The Journal of Animal & Plant Sciences, 26(1): 2016, Page: 123-130
ISSN: 1018-7081

INVESTIGATION OF DRYING PARAMETERS OF BROCCOLİ DURING FAN-ASSİSTED MİCROWAVE, AİR AND A COMBİNED MİCROWAVE/AIR DRYING

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ABSTRACT

Broccoli samples (*brassica oleracea*), with a moisture of 88.5% (w.b) were dried using three drying methods: fan-assisted microwave, combined microwave-air and air. Drying of broccoli samples continued until moisture decreased to 10% (w.b). Five different microwave powers, 180, 360, 540, 720 and 900 W, were used in microwave drying experiments. The combined microwave-air drying, in which microwave and air drying were applied together, was nine different combination levels. Three different air temperatures 100, 150 and 200 °C, were used in air drying experiments. Periods of drying experiments lasted for 52-13, 35-14 and 125-57 min for microwave, combined microwave-air and air drying, respectively. Drying characteristics of broccoli were determined and moisture content at any time of drying process was investigated by different drying models. These data were then applied to the thin layer drying models of Newton, Page, Henderson and Pabis, Logarithmic, Midilli-Küçük, Wang and Singh, Logistic, Two Term, Verma, Two Term exponential and Diffusion Approach for determination of the best suitable mathematical models. It was found that the Midilli-Kucuk model described the drying ratio satisfactorily in all drying methods.

Key words: Broccoli, drying time, drying ratio, mathematical models.

INTRODUCTION

Broccoli (*Brassica Oleracea Italica*) is considered a good source of nutrients because it is rich in vitamin C, carotenoids (vitamin A-like substances), fiber, calcium, and folate. Broccoli is also a source of many substances called phytochemicals, or plant chemicals, which may have anticancer properties. Broccoli displays have great potential to avoid a wide range of degenerative diseases, such as cancer (Mahn *et al*, 2012). Fresh broccoli is greatly perishable vegetable in the fresh state leading to waste and losses for the harvesting period. Broccoli has the highest food safety risk and has the shortest shelf life among fruits and vegetables because they have high metabolic reactions which cause to loss in weight, quality, food and economic values (Mrkic *et al*, 2007). Therefore, various methods have been used to develop the postharvest life of intact including refrigeration, frozen and dehydration for all the year round usage (Doymaz, 2014).

Dehydration is a basic technology for food industry. Furthermore it is a useful method of preserving the products through which spoilage can be prevented (Rayaguru and Routray, 2011). The basic disadvantages of conventional thermal treatments of foods are low energy efficiency and long drying time during the falling rate period. (Rayaguru and Routray, 2011). Because of the low thermal conductivity of food materials, heat transfer to the inner sections of foods during conventional heating is limited in this period (Wang and Xi, 2005; Karaaslan and Tunçer, 2010). The microwave energy is studied for food drying in order to prevent significant quality loss, and achieve fast and effective thermal processing (Wang and Xi, 2005 Karaaslan and Tunçer, 2010). Microwaves are electromagnetic waves within the range of radio frequencies from 300 MHz to 300 GHz. Electromagnetic energy 915 and 2450 MHz can be absorbed by water containing materials and is converted to heat (Maskan, 2000; Karaaslan and Tunçer, 2010).

Some of the advantages of the microwave heating in drying of foods and agricultural products over the conventional drying methods are faster and bigger volumetric heating**,** higher drying rate, shorter drying time, better quality of the product, reduced energy consumption and cost savings (Mujumdar, 2000).

Several researchers investigated the drying kinetics of various agricultural products and they developed different mathematical models for describing the microwave and hot air drying characteristics such as, Funebo and Ohlsson (1998) for apple and mushroom, Litvin *et al.* (1998) and Wang & Xi (2005) for carrot, Maskan (2000) for banana, Göğüs and Maskan (2001) for olive pomace, Sharma and Prasad (2001) for garlic, Torringa *et al.* (2001) for mushroom, Panchariya *et al*. (2002) for black tea, Soysal (2004) for parsley, and Alibas (2007) for nettle leaves, Özbek and Dadali (2007) for mint leaves, and Karaaslan and Tunçer (2008) for spinach leaves.

Microwave drying of broccoli has not been investigated to a great extent but few data about convective and freeze drying of broccoli are available in the literature (Mahn *et al*, 2012; Mrkic *et al*, 2007; Doymaz, 2014).

