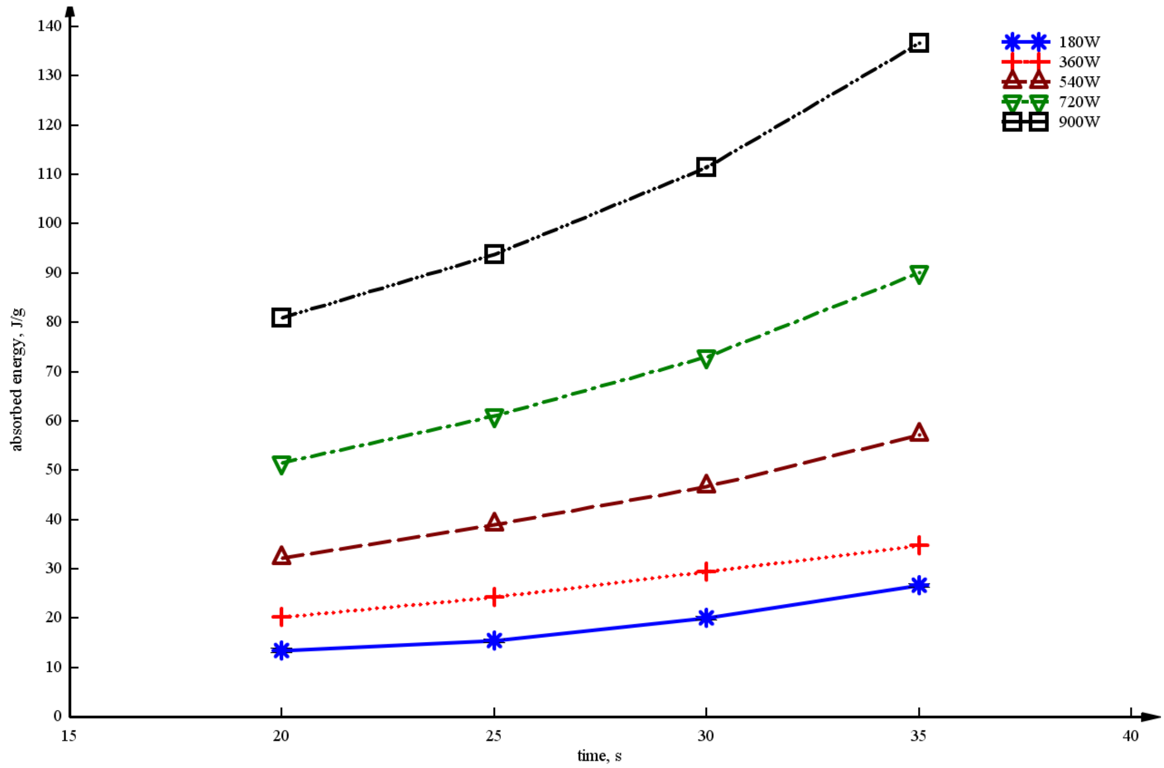

Figure 2 The averages of absorbed microwave energy in green bell pepper vs. time

The experimental data were presented as plot of absorbed energy vs. microwave power as shown in Figure 3.

