Effect of microwave energy on dehydration of celery leaves

Ahmad Kouchakzadeh*, Neda Shabani

(*Department of Biosystems Engineering, Ilam University– Pazoohesh Ave, Ilam– IRAN*)

Abstract: Celery leaves were dried in a microwave oven to determine the effects of microwave output power on drying rate, specific energy consumption, drying efficiency, leaves surface area and the color of dried product. Five different microwave output powers ranging from 180 to 900 W were used in the drying experiments. As the drying progressed, the loss of moisture caused a decrease in absorbing microwave power and resulted in a fall in the drying rate. Rising microwave power could reduce the rate of energy efficiency from 45.0% to 11.4% and growth of specific energy consumption from 5.3 to 18.7 MJ kg^{-1} water. Significant differences (p<0.01) were observed between the color's variables of leaf in five microwave powers, but changing of color in microwave drying were less than oven drying.

Keywords: celery leaves, microwave heating, drying rates, specific energy consumption, color assessment

Citation: Kouchakzadeh A., and N. Shabani. 2017. Effect of microwave energy on dehydration of celery leaves. Agricultural Engineering International: CIGR Journal, 19(1): 108–113.

1 Introduction

The high moisture expendable merchandises have a fairly short shelf life. It is required to reduce moisture content to safe level before storage or complement process. Hot air drying is a routine procedure used to reduce water from commodities. Each plant gave a different drying kinetics due to its compositions which was influenced the moisture removal (Krokida et al., 2003; Menges and Ertekin, 2006; Doymaz et al., 2006; Tariganc et al., 2007).

Drying procedure plays an important role in energy efficient production. There is a strong incentive for energy engineering processes. Widely used drying processes waste time or energy, and also it will damage the environment. Microwave drying is a modern drying technique, compared with convective air-drying (tunnel, flat bed, cabinet), spray, vacuum, foam mat and freeze-drying. The conversion of microwave energy into heat the food is caused by water. As the water molecules are bipolar and rotate in the rapidly changing electromagnetic field (billion times a second), heat is developed in the foodstuff caused by friction between the water molecules. Because the waves can penetrate directly into the material, and its heating is volumetric (from inside out) and provides fast and uniform heating throughout the product. Quick absorption of energy by water molecules causes rapid water evaporation, resulting in high drying rates of the food (Kouchakzadeh and Safari, 2015). This produces an outward flux of fast escaping vapor. Besides enhancing drying, this external flux can improve to delay the shrinkage of tissue structure, which succeeds in most convective drying techniques. The most widely commercially used frequency is 2450 MHz as the lower microwaves are rarely used alone (Ren and Chen, 1998; Schiffmann, 1992).

In recent years, many investigators have studied the drying behaviors of different aromatic plants and culinary herbs, such as parsley claimed by Soysal et al. (2003), bay leaves claimed by Gunhan et al. (2005), Citrus aurantium leaves claimed by Mohamed et al. (2005), rosemary leaves claimed by Arsalan and Ozcan (2008), some herbal leaves claimed by Kaya and Aydın (2009), mint claimed leaves by Kavak Akpinar (2010), baby leaves claimed by Castoldi et al. (2001), grape leaves claimed by Alibas (2014), borage leaves claimed by Dwivedy et al. (2013), mulberry leaves claimed by

Received date: 2015-12-08 **Accepted date:** 2017-01-16

*** Corresponding author: Ahmad Kouchakzadeh**, Department of Biosystems Engineering, Ilam University– Pazoohesh Ave, Ilam– IRAN. Email: akouchakzadeh@yahoo.com. Tel: +98 9124532128, Fax: +98 8412227015.

Thirugnanasambandham et al. (2015) and amaranth leaves claimed by Mujaffar and Lee Loy (2016). In this entire literary works, the researchers studied drying kinetics of matter such as drying rate and mathematical modeling of drying, and a little works about specific energy consumption and efficiency in microwave drying were founded. The aim of this work was to t study the drying kinetics of celery leaves from different surface area under microwave radiation. The effects of microwave power on specific energy consumption and microwave drying efficiency were investigated and the quality in term of color change was evaluated.