MATERIALS AND METHODS

Sample preparation: Broccoli samples were purchased at a local supermarket. The broccoli leaves were removed florets were separated from stems and so cut into pieces. Florets of broccoli were only used in these experiments. Prior to drying, fresh broccoli samples were blanched in boiling water for 3 min and cooled with water and then dried on the microwave oven. 100 g samples were dried in a dryer and the initial moisture content of the broccoli samples was determined as 88.5 % w.b. using standard method at 105º C for 24 h. This drying procedure was replicated three times (Soysal, 2004).

Dryer: Drying experiments were performed in a domestic microwave oven (Arçelik MD-824 ,Turkey) with maximum output of 900W at 2450 MHz in the Department of Agricultural Machinery, Faculty of Agriculture, Suleyman Demirel University, Isparta, Turkey.

The dimensions of the microwave cavity were 210 mm by 340 mm by 340 mm. The microwave oven can be operated at different microwave output powers of 180, 360, 540, 720 and 900 W. The broccoli was uniformly spread on the turn-table inside the microwave cavity, for an even absorption of microwave energy. For the mass determination, a digital balance of 0.01 g accuracy (Sartorius GP3202, Germany) was used. Depending on the drying conditions, moisture loss was recorded at 1 min intervals during drying at the end of power-on time by removing the turn-table from the microwave, and periodically placing the sample, on the digital balance (Soysal *et al*, 2006). Three different drying experiments were performed for all drying methods and the data obtained from these experiments were averaged and drying parameters were determined (Alibas, 2010).

Experiments: The drying systems were as follows:

Microwave drying: To investigate the effect of microwave output power on moisture content, drying rate and drying time, five microwave output powers, 180, 360, 540, 720 and 900 W were used for drying 100 g broccoli samples. A Teflon dish, containing the sample, was placed at the centre of the dryer turn-table in the microwave cavity. Samples were uniformly spread into a thin layer for an even absorption of microwave energy after the drying experiment started. Moisture loss was recorded at 1 min intervals during drying for determination of drying curves by an electronic balance (Maskan, 2001). Broccoli samples were dried until equilibrium moisture content (no weight change) was reached.

Combined microwave and air drying: Combined microwave and air drying were performed as a two-stage drying process at constant microwave powers of 180, 360 and 540 W. At the same time the drying was performed according to a first power and time schedule. Microwave dryer temperatures were 100, 150 and 200 ºC in both cases.

Air drying: Different temperature intensities (100, 150 and 200 ºC) were investigated in fan-assisted convection at constant sample loading density of 100 g. Moisture loss was recorded at 1-min intervals during drying by taking out and weighing the dish on a electronic balance. When the samples reached a constant weight, equilibrium moisture content was assumed to be obtained.

Mathematical modeling of drying curves: Drying curves were fitted with 11 thin layer drying models, namely, Newton, Page, Henderson and Pabis, Logarithmic, Midilli-Kucuk, Wang and Singh, Logistic, Two term, Verma, Two Term Exponential, Diffusion Approach Equation Models. The moisture ratio and drying rate of broccoli were calculated using the following equation:

$$MR = \frac{M - M_e}{M_0 - M_e} \qquad (1)$$

$$\text{Drying rate} = \frac{M_{t+dt} - M_t}{dt} \qquad (2)$$

where, M is the moisture content at any time, M_0 is the initial moisture content, and M_e is equilibrium moisture content, M_t is the moisture content at t, M_{t+dt} is the moisture content at t+dt in kg [H_2O] kg $^{-1}$dry matter, respectively and t is drying time in min.

The equilibrium moisture content was assumed to be zero for microwave drying (Maskan, 2000; Doymaz, 2005). The values of M_e are relatively small compared with M or M_0 for long drying time; thus, MR=$(M\text{-}M_e)/(M_o\text{-}M_e)$ can be simplified as MR=M/M_0 (Akgun and Doymaz, 2005).

Statistical analysis: The non-linear regression analysis was performed using sigma plot software (scientific graph system, version 12.00). Regression results include coefficient of determination (R^2), standard error of estimate (SEE), and residual sum of square (RSS). R^2, SEE and RSS are the important parameters for selecting the best model to define the drying curves of broccoli.