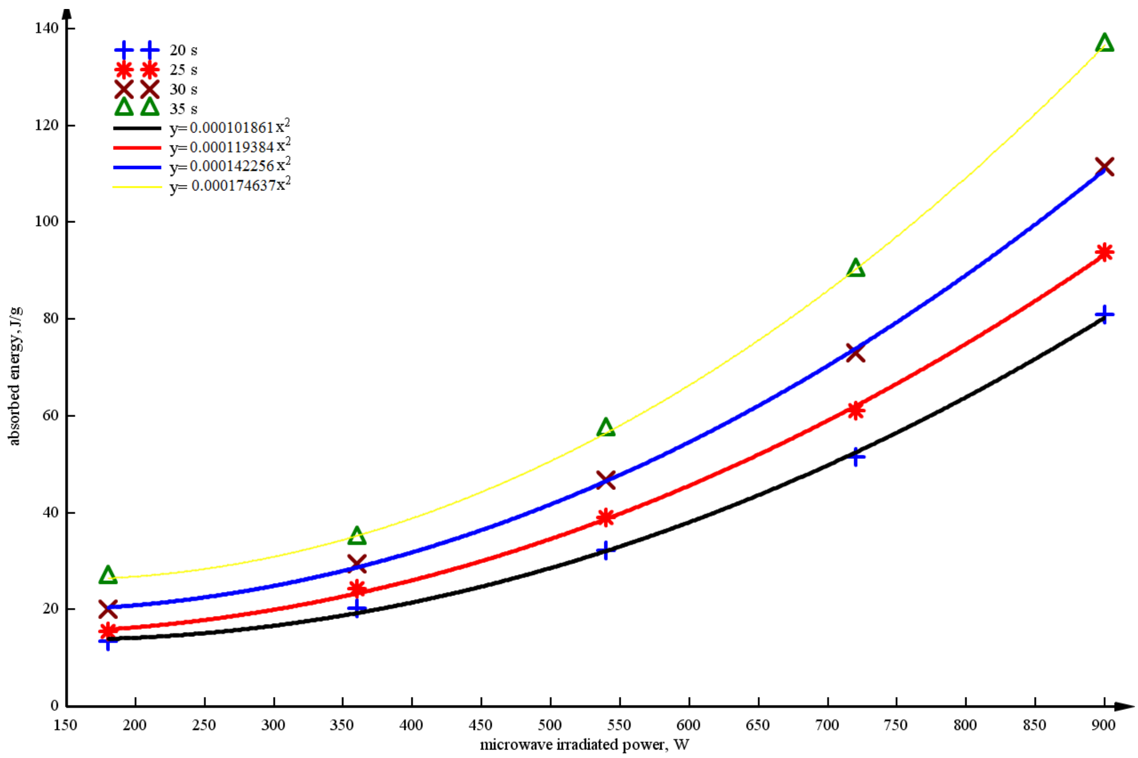

Figure 3 The variation of absorbed energy vs. microwave power

The quadratic regression's equations were fitted to data (using Statgraphics Centurion XVI software) as following Equation 8, Equation 9, Equation 10 and Equation 11:

$$Q = 0.000101861 p^2$$

(Irradiation time 20s, R^2= 0.94) (8)

$$Q = 0.000119384 p^2$$

(Irradiation time 25s, R^2= 0.94) (9)

$$Q = 0.000142256 p^2$$

(Irradiation time 30s, R^2= 0.93) (10)

$$Q = 0.000174637 p^2$$

(Irradiation time 35s, R^2= 0.92) (11)

where Q is the absorbed microwave energy by pepper per unit mass, J/g.

As can be observed in general from data and fitted curves, at all times the absorption energy as the 2nd degree functions with high correlation coefficients were identified. This showed consistence with Equation 1. Figure 4 shows the polynomial regression expression for absorbed microwave energy as function of time and power that were determined as following Equation 12:

$$Q = -40.7133 + 1.9528t + 0.000112013 p^2$$

(R^2= 0.96) (12)

