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DRYING CHARACTERISTICS OF RED BEET (*BETA VULGARIS ESCULENTACRUENTA*) PUREE IN A MICROWAVE OVEN

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Dirim, S. N., Talih, M., Çalışkan Koç, G. (2019). Kırmızı pancar püresinin (*Beta vulgaris esculentacruenta*) mikrodalga fırında kuruma kinetiği. GIDA (2019) 44 (4): 654-671 doi: 10.15237/gida.GD19028

ABSTRACT
The aims of this study are to observe the effects of different microwave power and amount of samples on the drying characteristics of red beet puree, to determine the physical properties of the red beet powders and to calculate the energy efficiency of the drying process. The drying experiments were conducted at five different microwave power and thicknesses of the sample. Seven thin-layer drying models were fitted to the experimental data and Page model which had the highest R^2 and lowest χ^2 and RMSE for all drying experiments was found to satisfactorily describe the drying behavior of red beet puree. The total drying times increased depending on an increasing amount of sample and decreasing microwave power. The D_{eff} and Ea values ranged between 1.095E-08 to 3.438E-06 $m^2.s^{-1}$ and 14.35 to 77.35W.g^{-1}, respectively. The energy efficiency values of the drying processes are evaluated in terms of MER and SEC.
Keywords: Red beet puree, microwave drying, thin layer modeling, effective moisture diffusivity, energy consumption, activation energy

KIRMIZI PANCAR PÜRESİNİN (*BETA VULGARIS ESCULENTACRUENTA*) MİKRODALGA FIRINDA KURUMA KİNETİĞİ

ÖZ
Bu çalışmanın amaçları farklı mikrodalga güçleri ve ürün miktarlarının kırmızı pancar püresinin kuruma karakteristiği üzerine etkisinin gözlenmesi, elde edilen kırmızı pancar püresi tozunun fiziksel özelliklerinin belirlenmesi ve kurutma işleminin verimliliğinin hesaplanmasıdır. Bu amaçla, kurutma çalışmaları beş farklı mikrodalga gücü ve ürün kalınlığında gerçekleştirilmiştir. Kırmızı pancar püresinin kuruma kinetiğinin belirlenmesi için, yedi ince tabaka kuruma modeli deneysel verilere uyarlanmıştır. En yüksek R^2 ve en düşük χ^2 ve RMSE değerleriyle Page modelin kırmızı pancar püresinin kuruma davranışını tanımladığı gözlenmiştir. Kırmızı pancar püresinin kuruma süresi artan örnek miktarı ve azalan mikrodalga gücüyle artmıştır. Ayrıca, etkin nem difüzyonu ve aktivasyon enerjisi değerleri sırasıyla 1.095E-08 - 3.438E-06 m^2. s^{-1} ve 14.35 - 77.35W. g^{-1} arasında değişmiştir. Kurutma işlemlerinin enerji verimliliğinin belirlenmesi için nem uzaklaştırma hızı (MER) ve özgün enerji tüketimi (SEC) değerleri hesaplanmıştır.
Anahtar kelimeler: Kırmızı pancar püresi, mikrodalga kurutma, ince tabaka modelleme, etkin nem difüzyonu, enerji tüketimi, aktivasyon enerjisi

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INTRODUCTION

Red beet (*Beta vulgaris esculentacruenta*) being one of the important root vegetable crops in the world, is also one of the major sources of betalains which are used both as natural colorants to enhance the redness of different food products such as dairy products, ice creams, jams, tomato paste, beverages, desserts, and important minerals (calcium, magnesium, potassium, and sodium) (López et al., 2009; Obón et al., 2009). Agricultural products continue their respiratory activity which causes deterioration of products quickly even after harvest. Drying is an alternative method to increase the post-harvest durability of agricultural products (Ertekin and Yaldiz, 2004; Alibas, 2006). Drying can be accomplished using many different methods such as spray, freeze, sun, microwave drying, etc. The most common drying methods are the sun and convective drying which at the same time have some disadvantages such as long drying time, microbial growth, loss of nutritional content, and high amount of energy consumption, etc. (Toğrul, 2006). For the given reasons above, the alternative drying methods must be used for decreasing the drying time and energy consumption and preventing the loss of nutritional compounds (Alibas - Özkan et al., 2007). In recent years, microwave drying has become a widely used method due to a decrease in drying time and energy consumption and the protection of the nutrients content (Alibas, 2006). In microwave heating, the internal generation of heat provides fast and uniform heating throughout the food product. Microwave drying results in high drying rates of the food because of the quick absorption of energy by the water molecules that cause rapid evaporation of water, therefore, creates an outward flux of rapidly escaping vapor from the food (Sharma and Prasad, 2006). The energy consumption of microwave drying is low because of the volumetric heating effect by microwaves, which reduced the drying time considerably. The microwave drying method was used for several kind of foods such as corn husk (Akdoğan et al., 2017), Swiss chard leaves (Alibas, 2006), spinach (Alibas-Özkan et al., 2007), kiwifruits (Maskan, 2001), banana (Maskan, 2000), nettle leaves (Alibas, 2007), mint (Özbek and Dadali 2007), apple pomace (Wang et al., 2007a), and celery leaves (Demirhan and Ozbek, 2011).

There are several types of research related with the drying of red beet using methods such as freeze-drying (Lejeune et al., 1991), tray drying (Kaleta and Gornicki, 2010), hot air drying (Gökhlae and Lele, 2011), microwave-convection drying (Singh et al., 2013), and spray drying red beet juice (Koul et al., 2002). So far, there is no published study about modeling and effective diffusivity of the microwave drying of red beet puree. The studies on the drying of red beet, which has a high amount of betalain pigments, provides a great significance for obtaining natural colorants (Bazaria and Kumar, 2016), increasing the consumption, creating new usage areas, and reducing environmental pollution by recycling the red beets produced in excess amounts of the demand. In addition, the dried products have some advantages such as easy-storage, smart-packaging, and easy transportation, and they can be used as natural and easily measurable ingredients in food recipes (Çalışkan and Dirim, 2013). The aims of this study are to observe the effects of different microwave power settings (in Watt) and the amount (grams) of the samples on the drying characteristics of red beet puree, to determine the physical properties of the obtained red beet powders and to calculate the energy efficiency of the drying process.

MATERIAL AND METHODS

Materials

The red beets were purchased from a local supermarket in Izmir, Turkey and were washed, peeled, and mashed with a home type blender (Tefal Smart, MB450141, Turkey).

Microwave Drying

The experiments were performed using a domestic microwave oven (Arçelik MD 595, Turkey) at 2450 MHz with a maximum output power of 900 W. The dimensions of the microwave inner cavity were 220x 330x 360mm. The drying experiments were performed at five different microwave power settings (180, 360, 540, 720, and 900W). The oven has a glass plate with a 300 mm diameter at the base of the oven.

Five different sample amounts (9, 12, 15, 18, and 21g) (corresponding to the thicknesses of 3, 4, 5, 6, and 7mm) were placed in petri dishes as a thin layer on the rotating glass plate in the oven. In order to determine the moisture losses, the petri dishes were taken out at uniform intervals (30s) and weighed using a digital scale with an 0.01 precision (Ohaus AR2140, USA). The drying experiments were completed when the weight of the sequent samples reached the same weight. The powder was obtained by grinding the dried material for one minute in a home type blender (Tefal Smart, MB450141, Turkey). Then, the powders were stored in heat-sealed aluminum-laminated multilayer commercial polyethylene packaging materials in the dark at room temperature until further tests were carried out.

Mathematical modeling of the drying data

The moisture ratio (MR) of the red beet puree samples was calculated during the microwave drying using equation (1).

$$\mathrm{MR} = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

Where M_0, M_t, and M_e represent the initial, anytime, and equilibrium moisture contents (kg water/kg dry matter, (DM)), respectively. The drying data was fitted to seven well-known thin layer drying models (Page, Jena and Das, Two Term Exponential, Diffusion, Midilli, Logarithmic, and Wang and Singh models) (Jaya and Das, 2007; Erbay and Icier, 2009). The coefficient of determination (R^2), root mean square error (RMSE), and the reduced chi-square (χ^2) values were determined according to Ergün et al. (2016). The higher values of the coefficient of determination (R^2) and the lower values of the root mean square error (RMSE), and reduced chi-square (χ^2) were chosen for the goodness of fit (Celma et al., 2008).