RESULTS AND DISCUSSION

Drying characteristics of broccoli: Fig. 1 shows the alteration of moisture content with respect to the microwave power level. As the microwave output power was increased, the drying time of broccoli samples was significantly decreased. The microwave drying experiment which reduced the moisture content of broccoli samples from the initial 88,5% (wet basis) to a final 10% (wet basis) took 52-13 min, depending on microwave output power applied. As seen in Fig.1, a reduction in drying time occurred with the increasing microwave powers. The drying periods of broccoli samples were 52, 26, 16, 14 and 13 min, in microwave powers of 180, 360, 540, 720, 900W, respectively. By working at 900 W instead of 180W the drying time was shortened by 75%. This result is similar to the result of drying mint leaves (Özbek and Dadalı, 2007), chard leaves (Alibaş, 2006), parsley leaves (Soysal,2004) and apple slices (Wang *et al*., 2007). According to the results of mathematical modelling, the Midilli-Kucuk model was found to be the best descriptive model for the broccoli drying. Therefore, experimental and predicted moisture ratio values with drying time by the Midilli-Kucuk model are shown in Fig. 1.

The drying rate(kg [H_2O] kg-1[dry matter] min^{-1}), defined as the quantity of water removed with time, is shown in Fig. 2 for broccoli samples during microwave drying at 180, 360, 540, 720 and 900 W. The total drying rates to reach the final moisture content for the broccoli samples were 3.003, 6.538, 10.477, 12.56, and 15.272 (kg [H_2O]kg^{-1}[dry matter] min^{-1}) at 180, 360, 540, 720 and 900 W, respectively (Fig. 2). The drying rate decreased continuously with the moisture content or drying time. In this curve, there was no constant–rate drying period and all the microwave drying experiments were seen to occur in the falling rate period. The results were generally in agreement with some literature studies on drying of various food products (Figiel, 2009).

To investigate the effect of microwave output power- temperature on moisture content, moisture ratio, drying rate, drying time, three microwave powers (180, 360, 540 W) and three temperatures (100, 150, 200 ºC) were used for drying 100 g broccoli samples. The total drying times to reach the final moisture ratio for the broccoli samples were 35, 31, 33, 21, 20, 20, 17, 15 and 14 min at 180 W-100 ºC, 180 W-150 ºC, 180W-200 ºC, 360 W-100 ºC, 360 W-150 ºC, 360 W-200 ºC and 540 W-100 ºC, 540 W-150 ºC, 540 W-200 ºC respectively (Fig. 3). Plots of experimental and predicted moisture ratios using the Midilli-Kucuk model versus drying time are shown in Fig.3.

The drying rates (kg [H_2O] kg^{-1}[dry matter].min^{-1}) curves during combined microwave-air drying are given in Fig. 4. The drying rates during combined microwave-air drying of broccoli samples of 180 W-100 ºC, 180 W-150 ºC, 180 W-200 ºC, 360 W-100 ºC, 360 W-150 ºC, 360 W-200 ºC and 540 W-100 ºC, 540 W-150 ºC, 540 W-200 ºC were 4.28, 4.91, 4.06, 7.46, 7.68, 7.71, 10.26, 10.13, 10.40 kg [H_2O]kg^{-1}[dry matter].min^{-1}, respectively.

The effect of changing the temperature in the microwave dryer on the moisture ratio curve of broccoli samples is shown in Fig. 5. The total drying times to reach the final moisture content for the broccoli samples were 125, 80 and 57 min at 100, 150, and 200 ºC, respectively.

The drying rate is shown in Fig. 6 for broccoli samples during air drying at 100, 150 and 200 ºC. The results were 0.91, 2.30 and 2.41 (kg [H_2O]kg^{-1}[dry matter].min^{-1}) at 100 ºC, 150 ºC and 200 ºC respectively. Drying rate decreased with increasing time. Air temperature is the most important factor affecting drying rate and similar results were reported by Doymaz (2006).

Modelling Drying Data: To describe the effect of microwave powers on drying kinetics of broccoli samples, 11 different thin layer drying models were used. For all drying conditions, the Midilli-Kucuk Model was the best descriptive model (Table 1). The Midilli-Kucuk model gave the highest values of R^2 and the lowest values of SEE and RSS. To take into account the effect of the drying variables on the Midilli–Kucuk model the constants a, k, m and b were regressed against those of drying air temperatures using multiple regression analysis.