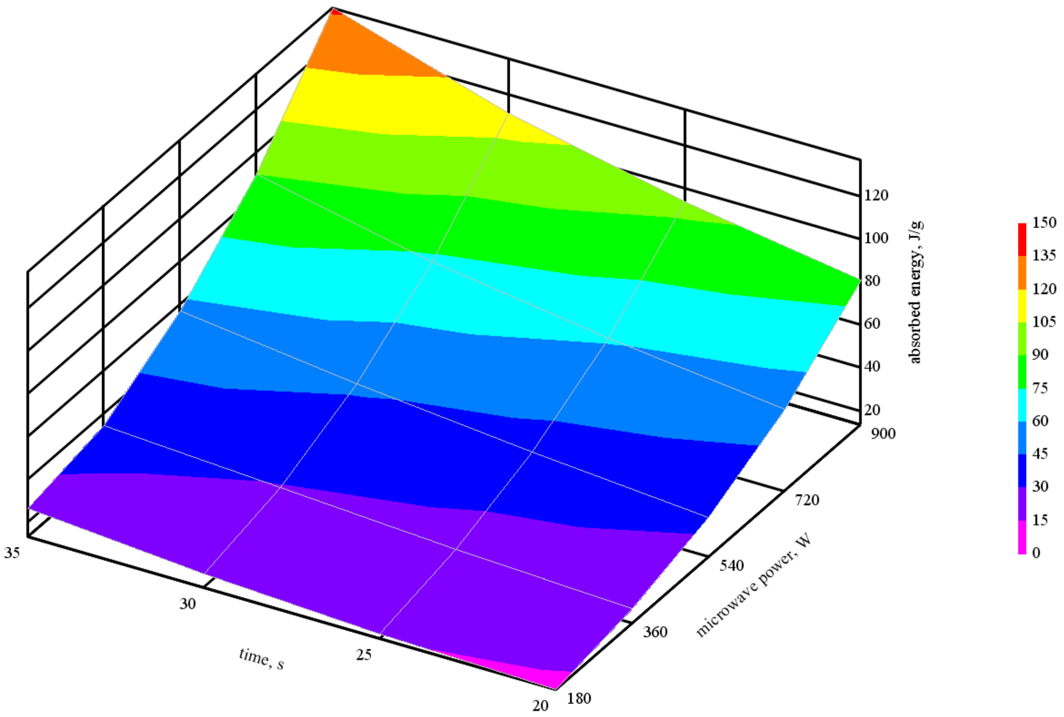

Figure 4 Absorbed microwave energy vs. time and power

4 Conclusions

It is not proper to use the rate of surface temperature to infer the microwave absorption behavior by foods; according to method presented, the absorption can be calculated directly. By using water as the medium material to absorb microwave irradiation, the quantities of absorption energy by pepper were measured. The results showed that energy absorb has quadratic proportionate to irradiated powers.

References

ASABE. 2006. Standard for measurement of moisture in grin and seed. Agricultural Engineers Yearbook. P:564.

Buffler, C. R. 1993. *Microwave cooking and processing*. Van Nostrand Reinhold.

Collin, R. E. 2007. *Foundations for microwave engineering*. John Wiley & Sons.

Hossan, M. R., D. Byun, and P. Dutta. 2010. Analysis of microwave heating for cylindrical shaped objects. *International Journal of Heat and Mass Transfer*, 53(23): 5129-5138.

Housova, J., and K. Hoke. 2002. Microwave heating–the influence of oven and load parameters on the power absorbed in the heated load. *Czech journal of food sciences*, 20(3): 117-124.

Jones, D. A., T. P. Lelyveld, S. D. Mavrofidis, S. W. Kingman, and N. J. Miles. 2002. Microwave heating applications in environmental engineering—a review. *Resources, conservation and recycling*, 34(2): 75-90.

Kouchakzadeh, A., and S. Shafeei. 2010. Modeling of microwave-convective drying of pistachios. *Energy Conversion and Management*, 51(10): 2012-2015.

Kouchakzadeh, A. 2013. Microwave Penetration Depth in Bulk Pistachios. *Int. J. Emerg. Sci*, 3(3): 303-310.

Ma, S. J., X. W. Zhou, X. J. Su, W. Mo, J. L. Yang, and P. Liu. 2009. A new practical method to determine the microwave energy absorption ability of materials. *Minerals Engineering*, 22(13): 1154-1159.

Metaxas, A. A., and R. J. Meredith. 1983. Industrial microwave heating (No. 4). IET.

Nelson, S. O. 2008. Dielectric properties of agricultural products and some applications. *Research in Agricultural Engineering*, 54(2): 104-112.

Sagar, V. R., and P. S. Kumar. 2010. Recent advances in drying and dehydration of fruits and vegetables: a review. *Journal of food science and technology*, 47(1): 15-26.

Sun, E., A. Datta, and S. Lobo. 1994. Composition-based prediction of dielectric properties of foods. The Journal of microwave power and electromagnetic energy: a publication of the *International Microwave Power Institute*, 30(4): 205-212.

Tulasidas, T. N., G. S. V. Raghavan, F. Van de Voort, and R. Girard. 1995. Dielectric properties of grapes and sugar solutions at 2.45 GHz. *Journal of microwave power and electromagnetic energy*, 30(2): 117-123.

Tunde-Akintunde, T. Y., T. J. Afolabi, and B. O. Akintunde. 2005. Influence of drying methods on drying of bell-pepper (Capsicum annuum). *Journal of Food Engineering*, 68(4): 439-442.

Uan, D. G., M. Cheng, Y. Wang, and J. Tang. 2004. Dielectric properties of mashed potatoes relevant to microwave and radio‐frequency pasteurization and sterilization processes. *Journal of Food Science*, 69(1): FEP30-FEP37.

Wang, S., M. Monzon, J. A. Johnson, E. J. Mitcham, and J. Tang. 2007. Industrial-scale radio frequency treatments for insect control in walnuts: I: Heating uniformity and energy efficiency. *Postharvest Biology and Technology*, 45(2): 240-246.

Wang, S., G. Tiwari, S. Jiao, J. A. Johnson, and J. Tang. 2010. Developing postharvest disinfestation treatments for legumes using radio frequency energy. *Biosystems engineering*, 105(3): 341-349.

Yang, J., Y. Zhao, and J. H. Wells. 2003. Computer simulation of capacitive radio frequency (RF) dielectric heating on vegetable sprout seeds. *Journal of food process engineering*, 26(3): 239-263.

Zhang, H., and A. K. Datta. 2003. Microwave power absorption in single-and multiple-item foods. *Food and bioproducts processing*, 81(3): 257-265.