2 Materials and methods

2.1 Materials

Celery was purchased from local market in Ilam Province, Iran. It was washed and drained by the excess water, then left was at room temperature on a screen. Sample was divided by cutting into different parts of leaves, roots and stems. The initial moisture content was determined using hot air oven at 105℃ for 24 h according to AOAC (2005) method. The initial moisture content of celery leaves was 70.9% ±1% (d.b).

2.2 Drying experiments

Samples were dried by thin layer drying in microwave oven (model CH-3071W, LG Electronics Ins) at the frequency of 2450 MHz with 180, 360, 540, 720 and 900 W radiated power.

Celery leaves were cutting to 2×2, 3×3 and 4×4 cm^2 dimensions and then weighted. Sample was placed on a screen tray and put into a drying chamber. The colorimetric data used to characterize the color of samples were L, a, and b using a color analyzer (LUTRON 1002, Taiwan). Each color value was ranging from zero to 1023. It was measured before and after drying. These values are commonly used as an index to compare to the color alteration of no lighting samples.

The samples were leaved from microwave oven to weight at every 30 s until constant weight. The drying rate vs. drying time was plotted.

2.3 Measurements and calculations

For the equilibrium moisture, every condition was got by static method to calculate the moisture ratio (MR) (Doymaz et al., 2006):

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

where, M, M_0 and M_e are present, first and dynamic equilibrium moisture contents.

If the equilibrium moisture content can be assumed zero for the microwave drying process, then moisture ratio can be rearranged as M_t/M_0 (Sarimeseli, 2011).

2.3.1 Drying rate

The drying rate during drying experiments was calculated using the following equation (Yongsawatdigul and Gunasekaran, 1996):

$$DR = \frac{M_{t+dt} - M_t}{dt} \tag{2}$$

where, DR is the drying rate, s^{-1}; t is drying time, s; M_t and $M_{t+\mathrm{dt}}$ are the moisture content at time t and $t+dt$ (kg water/kg dry matter), respectively,.

2.3.2 The microwave drying efficiency

The microwave drying efficiency was calculated as the ratio of heat energy used for evaporating water from the sample to the heat supplied by the microwave oven. The cumulative drying efficiency values were calculated as the averaged energy consumption for water evaporation divided by the supplied microwave energy in the total power-on time t_{on} in s (Mousa and Farid, 2002):

$$n_d = \frac{m_w \lambda_w}{P \Delta t_{on}} \times 100 \tag{3}$$

where, n_d is the microwave drying efficiency, %; m_w is the mass of evaporated water, kg; λ_w is latent heat of vaporization, J kg^{-1}; P is the average microwave power, W; Δt_{on} is the time interval, s. Latent heat of vaporization at the evaporating temperature (100℃) was taken as 2257 J kg^{-1} (Hayes, 1987).

2.3.3 The specific energy consumption

The specific energy consumption was calculated as the energy needed to evaporate a unit mass of water (Yongsawatdigul and Gunasekaran, 1996):

$$Q_s = \frac{t_{on} P \times 10^{-6}}{m_w} \tag{4}$$

where, Q_s is the specific energy consumption, MJ kg^{-1} water.

2.3.4 Color measurements

Color measurements of celery were made and the average values of L^*, a^* and b^* were reported. Color variation between fresh (denoted by the subscript '0') and dehydrated celery was used to describe the total color change ΔE after drying by the following equation:

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (5)$$

2.3.5 Statistical analysis

The data were analyzed using Statgraphics Centurion XVI program. Differences among mean values were analyzed using one-way ANOVA with Duncan tests and considered significantly different when $P \leq 0.01$.

3 Results and discussion

3.1 The effect of microwave power

Figure 1 and 2 illustrate that the decreasing celery leaves moisture content and miosture ratio vs. time, respectively. No significant differences ($p>0.05$) were found in 180-360 W and 540-720 W power. It means that the increase in drying rate is not significant for 180 to 360 W and 540 to 720 W power level. According to the microwave power supplied, the drying process was divided into three phases: I (180-360W), II (540-720W) and III (900W).