Based on the multiple regression analysis, the accepted model is the follow:

$$MR(a,k,m,b) = \frac{M - M_e}{M_0 - M_e} = a.\exp(-kt^m) + bt \qquad (3)$$

A validation of the determined model was established by comparing the experimental data, for each drying curve, with the values predicted by the Midilli-Kucuk model and the results are plotted in Fig.7. The data points are banded around a 45º straight line, demonstrating the suitability of the model in describing the microwave drying behaviour of the broccoli samples.

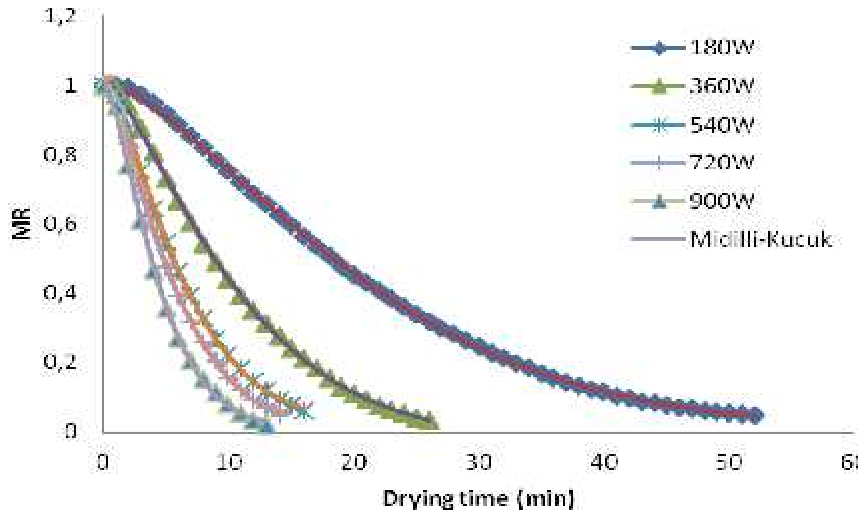

Fig.1. Variation of experimental and predicted moisture ratio by Midilli-Kucuk model with drying time at selected microwave output powers

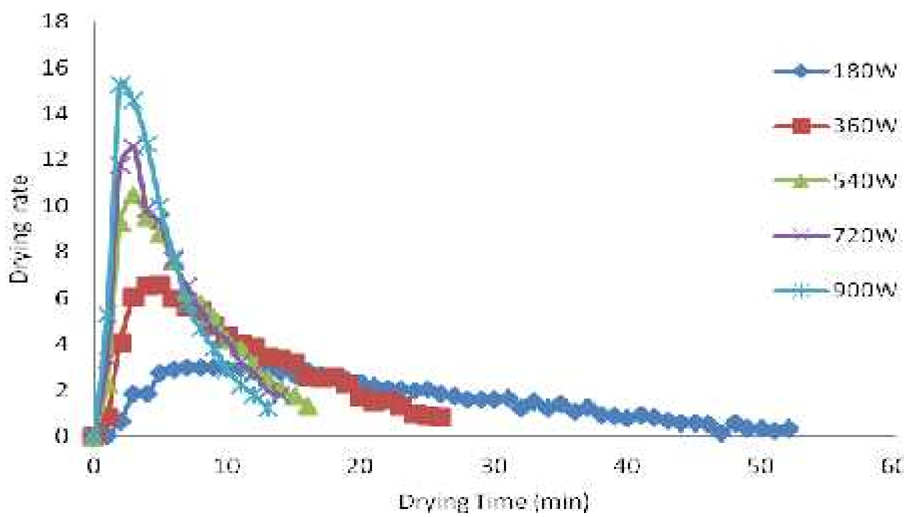

Fig. 2. Variation of drying rate as a function of drying time for different microwave output powers.