For the determination of the effective moisture diffusivity (D_{eff}) values of the red beet puree Fick's diffusion model (Eq. 2) was used:

$$MR = \frac{8}{\pi}\sum_{i=1}^{\infty}\frac{1}{(2i-1)^2}\exp\left[-(2i-1)^2\pi^2\frac{D_{eff}}{4L^2}t\right] \quad (2)$$

where t is the time (s), D_{eff} is the effective moisture diffusivity (m^2s^{-1}) and L (m) is the thickness of the sample. For long drying times (MR<0.6) (Crank, 1975), a limiting case of Eq. (3) is obtained, and expressed in a logarithmic form:

$$lnMR = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}\right)t \quad (3)$$

The effective moisture diffusivity is typically calculated by plotting the experimental moisture ratio versus the drying time. From Eq. (3), a plot of ln MR versus the drying time gives a straight line with the slope given in Eq. (4).

$$Slope = \frac{\pi^2 D_{eff}}{4L^2} \quad (4)$$

The modified Arrhenius type of exponential model as given in Eq. (5) is used for the calculation of effective moisture diffusivity.

$$D_{eef} = D_0\, exp\left(-E_a\,\frac{m}{p}\right) \quad (5)$$

Where D_{eff} is the effective moisture diffusivity (m^2. s^{-1}), D_0 is the pre-exponential factor ($m^2.s^{-1}$), E_a is the activation energy (W. g^{-1}), P is the microwave power (W) and m are the mass of the sample (g). The same form of the modified Arrhenius equation was also used for the determination of the reaction rate constant as given in Eq. (6):

$$k = k_0\, exp\left(-E_a\,\frac{m}{p}\right) \quad (6)$$

Where k is the drying rate constant obtained using the Page equation (min^{-1}), k_0 is the pre-exponential constant (min^{-1}), E_a is the activation energy (W. g^{-1}), P is the microwave power (W), and m is the mass of sample (g).

Determination of the energy efficiency of microwave drying

The energy consumption of the microwave drying processes was measured using a power measurement device (Makel M310.2218, Turkey). In order to determine the effectiveness of microwave drying the moisture extraction rate (MER) and specific energy consumption (SEC) values were calculated using the following equations (Eq. 7 and 8) (Chua et al., 2002; Jindarat et al., 2011)

$$MER = \frac{\textbf{Amount of water removed during drying (kg)}}{\textbf{Drying time (h)}} \quad (7)$$

$$SEC = \frac{\textbf{Total energy supplied in drying process (kJ)}}{\textbf{Amount of water removed during drying (kg)}} \quad (8)$$

Physical analyses

The moisture content of the fresh red beet puree and the red beet powders were determined according to AOAC (2000). The water activity and color values of the samples were measured using a Testo-AG 400, Germany, water activity measurement device and a Minolta CR-400 Colorimeter, Japan. The total color changes (ΔE), Chroma, and Browning Index (BI) values were calculated according to Pathare et al. (2013).

Statistical analysis

The data was analyzed using the statistical software SPSS 20.0 (SPSS Inc., Chicago, IL, U.S.A.). The data was also subjected to the analysis of variance (ANOVA) and Duncan's multiple range test (α=0.05) to determine the difference between means. The drying experiments were replicated twice, and all the analyses were triplicated.

RESULTS AND DISCUSSION

Drying curves

The drying characteristics of the red beet puree samples during microwave drying were determined from the mass loss in the samples of the known initial moisture content (87.00±0.01%, wet basis, wb). The drying experiments were conducted until the constant weight of the sample was obtained, and as expected, high amounts of moisture were removed in the early stages of drying and at the later stages, the removal of moisture decreased gradually. During the initial phase of the microwave drying, the absorption of microwave power is higher due to the higher moisture content of the red beet puree. Similar results were obtained by Demiray et al. (2017). The researchers reported that the moisture content of the onion slices was very high (89.83%) during the initial phase of the drying which resulted in higher absorption of microwave power (328, 447, and 557 W) and higher drying rates due to the higher moisture diffusion. The moisture ratio with respect to the drying time was calculated using the moisture content data and fitted to the thin layer drying models (Page, Jena and Das, Two Term Exponential, Diffusion, Midilli, Logarithmic, and Wang and Singh models). The summary of the model parameters and statistical evaluations (R^2, χ^2, and RMSE) are given in Table 1.

The higher values of the coefficient of determination (R^2) and the lower values of root mean square error (RMSE), and reduced chi-square (χ^2) should be chosen for the goodness of fit (Celma et al., 2008). The calculated R^2, RMSE, and χ^2 values ranged between 0.952 - 0.999, 0.0021 - 1.684, and 0.0001 – 1.3691, respectively. The lowest R^2 and highest RMSE, and χ^2 were obtained from the Midilli, Logarithmic, and Wang and Singh models. The Page model was chosen as the most suitable model for determining the microwave drying characteristics of the samples in different conditions. Although the average values of R^2 of the Page and Jena and Das model parameters were almost in the same range (0.980 - 0.999), the results indicated that the Page model has a higher R^2 and lower RMSE, and χ^2 values compared to the other models. The Page model was also found suitable for the determination of the drying characteristics of apple pomace (Wang et al., 2007a), celery leaves (Demirhan and Ozbek, 2011), onion (Demiray et al., 2017), carrot (Doymaz, 2004), and mint (Doymaz, 2006) in microwave oven drying. The experimental moisture ratio (EMR) and computed moisture ratio values of the Page model for five different microwave power settings and the amount of the samples are given in Fig. 1. (a-e with the order of increasing microwave power settings).

Table 1. The coefficients of the model equations obtained from the statistical analysis of the drying data