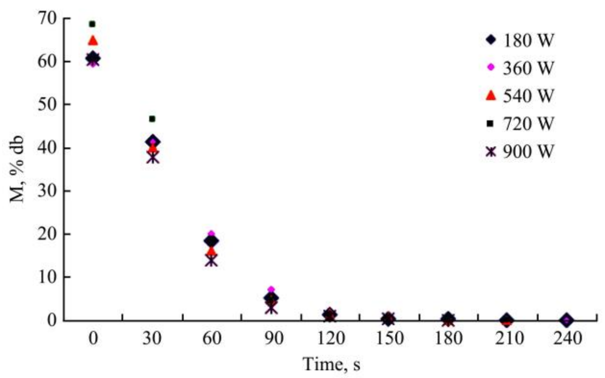

Figure 1 Effect of microwave power on celery leaves moisture content vs. time

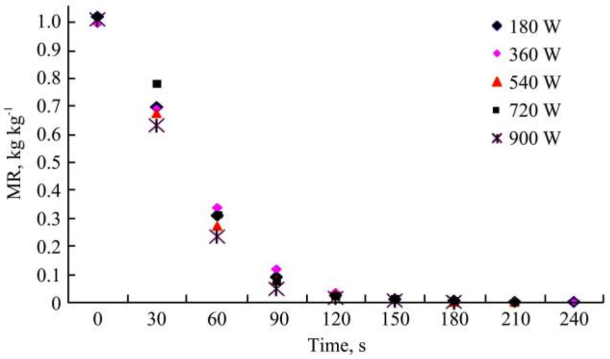

Figure 2 Effect of microwave power on moisture ratio of celery leaves vs. time

3.2 Drying rates

By using Equation (2), drying rate of celery leaves were calculated and shown in Figure 3. The moisture was high during the first phase of the drying, and that resulted in a higher absorption of microwave power and higher drying rates because of the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in absorption of microwave radiation and resulted in a falling in the drying rate. Higher drying rates were got at higher microwave output powers. So, the microwave output power had an important effect on the drying rate. Similar findings were reported in previous studies (Maskan, 2000; Sharma and Prasad, 2001; Krokida et al., 2003).

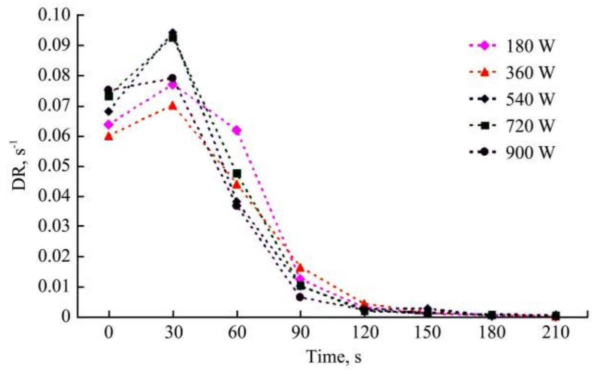

Figure 3 Effect of microwave power on drying rate of celery leaves vs. time

3.3 Specific energy consumption

Specific energy consumption between 900, 720, 540, 360 and 180 W decreases from 18.7 to 17.8, 13.6, 10.1 and 5.3 MJ kg^{-1} water when the energy efficiency rises to 11.4%, 13.0%, 16.6%, 23.1%, 45.0%, respectively. As shown in Figures 4 and 5, rising microwave power causes the cut of energy efficiency and growth of specific energy consumption.