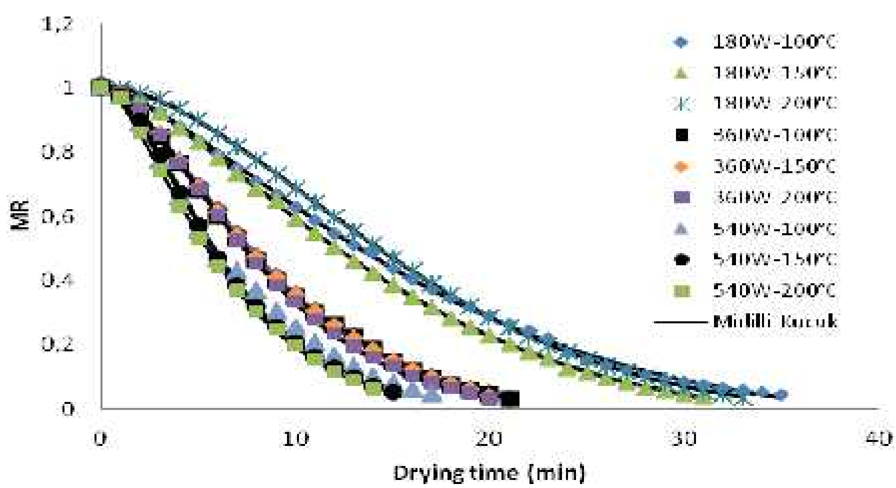

Fig. 3. Variation of experimental and predicted moisture ratio by Midilli-Kucuk model with drying time at selected temperatures and 180, 360 and 540 W microwave powers.

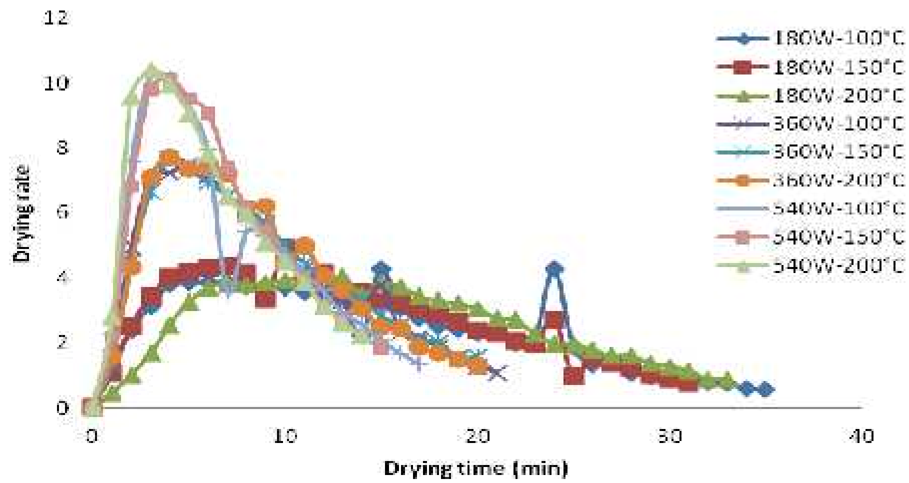

Fig. 4. Variation of drying rate as a function of drying time at selected temperatures and 180, 360 and 540 W microwave powers.

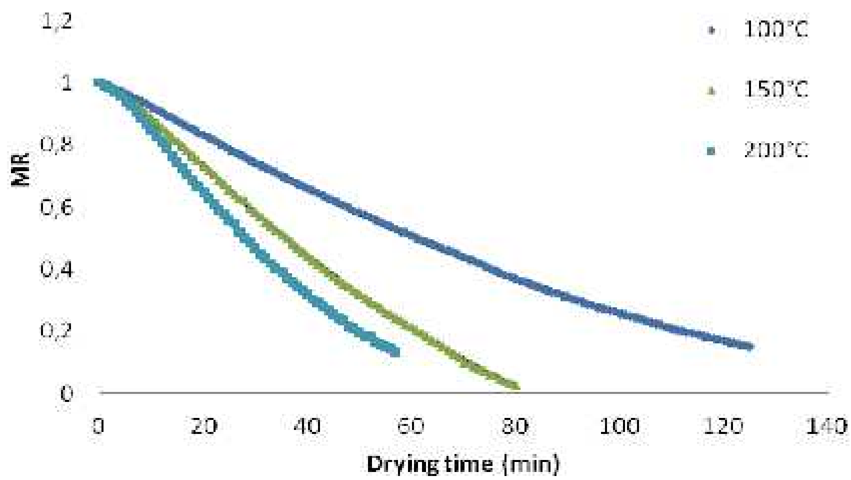

Fig. 5. Variation of experimental and predicted moisture ratio by Midilli-Kucuk model with drying time at selected temperatures.