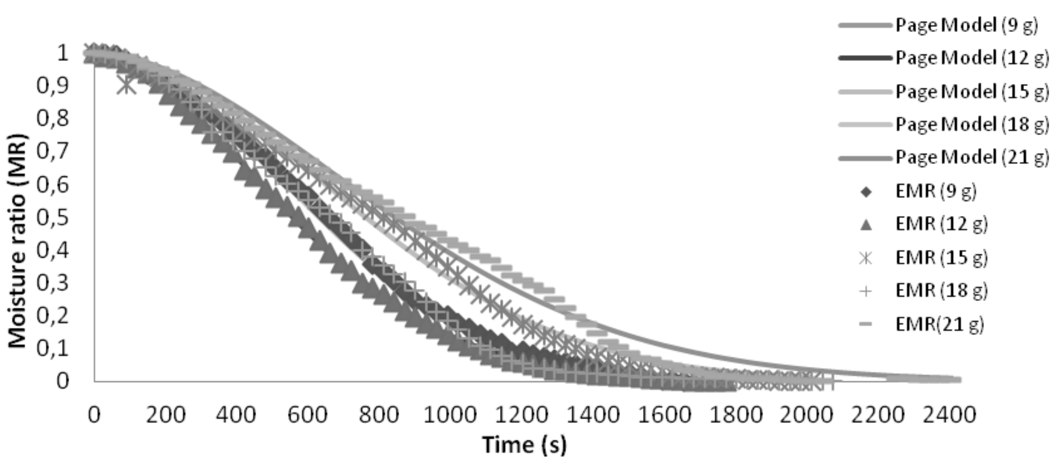
Sample Amount (g) *Miktarı (g)*	Microwave Power (W)	Page Model	Jena And Das Model	Two Term Exponential Model	Diffusion Model	Midilli Model	Logarithmic Model	Wang and Singh Model
9	180	k=2.540E-6 n=1.938 R^2=0.999 RMSE=0.0111 χ2=0.0001	k=0.003 a=-0.005 b=0.273 c=1.021 R^2=0.999 RMSE=0.6943 χ2=0.5185	k=0.002 a=2.200 R^2=0.986 RMSE=0.0735 χ2=0.0056	k=0.003 a=-89.405 b=0.986 R^2=0.990 RMSE=0.0465 χ2=0.0023	k=0.001 a=1.119 b=0.000 R^2=0.980 RMSE=0.1717 χ2=0.0311	k=0.001 a=1.635 b=-0.518 R^2=0.982 RMSE=0.1456 χ2=0.0224	a=-0.001 b=-1.648E-7 R^2=0.973 RMSE=0.1064 χ2=0.0117
	360	k=8.861E-7 n=2.271 R^2=0.994 RMSE=0.0307 χ2=0.0010	k=0.002 a=1.640 b=0.019 c=-0.689 R^2=0.992 RMSE=0.1256 χ2=0.0178	k=0.004 a=2.296 R^2=0.967 RMSE=0.0708 χ2=0.0053	k=0.006 a=-130.772 b=0.989 R^2=0.974 RMSE=0.0652 χ2=0.0046	k=0.001 a=1.126 b=0.000 R^2=0.977 RMSE=0.3688 χ2=0.1488	k=0.001 a=1.935 b=-0.826 R^2=0.979 RMSE=0.057 χ2=0.0036	a=-0.001 b=3.215E-7 R^2=0.967 RMSE=0.2841 χ2=0.0856
	540	k=1.627E-6 n=2.301 R^2=0.998 RMSE=0.0147 χ2=0.0002	k=0.005 a=1.132 b=0.045 c=-0.195 R^2=0.983 RMSE=0.0757 χ2=0.0068	k=0.006 a=2.287 R^2=0.974 RMSE=0.0683 χ2=0.0051	k=0.008 a=-126.567 b=0.989 R^2=0.980 RMSE=0.0535 χ2=0.0032	k=0.002 a=1.133 b=0.000 R^2=0.963 RMSE=0.2464 χ2=0.0689	k=0.002 a=1.676 b=-0.543 R^2=0.965 RMSE=0.0929 χ2=0.0098	a=-0.002 b=9.337E-7 R^2=0.954 RMSE=0.1095 χ2=0.0130
	720	k=8.612E-5 n=1.887 R^2=0.996 RMSE=0.0222 χ2=0.0006	k=0.013 a=1.016 b=0.078 c=-0.032 R^2=0.990 RMSE=0.0349 χ2=0.0016	k=0.013 a=2.236 R^2=0.993 RMSE=0.0309 χ2=0.0011	k=0.018 a=-71.951 b=0.982 R^2=0.995 RMSE=0.0257 χ2=0.0008	k=0.008 a=1.129 b=0.000 R^2=0.964 RMSE=0.0760 χ2=0.0069	k=0.007 a=1.206 b=-0.081 R^2=0.967 RMSE=0.0646 χ2=0.0050	a=-0.005 b=6.127E-6 R^2=0.969 RMSE=0.0657 χ2=0.0049
	900	k=2.751E-5 n=1.990 R^2=0.999 RMSE=0.0077 χ2=0.0006	k= k= 0.007 a=1.196 b=0.044 c=-0.213 R^2=0.995 RMSE=0.0619 χ2=0.0050	k=0.009 a=2.249 R^2=0.990 RMSE=0.0420 χ2=0.0020	k=0.013 a=-103.717 b=0.987 R^2=0.993 RMSE=0.0333 χ2=0.0013	k=0.005 a=1.131 b=0.000 R^2=0.968 RMSE=0.1170 χ2=0.0167	k=0.004 a=1.354 b=-0.226 R^2=0.971 RMSE=0.0667 χ2=0.0054	a=-0.004 b=3.733E-6 R^2=0.972 RMSE=0.0688 χ2=0.0054
12	180	k=8.188E-6 n=1.795 R^2=0.999 RMSE=0.0074 χ2=0.0001	k=0.003 a=-0.012 b=0.235 c=1.046 R^2=0.999 RMSE=0.1017 χ2=0.0110	k=0.003 a=2.165 R^2=0.992 RMSE=0.0044 χ2=0.0649	k=0.004 a=-80.913 b=0.985 R^2=0.995 RMSE=0.0485 χ2=0.0025	k=0.001 a=1.128 b=0.000 R^2=0.982 RMSE=0.2071 χ2=0.0452	k=0.001 a=1.398 b=-0.274 R^2=0.983 RMSE=0.0599 χ2=0.0038	a=-0.001 b=2.864E-7 R^2=0.979 RMSE=0.1122 χ2=0.0130
	360	k=7.132E-7 n=2.253 R^2=0.999 RMSE=0.0116 χ2=0.0001	k=0.002 a=1.251 b=0.031 c=-0.330 R^2=0.989 RMSE=0.1469 χ2=0.0243	k=0.003 a=2.291 R^2=0.976 RMSE=0.0838 χ2=0.0074	k=0.005 a=-111.752 b=0.988 R^2=0.982 RMSE=0.0545 χ2=0.0032	k=0.001 a=1.121 b=0.000 R^2=0.975 RMSE=0.2995 χ2=0.0978	k=0.001 a=2.293 b=-1.170 R^2=0.976 RMSE=0.2280 χ2=0.0567	a=-0.001 b=1.095E-7 R^2=0.963 RMSE=0.1220 χ2=0.0158
	540	k=1.316E-5 n=1.903 R^2=0.998 RMSE=0.0162 χ2=0.0003	k=0.004 a=1.117 b=0.034 c=-0.163 R^2=0.991 RMSE=0.0471 χ2=0.0026	k=0.005 a=2.187 R^2=0.985 RMSE=0.0455 χ2=0.0022	k=0.007 a=-88.890 b=0.986 R^2=0.989 RMSE=0.0398 χ2=0.0018	k=0.002 a=1.113 b=0.000 R^2=0.978 RMSE=0.1882 χ2=0.0395	k=0.002 a=1.505 b=-0.394 R^2=0.980 RMSE=0.0724 χ2=0.0059	a=-0.002 b=8.936E-7 R^2=0.975 RMSE=0.0570 χ2=0.0035
	720	k=6.081E-5 n=1.750 R^2=0.996 RMSE=0.0221 χ2=0.0005	k=0.005 a=1.122 b=0.034 c=-0.142 R^2=0.994 RMSE=0.0332 χ2=0.0013	k=0.007 a=2.131 R^2=0.987 RMSE=0.0426 χ2=0.0020	k=0.009 a=-84.005 b=0.987 R^2=0.990 RMSE=0.0362 χ2=0.0015	k=0.003 a=1.098 b=0.000 R^2=0.983 RMSE=0.1649 χ2=0.0315	k=0.003 a=1.392 b=-0.298 R^2=0.985 RMSE=0.0533 χ2=0.0033	a=-0.003 b=2.035E-6 R^2=0.985 RMSE=0.0506 χ2=0.0028
	900	k=1.817E-5 n=2.143 R^2=0.998 RMSE=0.0154 χ2=0.0003	k=0.009 a=-0.026 b=0.371 c=1.076 R^2=0.981 RMSE=0.0697 χ2=0.0062	k=0.011 a=2.236 R^2=0.984 RMSE=0.0024 χ2=0.0465	k=0.015 a=-112.204 b=0.988 R^2=0.988 RMSE=0.0447 χ2=0.0024	k=0.003 a=1.135 b=0.000 R^2=0.952 RMSE=0.0909 χ2=0.0098	k=0.006 a=1.233 b=-0.103 R^2=0.955 RMSE=0.0766 χ2=0.0070	a=-0.005 b=5.256E-6 R^2=0.967 RMSE=0.1293 χ2=0.0187