Maximum loading rate of the microwave dryer used in this study is limited to about 30 grams when drying the leaf celery. So, these data are specific to microwave dryer used in this study. A considerable rise in drying efficiency with rising material load signifies that the microwave was efficiently absorbed by water. So as water is depleted, microwave absorption is reduced leading to lower efficiency values (Yongsawatdigul and Gunasekaran, 1996; Khraisheh et al., 1997; Mousa and Farid, 2002; Venkatesh and Raghavan, 2004). The size of leaves relative to cavity determines the power reflection back to the magnetron, the larger the load size, the lower the power cut by reflection, cavity loss and the higher the efficiency of power absorption. It can be said that the energy required of removing unit mass water from the product at higher material loads is less than at lower load size. The higher the material loads was, the lower the specific energy consumption required. As the intensity of heat generation is proportional to the moisture in a dielectrically dried material (Araszkiewicz et al., 2004), the large quantity of water trapped inside the material provided the higher drying efficiency and lower specific energy consumption values.

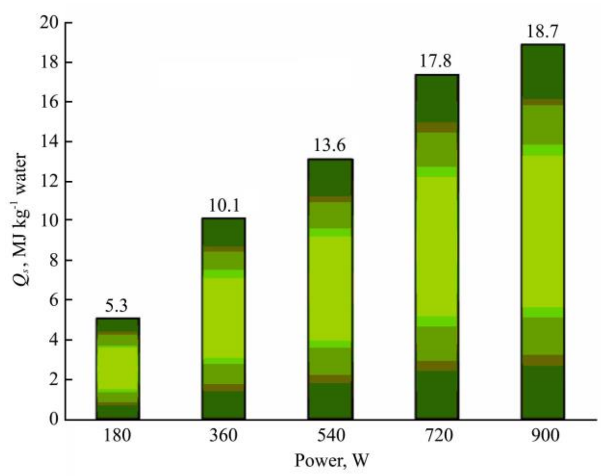

Figure 4 Effect of microwave power on specific energy consumption

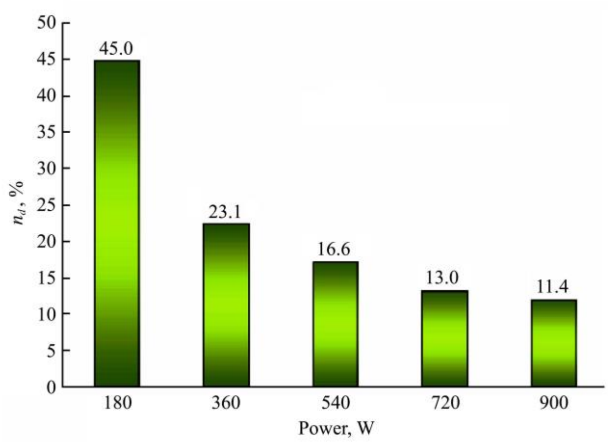

Figure 5 Effect of microwave power on energy efficiency

3.4 Effect of leaves surface area

The analysis of variance for the effect of leaves surface area and microwave power show that a significant respect differences between them. As shown in Table 1, these two factors act dependably. The results show the effect of leave surface area and microwave power are significantly (p<0.01).

Table 1 ANOVA results for the factor of leaves surface area and microwave power

Variable	Sum of squares	df	Variance	F	$F_{0.05}$	$F_{0.01}$
Treatment	67524.44	14	4823.17	57.17**	2.04	2.74
Leaves surface	28924.44	2	14462.22	171.26**	3.32	5.39
Microwave power	23168.89	4	5792.22	68.60**	2.69	4.02
Leaves surface× microwave power	15431.11	8	1928.89	22.84**	2.27	3.17
Errors	2533.33	30	84.44	-		
Total	70057.79	44				

The limiting process is water transfer from the leaves surface to the air, as the external resistance to the mass flow is higher than the internal one due to the water diffusion. This could be explained by a reduction in the absorbed energy by the leaves surface while the drying process advances and could also be due to the lower water content of the product partially dried as well as the dried surface which constitutes a barrier against heat penetration and water migration (Sharma and Prasad, 2006).