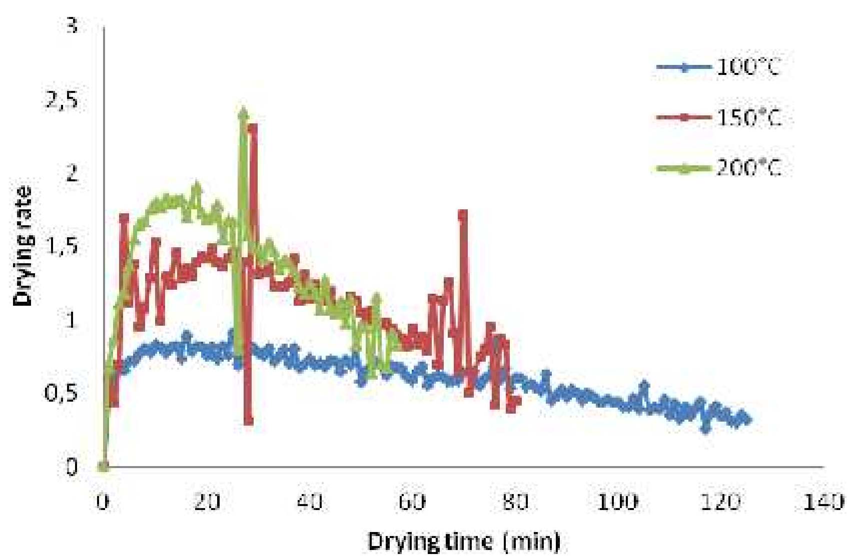

Fig. 6. Variation of drying rate as a function of drying time at selected temperatures