Table 1. continuing

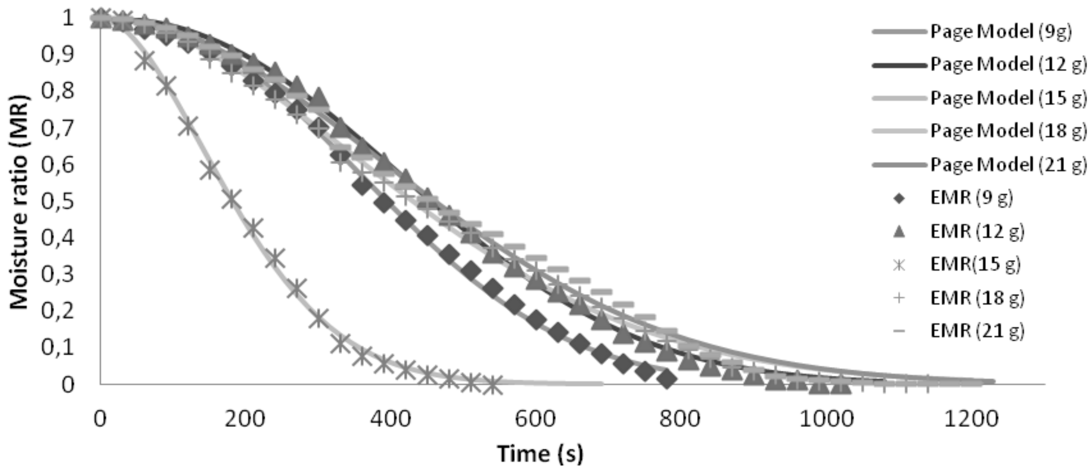
Sample Amount (g) *Miktarı (g)*	Microwave Power (W)	Page Model	Jena And Das Model	Two Term Exponential Model	Diffusion Model	Midilli Model	Logarithmic Model	Wang and Singh Model
15	180	k=2.104E-6 n=1.915 R^2=0.992 RMSE=0.0111 χ2=0.0001	k=0.003 a=-0.003 b=0.264 c=0.986 R^2=0.998 RMSE=0.0217 χ2=0.0005	k=0.002 a=0.002 R^2=0.973 RMSE=0.6948 χ2=0.5054	k=0.003 a=-94.281 b=0.988 R^2=0.978 RMSE=0.0799 χ2=0.0067	k=0.001 a=1.059 b=0.000 R^2=0.988 RMSE=0.1189 χ2=0.0148	k=0.001 a=3.238 b=-2.177 R^2=0.989 RMSE=0.4047 χ2=0.1714	a=-0.001 b=2.114E-8 R^2=0.985 RMSE=0.4414 χ2=0.2009
	360	k=6.706E-5 n=1.778 R^2=0.997 RMSE=0.0249 χ2=0.0006	k=0.004 a=-0.090 b=0.205 c=1.182 R^2=0.983 RMSE=0.0441 χ2=0.0022	k=0.008 a=2.174 R^2=0.992 RMSE=1.1120 χ2=1.3691	k=0.011 a=-92.927 b=0.987 R^2=0.994 RMSE=0.0266 χ2=0.0008	k=0.005 a=1.148 b=-0.00001 R^2=0.975 RMSE=0.0536 χ2=0.0032	k=0.005 a=1.221 b=-008 R^2=0.978 RMSE=0.7627 χ2=0.6464	a=-0.003 b=2.326E-6 R^2=0.975 RMSE=0.1653 χ2=0.0293
	540	k=1.339E-5 n=1.930 R^2=0.997 RMSE=0.0175 χ2=0.0003	k=0.006 a=-0.010 b=0.348 c=1.046 R^2=0.997 RMSE=0.3079 χ2=0.1044	k=0.005 a=2.221 R^2=0.987 RMSE=0.0512 χ2=0.0029	k=0.007 a=-93.789 b=0.987 R^2=0.990 RMSE=0.0409 χ2=0.0019	k=0.003 a=1.142 b=0.000 R^2=0.972 RMSE=0.1071 χ2=0.0128	k=0.002 a=1.377 b=-0.239 R^2=0.974 RMSE=0.7315 χ2=0.5924	a=-0.002 b=1.257E-6 R^2=0.972 RMSE=0.1057 χ2=0.0119
	720	k=2.509E-5 n=2.101 R^2=0.997 RMSE=0.0181 χ2=0.0004	k=0.006 a=-0.091 b=0.243 c=1.192 R^2=0.966 RMSE=0.1857 χ2=0.0417	k=0.012 a=2.312 R^2=0.990 RMSE=0.0343 χ2=0.0014	k=0.017 a=-98.959 b=0.986 R^2=0.993 RMSE=0.0288 χ2=0.0010	k=0.007 a=1.166 b=0.000 R^2=0.958 RMSE=0.0876 χ2=0.0088	k=0.007 a=1.234 b=-0.073 R^2=0.962 RMSE=0.7464 χ2=0.6407	a=-0.004 b=4.489E-6 R^2=0.954 RMSE=0.1890 χ2=0.041
	900	k=0.0001 n=1.707 R^2=0.998 RMSE=0.0493 χ2=0.0027	k=0.007 a=-0.030 b=0.327 c=1.073 R^2=0.995 RMSE=0.1814 χ2=0.0407	k=0.009 a=2.134 R^2=0.992 RMSE=1.0647 χ2=1.3226	k=0.012 a=-86.928 b=0.987 R^2=0.994 RMSE=0.0275 χ2=0.0009	k=0.005 a=1.115 b=0.000 R^2=0.977 RMSE=0.0939 χ2=0.0103	k=0.005 a=1.238 b=-0.128 R^2=0.980 RMSE=0.7180 χ2=0.6014	a=-0.004 b=3.730E-6 R^2=0.988 RMSE=0.0498 χ2=0.0028
18	180	k=2.302E-6 n=1.957 R^2=0.996 RMSE=0.0021 χ2=0.0001	k=0.004 a=-0.004 b=0.285 c=1.012 R^2=0.998 RMSE=0.2636 χ2=0.0738	k=0.002 a=2.199 R^2=0.980 RMSE=0.0367 χ2=0.0014	k=0.003 a=-95.018 b=0.987 R^2=0.985 RMSE=0.0224 χ2=0.0005	k=0.001 a=1.124 b=0.000 R^2=0.977 RMSE=0.1086 χ2=0.0123	k=0.001 a=1.588 b=-0.466 R^2=0.978 RMSE=0.4015 χ2=0.1614	a=-0.001 b=1.858E-7 R^2=0.970 RMSE=0.3688 χ2=0.1488
	360	k=1.022E-5 n=1.835 R^2=0.996 RMSE=0.0179 χ2=0.0003	k=0.004 a=-0.009 b=0.286 c=1.035 R^2=0.999 RMSE=0.2392 χ2=0.0636	k=0.003 a=2.175 R^2=0.986 RMSE=0.0591 χ2=0.0038	k=0.005 a=-84.341 b=0.986 R^2=0.989 RMSE=0.0311 χ2=0.0011	k=0.001 a=1.110 b=0.000 R^2=0.985 RMSE=0.2757 χ2=0.0821	k=0.001 a=1.582 b=-0.474 R^2=0.986 RMSE=0.1452 χ2=0.1234	a=-0.001 b=3.898E-7 R^2=0.980 RMSE=0.265 χ2=0.0561
	540	k=3.636E-5 n=1.735 R^2=0.997 RMSE=0.0181 χ2=0.0004	k=0.005 a=-0.014 b=0.302 c=1.044 R^2=0.998 RMSE=0.1659 χ2=0.0316	k=0.005 a=2.137 R^2=0.989 RMSE=0.0372 χ2=0.0015	k=0.007 a=-84.520 b=0.987 R^2=0.992 RMSE=0.0408 χ2=0.0018	k=0.002 a=1.111 b=0.000 R^2=0.983 RMSE=0.1809 χ2=0.0363	k=0.002 a=1.382 b=-0.275 R^2=0.985 RMSE=0.2516 χ2=0.1234	a=-0.002 b=1.032E-6 R^2=0.984 RMSE=0.3524 χ2=0.2478
	720	k=2.111E-5 n=1.930 R^2=0.990 RMSE=0.0322 χ2=0.0011	k=0.006 a=1.079 b=0.045 c=-0.115 R^2=0.985 RMSE=0.0439 χ2=0.0023	k=0.007 a=2.189 R^2=0.974 RMSE=0.0577 χ2=0.0038	k=0.009 a=-119.350 b=0.990 R^2=0.979 RMSE=0.0517 χ2=0.0030	k=0.004 a=1.131 b=0.000 R^2=0.963 RMSE=0.1019 χ2=0.0118	k=0.003 a=1.347 b=-0.220 R^2=0.971 RMSE=0.1129 χ2=0.0315	a=-0.003 b=2.042E-6 R^2=0.976 RMSE=0.4561 χ2=0.2345
	900	k=0.0011 n=1.830 R^2=0.991 RMSE=0.2431 χ2=0.0768	k=0.006 a=-0.084 b=0.252 c=1.157 R^2=0.980 RMSE=0.0606 χ2=0.0053	k=0.012 a=2.192 R^2=0.983 RMSE=0.0415 χ2=0.0024	k=0.016 a=-107.779 b=0.989 R^2=0.986 RMSE=0.0382 χ2=0.0020	k=0.007 a=1.133 b=0.000 R^2=0.968 RMSE=0.0774 χ2=0.0082	k=0.007 a=1.218 b=-0.097 R^2=0.972 RMSE=0.1266 χ2=0.0548	a=-0.005 b=4.866E-6 R^2=0.971 RMSE=0.3888 χ2=0.2578