3.5 Color assessment

The effects of microwave drying on discoloration of celery leaf are presented in Table 1. As shown in Table the rising in microwave power makes intense the L^*, a^*, b^* values, respectively. The greatest discoloration is in 720W for b-value. It is no doubt that drying at higher power caused the higher discoloration. Similar results was found in peppermint and rosemary leaves discoloration (Arslan and Ozcan, 2008; Arslan et al., 2010). This could be the pigment degradation during drying process and browning reaction that occur in food matter as it is heated (Negi and Roy, 2001; Sinnecker et al., 2005). A comparison between discoloration in microwave drying (Table 2) and oven drying (Table 3) shows that the lower changing in color for all microwave powers as compared to oven drying at 50℃, 60℃ and 75℃.

Table 2 Color properties for celery leaves in different microwave power

Power, W	L_0^*- L^*	a_0^* - a^*	b_0^* - b^*	ΔE
180	26	13	-40	49.45
360	31	11	-41	52.56
540	54	29	-68	91.55
720	57	25	-62	87.85
900	26	12	-39	48.38

Table 3 Color properties for celery leaves in different temperature

Temperature, ℃	L_0^* - L^*	a_0^* - a^*	b_0^* - b^*	ΔE
50	80	-19	-0.8	82.23
60	90	-4.5	-15	91.35
75	89	-4.5	-15	90.37

As shown in Table 2 the maximum and minimum of color changes was happened in 540 W and 900 W. However, as shown in Table 3 in oven drying the maximum and minimum total color changes occurred in 60 ℃ and 50 ℃, respectively. The color change of celery leaves using the L, a, b system totally explained the real behavior of celery leaves samples undergoing microwave drying. The final values of L, a, b and total color change (ΔE) were influenced by microwave drying. This result was supported by the decrease in b^* values and increase in a^* and L^* values. But in oven drying only the values of L^* have been increased.

4 Conclusions

Drying kinetics of celery leaves were investigated in a microwave oven at various microwave output powers and sample amounts. Drying time decreased considerably with rising microwave output power and decreasing celery leaves samples as well by using microwave-drying technique. Results showed that the microwave output power affected the drying rate and specific energy consumption. The effect of leaves surface area is consequential. Drying at higher power caused the higher discoloration.

References

Alibas, I. 2014. Microwave, air and combined microwave-air drying of grape leaves (Vitis vinifera l.) and the determination of some quality parameters. *International Journal of Food Engineering*, 10(1): 69–88.

AOAC. 2005. International, Official methods of analysis of AOAC International.

Araszkiewicz, M., A. Koziol, A. Oskwarek, and M. Lupinski. 2004. Microwave drying of porous materials. *Drying Technology*, 22(10): 2331–2341.

Arslan, D., and M. M. Özcan. 2008. Evaluation of drying methods with respect to drying kinetics, mineral content and colour characteristics of rosemary leaves. *Energy Conversion and Management*, 49(5): 1258–1264.

Arslan, D., M. M. Özcan, H. O. and Mengeş. 2010. Evaluation of drying methods with respect to drying parameters, some nutritional and colour characteristics of peppermint (*Mentha x piperita* L.). *Energy Conversion and Management*, 51(12): 2769–2775.

Doymaz, İ., N. Tugrul, and M. Pala. 2006. Drying characteristics of dill and parsley leaves. *Journal of Food Engineering*, 77(3): 559–565.

Dwivedy, S., K. Rayaguru, and G. R. Sahoo. 2013. Mathematical modeling and quality characteristics of microwave dried medicinal borage leaves. *International Food Research Journal*, 20(2): 769–774.

Gunhan, T., V. Demir, E. Hancioglu, and A. Hepbasli. 2005. Mathematical modelling of drying of bay leaves. *Energy Conversion and Management*, 46(11): 1667–1679.

Hayes, G. D. 1987. *Food Engineering Data Handbook*. Longman Scientific and Technical.

Akpinar, E. K. 2010. Drying of mint leaves in a solar dryer and under open sun: modelling, performance analyses. *Energy Conversion and Management*, 51(12): 2407–2418.