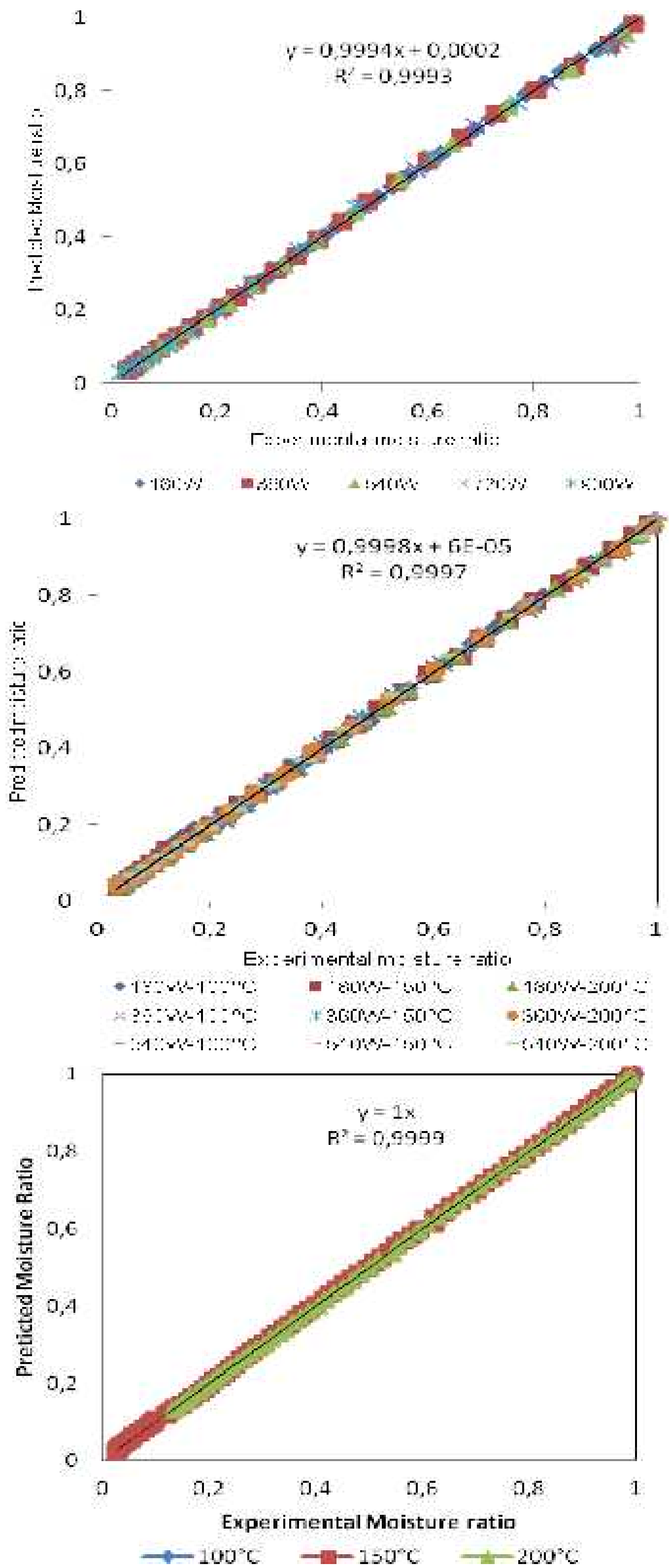

Fig 7. Experimental and predicted moisture ratio at different drying conditions.

Table 1. Non-linear regression analysis of the semi-empirical Midilli-Kucuk's equation [Eq. (3)] for microwave drying of broccoli under various microwave output power, combination and air

Controlled variable parameters	Constants	R^2	SEE (ï)	RSS
Microwave drying				
180W	a=1.0160 k=0.0105 m=1.4466 b=0.0000	0.9998	0.0046	0.0010
360W	a=1.0199 k=0.0364 m=1.3537 b=-0.0007	0.9995	0.0076	0.0013
540W	a=1.0174 k=0.0656 m=1.3877 b=0.0011	0.9992	0.0096	0.0012
720W	a=1.0177 k=0.0834 m=1.3626 b=0.0003	0.9989	0.0119	0.0016
900W	a=1.0169 k=0.1072 m=1.4111 b=0.0008	0.9989	0.0131	0.0017
MW-air drying				
180W-100^{0}C	a=1.0012 k=0.0171 m=1.4168 b=-0.0010	0.9993	0.0081	0.0021
180W-150^{0}C	a=1.0046 k=0.0173 m=1.4671 b=-0.0012	0.9999	0.0031	0.0003
180W-200^{0}C	a=1.0063 k=0.0071 m=1.7198 b=-0.0005	0.9999	0.0029	0.0003
360W-100^{0}C	a=1.0154 k=0.0388 m=1.4286 b=-0.0007	0.9995	0.0075	0.0010
360W-150^{0}C	a=1.0145 k=0.0344 m=1.4796 b=-0.0003	0.9996	0.0067	0.0008
360W-200^{0}C	a=1.0124 k=0.0330 m=1.5293 b=-0.0000	0.9997	0.0060	0.0006
540W-100^{0}C	a=1.0221 k=0.0656 m=1.3324 b=-0.0004	0.9980	0.0158	0.0035
540W-150^{0}C	a= 1.0135 k=0.0468 m=1.5574 b=0.0013	0.9998	0.0087	0.0009
540W-200^{0}C	a=1.0146 k=0.0655 m=1.4070 b=0.0000	0.9994	0.0092	0.0009
Air drying				
100^{0}C	a=0.9995 k=0.0048 m=1.1772 b=-0.0008	0.9999	0.0025	0.0008
150^{0}C	a=1.0039 k=0.0051 m=1.3017 b=-0.0024	0.9998	0.0033	0.0009
200^{0}C	a=1.0029 k=0.0068 m=1.3646 b=-0.0009	0.9999	0.0018	0.0002

SEE, Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square

Conclusion: In this study, the effects of three different drying methods on the drying of broccoli samples were evaluated based on the drying parameters such as moisture content, the drying rate. Combined microwave-air drying of broccoli samples was faster than the other drying methods. Results obtained for combined microwave- air drying kinetics of broccoli samples show that the increase in microwave power and temperatures from 180W-100°C to 540W-200°C decreased the drying time from 35-14 min. The drying process occurred in the falling rate period. Two stage drying process was observed, composed of an increasing rate period initially followed by a falling rate period until the end of the drying. In this present study, experimental data for broccoli samples were used to evaluate several thin layer drying models available in the literature. Among these models, the drying model developed by Midilli-Kucuk showed good agreement with the data obtained from the drying curve best in all drying methods.

REFERENCES

Akgun, N.A. and I. Doymaz. (2005). Modelling of olive cake thin-layer drying process. J. of Food Eng. 68:455-461.