Table 1. continuing

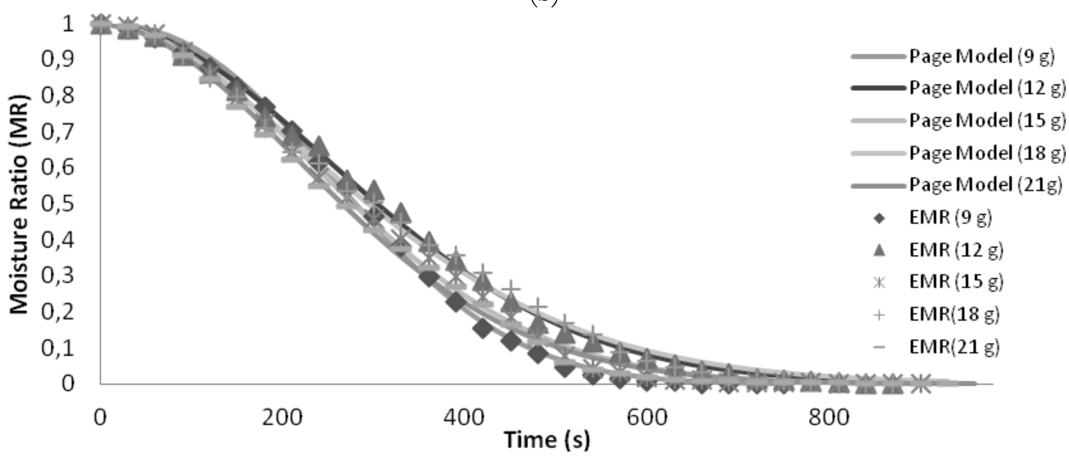
Sample Amount (g) *Miktarı (g)*	Microwave Power (W)	Page Model	Jena And Das Model	Two Term Exponential Model	Diffusion Model	Midilli Model	Logarithmic Model	Wang and Singh Model
21	180	k=3.303E-6 n=1.819 R^2=0.989 RMSE=0.0112 χ2=0.0001	k=0.004 a=-0.020 b=0.154 c=1.054 R^2=0.998 RMSE=1.0628 χ2=1.1852	k=0.002 a=2.121 R^2=0.976 RMSE=0.0135 χ2=0.0002	k=0.002 a=-70.502 b=0.984 R^2=0.980 RMSE=0.0393 χ2=0.0616	k=0.001 a=1.049 b=-0.001 R^2=0.997 RMSE=1.0851 χ2=1.2206	k=0.001 a=24.006 b=-22.957 R^2=0.997 RMSE=1.684 χ2=1.259	a=-0.001 b=4.509E-8 R^2=0.994 RMSE=0.4288 χ2=0.1699
	360	k=4.011E-6 n=1.967 R^2=0.996 RMSE=0.0180 χ2=0.0003	k=0.005 a=-0.006 b=0.307 c=1.034 R^2=0.998 RMSE=0.2446 χ2=0.0659	k=0.003 a=2.235 R^2=0.983 RMSE=0.0551 χ2=0.0033	k=0.005 a=-98.789 b=0.987 R^2=0.987 RMSE=0.0282 χ2=0.0009	k=0.002 a=1.133 b=0.000 R^2=0.978 RMSE=0.2659 χ2=0.0759	k=0.001 a=1.583 b=-0.452 R^2=0.979 RMSE=0.5423 χ2=0.2568	a=-0.001 b=3.501E-7 R^2=0.970 RMSE=0.2458 χ2=0.1988
	540	k=2.030E-5 n=1.868 R^2=0.998 RMSE=0.0152 χ2=0.0003	k=0.006 a=-0.018 b=0.302 c=1.070 R^2=0.996 RMSE=0.2238 χ2=0.0573	k=0.006 a=2.205 R^2=0.989 RMSE=0.0322 χ2=0.0011	k=0.008 a=-92.375 b=0.987 R^2=0.992 RMSE=0.0284 χ2=0.0009	k=0.003 a=1.150 b=0.000 R^2=0.972 RMSE=0.1051 χ2=0.0122	k=0.003 a=1.304 b=-0.159 R^2=0.974 RMSE=0.1049 χ2=0.0198	a=-0.002 b=1.413E-6 R^2=0.977 RMSE=0.3548 χ2=0.1248
	720	k=3.046E-6 n=2.329 R^2=0.999 RMSE=0.0104 χ2=0.0001	k=0.007 a=-0.025 b=0.322 c=1.105 R^2=0.981 RMSE=0.1349 χ2=0.0214	k=0.008 a=2.317 R^2=0.981 RMSE=0.0445 χ2=0.0022	k=0.011 a=-126.193 b=0.989 R^2=0.986 RMSE=0.0399 χ2=0.0018	k=0.005 a=1.184 b=0.000 R^2=0.948 RMSE=0.0811 χ2=0.0074	k=0.004 a=1.298 b=-0.119 R^2=0.952 RMSE=0.0854 χ2=0.0064	a=-0.003 b=2.586E-6 R^2=0.959 RMSE=0.3690 χ2=0.1587
	900	k=4.253E-5 n=1.875 R^2=0.998 RMSE=0.0138 χ2=0.0002	k=0.007 a=-0.029 b=0.318 c=1.089 R^2=0.991 RMSE=0.0514 χ2=0.0032	k=0.008 a=2.208 R^2=0.991 RMSE=0.0352 χ2=0.0014	k=0.012 a=-87.314 b=0.986 R^2=0.994 RMSE=0.0319 χ2=0.0012	k=0.005 a=1.146 b=0.000 R^2=0.968 RMSE=0.0786 χ2=0.0071	k=0.005 a=1.250 b=-0.110 R^2=0.971 RMSE=0.0687 χ2=0.1688	a=-0.004 b=3.082E-6 R^2=0.978 RMSE=1.2588 χ2=0.6845



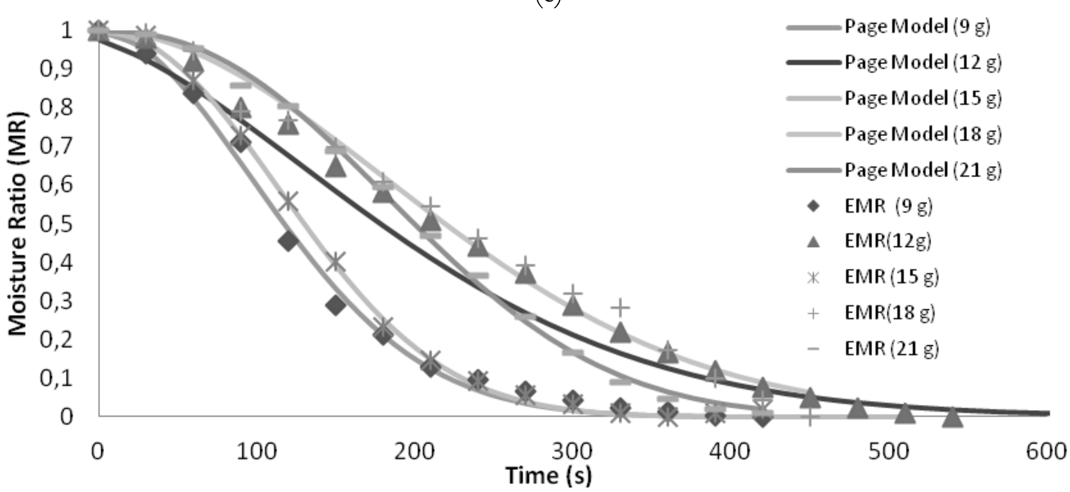
(a)


Moisture ratio (MR)
Time (s)
Page Model (9g)
Page Model (12 g)
Page Model (15 g)
Page Model (18 g)
Page Model (21 g)
EMR (9 g)
EMR (12 g)
EMR(15 g)
EMR (18 g)
EMR (21 g)

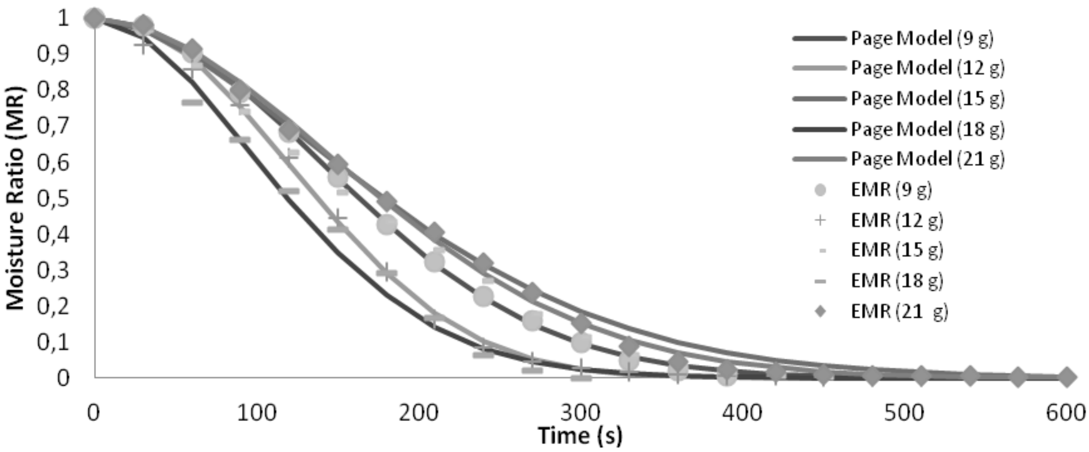
(b)


Moisture Ratio (MR)
Time (s)
Page Model (9 g)
Page Model (12 g)
Page Model (15 g)
Page Model (18 g)
Page Model (21g)
EMR (9 g)
EMR (12 g)
EMR (15 g)
EMR(18 g)
EMR(21 g)

(c)


Moisture Ratio (MR)
Time (s)
Page Model (9 g)
Page Model (12 g)
Page Model (15 g)
Page Model (18 g)
Page Model (21 g)
EMR (9 g)
EMR(12g)
EMR (15 g)
EMR(18 g)
EMR (21 g)

(d)

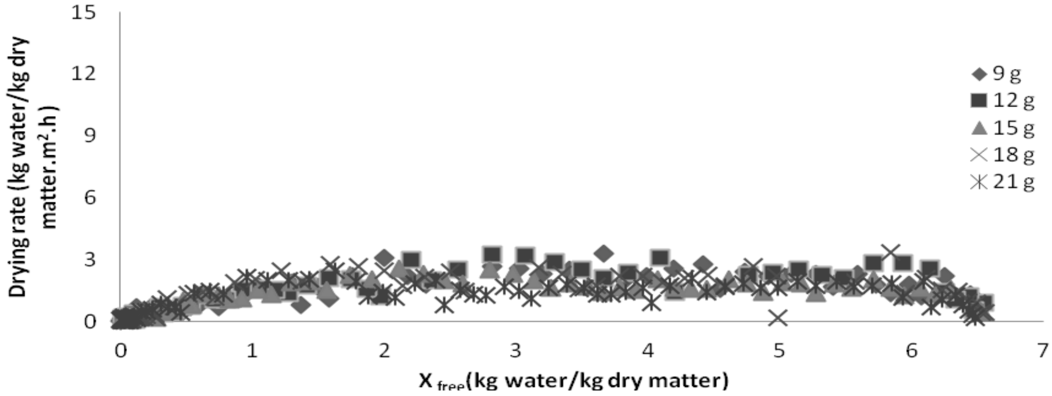


(e)