Kaya, A., and O. Aydın. 2009. An experimental study on drying kinetics of some herbal leaves. *Energy Conversion and Management*, 50(1): 118–124.

Khraisheh, M. A. M., T. J. R. Cooper, and T. R. A. Magee. 1997. Microwave and air drying I. Fundamental considerations and assumptions for the simplified thermal calculations of volumetric power absorption. *Journal of Food Engineering*, 33(1): 207–219.

Kouchakzadeh, A., and A. Safari. 2015. Studies on microwave energy absorption of fresh green bell pepper (Capsicum). *Agricultural Engineering International: CIGR Journal*, 17(2): 105–111.

Krokida, M. K., V. T. Karathanos, Z. B. Maroulis, and D. Marinos-Kouris. 2003. Drying kinetics of some vegetables. *Journal of Food engineering*, 59(4): 391–403.

Maskan, M. 2000. Microwave/air and microwave finish drying of banana. *Journal of Food Engineering*, 44(2): 71–78.

Menges, H. O., and C. Ertekin. 2006. Mathematical modeling of thin layer drying of Golden apples. *Journal of Food Engineering*, 77(1): 119–125.

Mohamed, L. A., M. Kouhila, A. Jamali, S. Lahsasni, N. Kechaou, and M. Mahrouz. 2005. Single layer solar drying behaviour of Citrus aurantium leaves under forced convection. *Energy Conversion and Management*, 46(9): 1473–1483.

Mousa, N., and M. Farid. 2002. Microwave vacuum drying of banana slices. *Drying Technology*, 20(10): 2055–2066.

Mujaffar, S., and A. Lee Loy. 2016. The rehydration behavior of microwave-dried amaranth (Amaranthus dubius) leaves. *Food Science and Nutrition*, 7(16): 1–9.

Negi, P. S., and S. K. Roy. 2001. Effect of drying conditions on quality of green leaves during long term storage. *Food*

Research International, 34(4): 283–287.

Ren, G., and F. Chen. 1998. Drying of American ginseng (Panax quinquefolium roots by microwave-hot air combination. *Journal of Food Engineering*, 35(4): 433–443.

Sarimeseli, A. 2011. Microwave drying characteristics of coriander (*Coriandrum sativum* L.) leaves. *Energy Conversion and Management*, 52(2): 1449–1453.

Sharma, G. P., and S. Prasad. 2001. Drying of garlic (Allium sativum) cloves by microwave–hot air combination. *Journal of Food Engineering*, 50(2): 99–105.

Sharma, G. P., and S. Prasad. 2006. Optimization of process parameters for microwave drying of garlic cloves. *Journal of Food Engineering*, 75(4): 441–446.

Sinnecker, P., N. Braga, E. L. Macchione, and U. M. Lanfer-Marquez. 2005. Mechanism of soybean (Glycine max L. Merrill) degreening related to maturity stage and postharvest drying temperature. *Postharvest Biology and Technology*, 38(3): 269–279.

Soysal, Y., S. Öztekin, and Ö. Eren. 2006. Microwave drying of parsley: modelling, kinetics, and energy aspects. *Biosystems Engineering*, 93(4): 403–413.

Tarigan, E., G. Prateepchaikul, R. Yamsaengsung, A. Sirichote, and P. Tekasakul. 2007. Drying characteristics of unshelled kernels of candle nuts. *Journal of Food Engineering*, 79(3): 828–833.

Thirugnanasambandham, K., V. Sivakumar, and J. P. Maran. 2015. Microwave-assisted extraction of polysaccharides from mulberry leaves. *International Journal of Biological Macromolecul*es, 72, 1–5.

Venkatesh, M. S., and G. S. V. Raghavan. 2004. An overview of microwave processing and dielectric properties of agri-food materials. *Biosystems Engineering*, 88(1): 1–18.

Yongsawatdigul, J., and S. Gunasekaran. 1996. Microwave-vacuum drying of cranberries: Part I. Energy use and efficiency. *Journal of Food Processing and Preservation*, 20(2): 121–143.