Alibas, I. (2006). Characteristics of chard leaves during microwave, convective and combined microwave-convective drying, Drying Techn.: An International J. 24:11, 1425-1435.

Alibas, I. (2007). Energy Consumption and Colour Characteristics of nettle leaves during microwave, vacuum and convective drying. Biosystems Eng. 96(4): 495-502.

Alibas, I. (2010). Determination of drying parameters, ascorbic acid contents and color characteristics of nettle leaves during microwave-, air- and combined microwave-air drying. J. Food Process Engineering. 33,2, pp:213-233.

Doymaz, İ. (2005). Drying characteristics and kinetics of okra. J. Food Eng. 69: 275-279.

Doymaz, İ. (2006). Thin-layer drying behaviour of mint leaves. J. Food Eng. 74: 370-375.

Doymaz, I. (2014). Effect of blanching temperature and dipping time on drying time of broccoli. Food Science and Technology International. 20(2), 149-157.

Figiel, A. (2009). Drying kinetics and quality of vacuum-microwave dehydrated garlic cloves and slices . J. Food Eng. 94(1): 98-104

Funebo, T. and T. Ohlsson (1998). Microwave-assisted air dehydration of apple and mushroom. J. of Food Eng. 38: 353-367.

Goğus, F. and M. Maskan (2001). Drying of olive pomace by a combined microwave-fan assisted convection oven. Nahrung/Food. pp:129-132.

Karaaslan, S.N. and İ.K. Tunçer (2008). Development of a drying model for combined microwave-fan assisted convection drying of spinach. Biosystems Eng. 100: 44-52.

Karaaslan, S. and İ. K. Tunçer (2010). Combined microwave fan-assisted convection dehydration of banana [*Musa acuminata* Colla (Cavendish Group)]. Philippine Agricultural Scientist. 93: 76-87.

Litvin, S., C.H. Mannheim and J. Miltz (1998). Dehydration of carrots by a combination of freeze drying, microwave heating and air or vacuum drying. J. Food Eng. 36: 103-111.

Mahn, A., M. Zamorano, H. Barrientos and A. Reyes (2012). Optimization of a process to obtain selenium-enriched freeze-dried broccoli with high antioxidant properties. LWT-Food Science and Technology 47: 267-273.

Maskan, M. (2000). Microwave /air and microwave finish drying of banana. J. Food Eng. 44: 71-78.

Maskan, M. (2001). Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. J. Food Eng. 48:177-182.

Mrkic, V., M. Ukrainczyk and B. Tripalo (2007). Applicability of moisture transfer bi-di correlation for convective drying of broccoli. J. Food Eng. 79:640-646.

Mujumdar, A. S. (2000). Drying Technology in agriculture and food sciences. Science Publishers, Inc. Enfield (NH), USA.

Ozbek, B. and G. Dadali (2007). Thin layer drying characteristics and modelling of mint leaves undergoing microwave treatment. J. Food Eng. 83: 541-549.

Panchariya, P.C., D. Popovic and A.L. Sharma (2002). Thin-layer modelling of black tea drying process. J. Food Eng. 52 (4): 349-357.

Rayaguru, K., W. Routray (2011). Microwave drying kinetics and quality characteristics of aromatic *Pandanus amaryllifolius* leaves. Intl. Food Res. J. 18 (3):1035-1042.

Sharma, G.P., S. Prasad (2001). Drying of garlic (Allium sativum)cloves by microwave-hot air combination. J. Food Eng. 50: 99-105.

Soysal, Y. (2004). Microwave drying Characteristics of Parsley. Biosystems Engineering 89:167-173.

Soysal, Y., S. Öztekin and Ö. Eren (2006). Microwave drying of parsley: modelling, kinetics, and energy aspects. Biosystems Engineering 93(4): 403–13.

Torringa, E., E. Esveld, I. Scheewe, R. Berg, P. Bartels (2001). Osmotic dehydration as a pre-treatment before combined microwave-hot-air drying of mushrooms. J.of Food Eng. 49: 185-191.

Wang, J., Y.S. Xi (2005). Drying characteristics and drying quality of carrot using a two- stage microwave process. J. Food Eng. 68: 505-511.

Wang, Z., J. Sun, F. Chen, X. Liao and X. Hu (2007). Mathematical modeling on thin layer microwave drying of apple pomace with and without hot air pre-drying. J.of Food Eng. 80: 536-544.