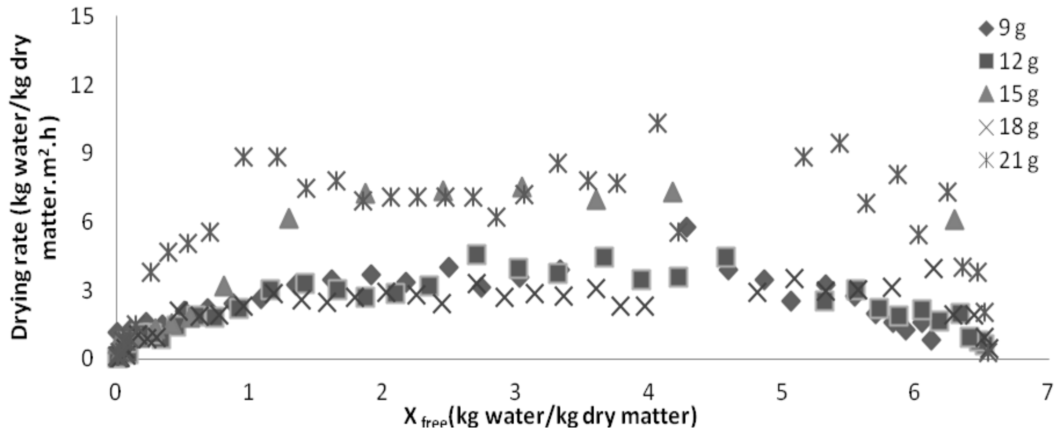
Fig. 1. The experimental moisture ratio values of red beet puree at different microwave powers ((a) 180W, (b) 360W, (c) 540W, (d) 720W and (e) 900W)

According to Fig. 1., it can be seen that the drying time decreased depending on the increase of microwave power and the drying time of the samples dried at 900W was found to be less than half of the drying time of the samples that are dried at 180W. It may be due to the rapid mass transfer in the sample at the high microwave power due to higher generation in the sample. For this reason, the higher generation rate may result in a higher evaporation rate and lower drying time. Similar results were obtained by Süfer et al. (2017), who studied the microwave drying of onion slices of two different thicknesses (3 and 7mm) and three different microwave power settings (80, 240, and 400W). The researchers reported that the internal water heating and evaporation rate were influenced by the microwave power and thus, a higher vapor pressure difference occurs in the center and surface of the samples. The drying time, when the moisture ratio reached 0.5, was measured as between 11.0 - 14.5, 6.5 - 7.5, 5.0 - 5.5, 1.8 - 3.2, and 2.8 - 2.9 min for red beet puree at the output power settings of 180, 360, 540, 720, and 900W, respectively (Fig. 1), accounting for 35.4 - 40.7%, 37.5 - 50.0%, 35.5 - 40.0%, 26.2 - 45.3%, and 25.4 - 41.1% of the corresponding total drying time. Increasing the mass of the sample resulted in a longer drying time. Similar results were obtained by Süfer et al., 2017, and Dadali et al., 2007a.

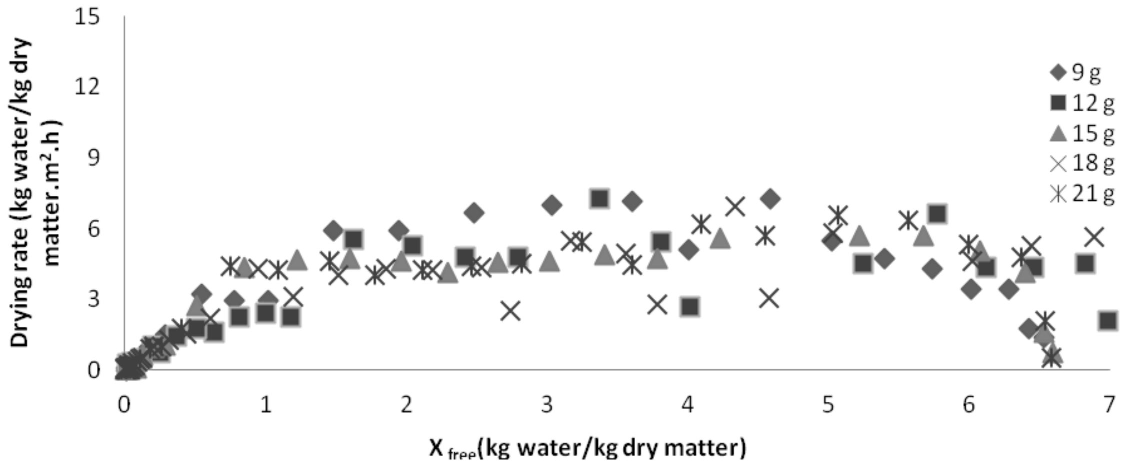
The drying rates were calculated (kg water/kg dry matter.h.m^2) and plotted against the free moisture content (kg water/kg dry matter) as shown in Fig. 2. (a - e with the order of increasing microwave power settings).



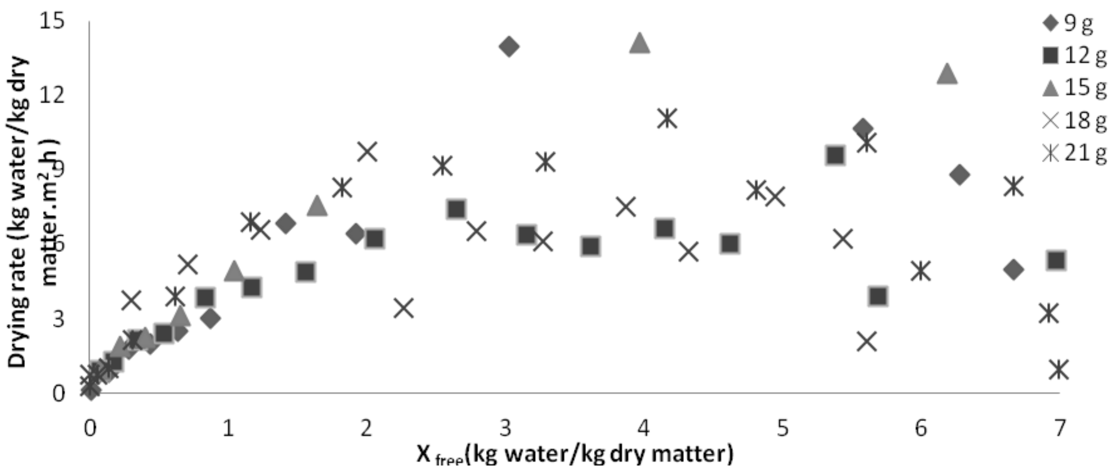
(a)


15
12
9
6
3
0
Drying rate (kg water/kg dry matter.m².h)
0
1
2
3
4
5
6
7
X free(kg water/kg dry matter)
9 g
12 g
15 g
18 g
21 g

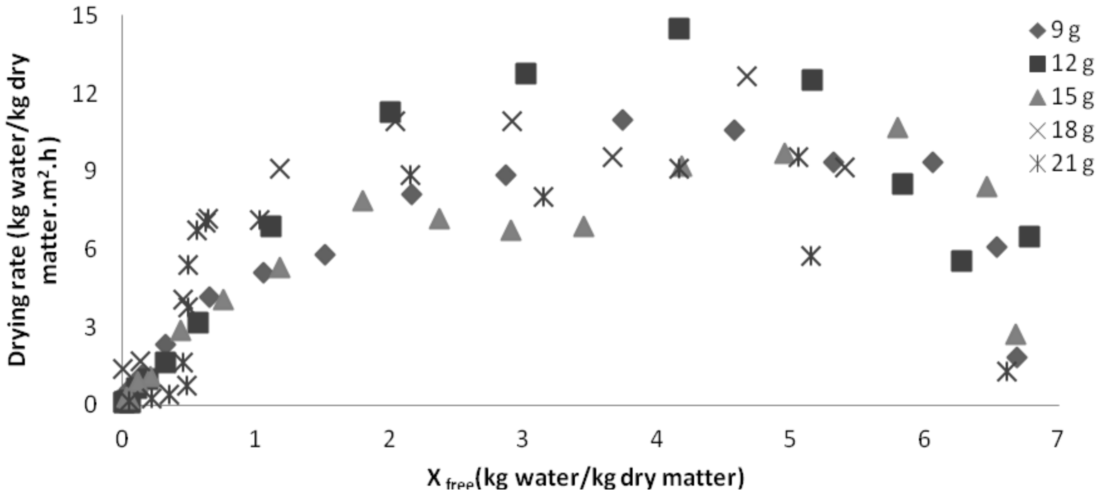
(b)


15
12
9
6
3
0
Drying rate (kg water/kg dry matter.m².h)
0
1
2
3
4
5
6
7
X free(kg water/kg dry matter)
9 g
12 g
15 g
18 g
21 g

(c)


15
12
3
0
Drying rate (kg water/kg dry matter.m².h)
0
1
2
3
4
5
6
7
X free(kg water/kg dry matter)
9 g
12 g
15 g
18 g
21 g

(d)



(e)

Fig. 2. The drying rate of red beet puree versus free moisture content at different microwave powers ((a) 180W, (b) 360W, (c) 540W, (d) 720W and (e) 900W)

As can be seen from Fig. 2, the drying rate behavior can be defined to take place in a combined form of constant and falling rate regions. The drying rates significantly increased with the increasing microwave power ($P<0.05$), however, the dependence on the amount of sample is not clearly defined. At the same time, for all the drying experiments it can be stated that drying takes places mostly in the falling rate period. The higher drying rate of red beet puree was observed at the initial phase of the drying due to the higher moisture diffusion. As the drying progressed, the moisture loss caused a decrease in the absorption of microwave power and resulted in a lower drying rate. This observation is in agreement with previous reports on thin-layer drying of biological products such as apple pomace (Wang et al., 2007a), onion (Demiray et al., 2017), pumpkin (Wang et al., 2007b), and olive pomace (Sadi and Meziane, 2015). The drying rate increased with the increase in microwave output power and the highest values of drying rate were obtained during the experiment at 900W. The higher microwave power resulted in higher rates of evaporation and moisture loss which is related to the drying rate. Therefore, the microwave power level has an important effect on drying rates. It may be due to the high evaporation rate at the higher microwave power settings. Our results are in agreement with Maskan (2000), Sharma and Prasad, (2006), Alibas -Özkan et al. (2007), Sadi and Meziane (2015), and Demiray et al. (2017). In addition, Maskan, (2000) reported that the higher drying rates observed for products processed by microwaves due to the internal heat generation caused by microwaves establishing a greater vapor pressure difference between the surface and center of the product, thus increasing the product's moisture diffusivity.

It has been accepted that the drying characteristics of biological products in the falling rate period can be described using Fick's diffusion equation (Wang et al., 2007a). The D_{eff} values of microwave dried red beet puree samples placed as a thin layer were calculated from the Fick's diffusion model and the results were given in Table 2.

As can be seen in Table 2, the D_{eff} values generally increased with increasing microwave power settings as expected and only for the samples with the thickness of 6 mm (18g), a decrease of D_{eff} was observed which finally increased to the microwave power of 900 W. Thus, the drying rate can be increased, and the drying time can be shortened by using higher microwave power settings, which increase the D_{eff} values (Sadi and Meziane, 2015). The results are also consistent with Demiray et al. (2017). Where the researchers reported that this increase may be due to higher heating energy, which would increase the activity of the water molecules leading to higher moisture diffusivity when the samples were dried at higher microwave power settings (Chua et al., 2002). The D_{eff} values of the red beet powder ranged between 1.095E-8 and 3.438E-6 $m^2 s^{-1}$ which is in the same range as (10E−12 to 10E−6 $m^2. s^{-1}$) most foods (Erbay and İcier, 2009). The D_{eff} values of the microwave dried apple pomace (150 – 600 W), okra (180 – 900 W), spinach (180 – 900 W), and onion slices (328, 447, and 557 W) ranged between 1.05E-8 - 3.69E-8 $m^2. s^{-1}$ (Wang et al., 2007a), 2.05E-9 – 11.91E-9 $m^2. s^{-1}$ (Dadalı et al., 2007a), 7.6E-11 – 52.4E-11 $m^2. s^{-1}$ (Dadali et al., 2007b), and 2.59E-7 - 5.08E-7 $m^2 .s^{-1}$ (Demiray et al., 2017). The D_{eff} values generally increased depending on the increasing microwave power settings and sample thickness. But, Süfer et al. (2017) reported that smaller slice thicknesses provided higher D_{eff} values during microwave dehydration. The differences between these two studies are mainly the differences in the food structure. For the samples in the form of puree, the water to be dehydrated is free for movement and in the mechanism of microwave drying more energy is absorbed due to the existence of more water in the increased sample thicknesses. On the other hand, the structure of the onion is compact, and the onion skins behave as a protective layer for moisture removal and for this reason a decrease in thickness of the slices increase the D_{eff} value.

Table 2. The estimated effective moisture diffusivity (D_{eff}), pre-exponential factor (D_0), and activation energy (E_a) values.

Sample Amount (g)	Microwave Power (W)	D_{eff} ($m^2.s^{-1}$)	R^2	Do ($m^2.s^{-1}$)	Ea ($W.g^{-1}$)	R^2
9	180	1.095E-08	0.991	9.40E-08	77.35	0.942
	360	1.461E-08	0.980			
	540	2.191E-08	0.949			
	720	4.382E-08	0.984			
	900	4.747E-08	0.975			
12	180	1.947E-08	0.983	2.20E-07	65.44	0.977
	360	2.596E-08	0.780			
	540	4.544E-08	0.977			
	720	3.246E-08	0.977			
	900	9.737E-08	0.988			
15	180	3.043E-08	0.977	2.36E-07	24.46	0.999
	360	3.438E-06	0.980			
	540	1.217E-07	0.981			
	720	1.420E-07	0.982			
	900	1.521E-07	0.971			
18	180	4.382E-08	0.972	1.78E-07	14.35	0.895
	360	2.921E-08	0.976			
	540	8.763E-08	0.971			
	720	5.842E-08	0.990			
	900	1.607E-07	0.972			
21	180	1.988E-08	0.976	6.61E-07	28.50	0.935
	360	1.988E-07	0.975			
	540	2.187E-07	0.976			
	720	2.783E-07	0.976			
	900	2.584E-07	0.985			

The activation energy is related to the temperature dependence of any rate operation, however, in microwave heating systems it is not possible to measure exact temperature values (Demiray et al., 2017). For this reason, the modified form of the Arrhenius equation (Eq. 5) was used for calculation of activation energy values which were changing between 14.35 - 77.35 W.g^{-1} and generally decreased depending on the increase in the amount of the sample. Süfer et al. (2017) reported that the activation energy values of onion slices in two different thicknesses (3 and 7 mm) range between 2.25 – 6.08 W.g^{-1} for microwave drying. The activation energy of spinach, onion, olive pomace, and corn husk were found to be 9.62 W. g^{-1} (Dadali et al., 2007b), 7.90 W. g^{-1} (Demiray et al., 2017), 20.98 W. g^{-1} (Sadi and Meziane, 2015), and 27.149 W. g^{-1} (Akdoğan et al., 2017).

In processes where energy is involved, the temperature dependence of the reaction rates (k) is expressed in terms of the Arrhenius equation. In this study, the modified form of the Arrhenius equation (Eq. 6) to relate to the dependence of k on m/P (g.W^{-1}) was used to calculate the activation energy (E_a) and it decreased with the increasing amount of the sample. According to Table 3., The activation energy values ranged between 26.13 and 222.60 W.g^{-1}. When the amount of the sample was kept constant while the microwave power used for the drying operation was changed the k_0 values changed between 4.45E-05 and 1.578E-04 min^{-1}. Where the k_0 values generally increased according to a decreasing amount of sample.

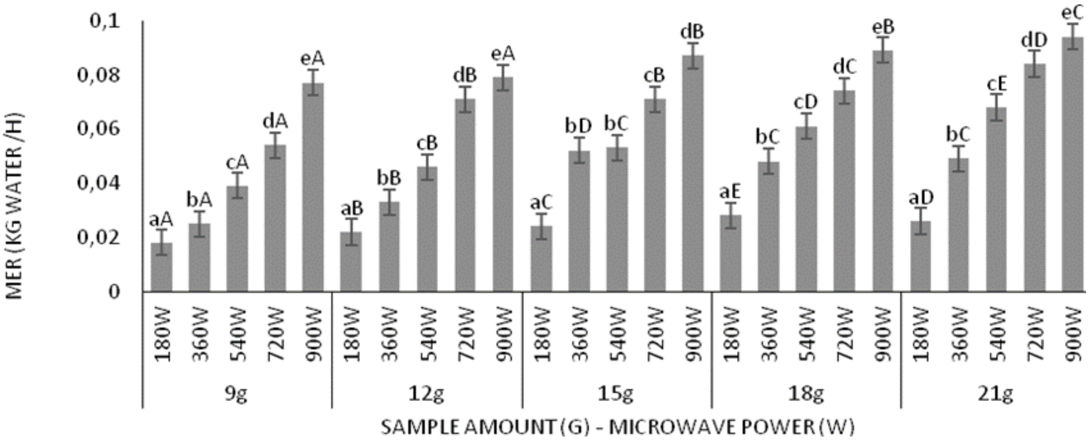
Table 3. The drying rate constant values (k), the pre-exponential constant (k_0), and activation energy (E_a) values.

Sample Amount (g)	Microwave Power (W)	k (min^{-1})	R^2	k_0 (min^{-1})	Ea (W.g^{-1})	R^2
9	180	2.540E-06	0.999	1.578E-04	222.60	0.832
	360	8.861E-07	0.994			
	540	1.627E-06	0.998			
	720	8.612E-05	0.996			
	900	2.751E-05	0.999			
12	180	8.188E-06	0.999	1.407E-04	166.00	0.869
	360	7.132E-07	0.999			
	540	1.316E-05	0.998			
	720	6.081E-05	0.996			
	900	1.817E-05	0.998			
15	180	2.104E-06	0.992	9.383E-05	47.10	0.836
	360	6.706E-05	0.997			
	540	1.339E-05	0.997			
	720	2.509E-05	0.997			
	900	1.000E-04	0.998			
18	180	2.302E-06	0.996	4.450E-05	29.58	0.999
	360	1.022E-05	0.996			
	540	3.636E-05	0.997			
	720	2.111E-05	0.990			
	900	1.100E-03	0.991			
21	180	3.303E-06	0.989	6.773E-05	26.13	0.985
	360	4.011E-06	0.996			
	540	2.060E-05	0.998			
	720	3.046E-06	0.999			
	900	4.253E-05	0.998			

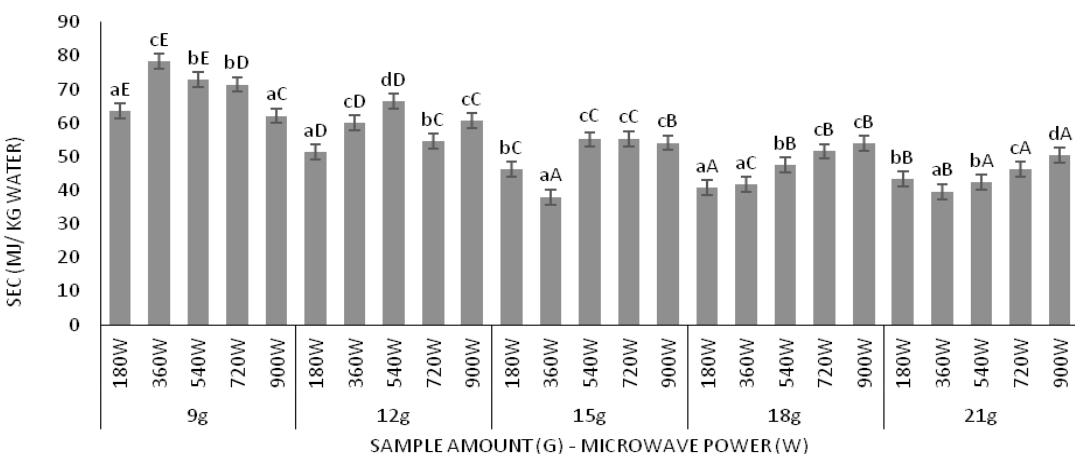
The results of the energy efficiency of microwave drying

Since drying is a highly energy-intensive process (due to the latent heat of evaporation required), it is important that the drying should be energy efficient (Varith et al., 2007). For this reason, energy efficiency and product quality have been identified as the key factors of research in drying studies. The energy consumption of the microwave oven at five different microwave power settings (expressed per unit amount of samples) ranged between 0.0094 and 0.0125 $kWh.g^{-1}$. The energy consumption increased according to the increasing microwave power settings and amount of sample due to longer drying times at the higher amount of sample and high energy consumption at high microwave power settings. Similar results were obtained by Alibas-Özkan et al. (2007). The researchers reported that the energy consumption of the microwave oven during the drying of spinach leaves at eight different microwave power settings (90 - 1000W) ranged between 0.16 and 0.26 kWh and the energy consumption at low microwave power levels yielded longer drying periods.

The MER and SEC values of the different amounts of red beet puree under various conditions of the microwave drying process are presented in Fig. 3.



(a)



(b)

Fig. 3. MER (a), and SEC (b) values (a - e; shows significant difference between the microwave power settings and A - E shows significant difference between the sample amount)

According to Fig 3, when the amount of sample is kept constant, the MER values of the samples generally increased depending on the increasing microwave power settings ($P<0.05$). It may be due to the quick absorption of energy of the water molecules at higher microwave power settings which caused the rapid evaporation of water. In this way, the total drying time decreased, and the MER values increased. At the same microwave power setting, the MER value generally increased depending on the increasing amount of sample ($P<0.05$). It may be due to a higher amount of evaporated water at the higher sample amounts. The thermal efficiency of a dryer is commonly defined in terms of its specific energy consumption (SEC) which indicates the quantity of heat required to evaporate a unit mass of water. The analysis of specific energy consumption during the applied microwave energy on the heating and drying processes has been investigated in many studies such as garlic cloves (Sharma and Prasad, 2006), peeled longan (Varith et al., 2007), and olive pomace (Sadi and Meziane, 2015). An increase in the amount of sample generally resulted in a decrease in the SEC values except for the 15g sample amount ($p<0.05$). When the amount of sample increased, the amount of water to be removed increased and as a result, the SEC value decreased. In addition, generally the lower moisture contents of a higher amount of dried samples which indicated the higher amount of evaporated water may also be the reason for the lower SEC values. In this study, the SEC values ranged between 37.98 and 78.43 $MJ.kg^{-1}$water. These values are in a comparable range with the values obtained during the drying of olive pomace (25.32 - 52.56 $MJ.kg^{-1}$water) (Sadi and Meziane, 2015). Sharma and Prasad, (2006), studied the microwave-convective drying (10 - 40W microwave power, 40 - 70°C drying air temperature and 1 and 2 $m.\ s^{-1}$ air velocity) of garlic cloves and reported that the microwave drying reduced the energy consumption due to the volumetric heating effect which causes a lower drying time. Baker and McKenzie, (2005), reported that the highly efficient dryers are characterized by lower SEC values. In this study, the lower SEC values were obtained at a 180 and 360W microwave power setting compared to other microwave power settings due to lower energy consumption, but in any case, when these values are to be used in efficiency evaluations the results should be considered together with drying data.

The results of the physical analyses

The moisture content and water activity values of the powders ranged between 2.48 and 7.38% (wb), and 0.172 and 0.447, respectively (Table 4). Results showed that the moisture content and water activity values of the red beet powders generally decreased with increasing microwave power settings and increased with an increasing amount of sample ($P<0.05$). The high microwave power increases the driving force of mass transfer and accelerates the rate of water vapor diffusion and may result in a lower moisture content and water activity of the red beet powders. The values of water activity under 0.6 is generally considered as microbiologically stable (Quek et al., 2007) and at 0.20 and 0.40 ensure the stability of the product against browning and hydrolytic reactions, lipid oxidation, auto-oxidation, and enzymatic activity (Marques et al., 2007). The measured water activity values of red beet powders are within acceptable limits for the safe storage of the products. The lowest moisture content values and the lowest water activity values were obtained from the samples which were dried at 900W. The color values of the fresh red beet and microwave dried red beet powders are given in Table 4. According to the results, significant differences were observed between the red beet puree and the red beet powders ($P<0.05$). Results showed that the increase of microwave power settings caused a generally significant increase in the L*, a*, ΔE, Chroma, and BI values of the red beet powders ($P<0.05$). At the higher microwave power settings, the degradation of the pigments or browning reactions are higher, and these may be related to the pigment destruction and may cause higher ΔE and BI values.

CONCLUSION

In this study, red beet powders were obtained using a microwave drying technique. The obtained powders will provide different application areas in addition to possible use of red beets outside of the production season and easy storage and transportation properties. Generally, the moisture content of the powders decreased with the increase of microwave power (2.60% at 900W and 5.40% at 180W on the average). On the evaluation of the seven thin layer drying models by comparing the R^2, χ^2, and RMSE, the Page model gave an excellent fitting to the drying data of the red beet puree. The drying time of the sample which has the highest amount of mass (21 gram) significantly decreases from the 2100s (180W) to 600s (900W) with an increase in the microwave power ($P<0.05$). The drying rate generally increased with the increase in microwave output power and the average drying rate values significantly increased from 2.08 kg water/kg dry matter.m^2.h (180W) to 14.50 kg water/kg dry matter.m^2.h (900W) with an increase in the microwave power setting ($P<0.05$). The k_0 values increased and D_0 values decreased generally according to the decreasing amount of the sample. The calculated MER values increased with the amount of sample and microwave power setting and the highest values ranged between 0.017 to 0.094 kg water.h^{-1}. Our results showed that increasing the microwave power setting caused a significant increase in the L*, a*, ΔE, Chroma, and BI values of the red beet powders ($P<0.05$).

Table 4. The moisture content, water activity, and color values of red beet puree and the powders

Sample		Microwave Power (W)	Moisture content (wb,%)	Water activity	Color Values					
					L*	a*	b*	ΔE	Chroma	BI
Fresh	Puree	-	80.01±0.01	0.999±0.00	14.89±0.30	16.43±0.14	3.94±0.17	-	14.96±0.14	-
Microwave Dried Red Beet Powder Sample Mass (g)	9	180	7.38±0.02^{ew}	0.447±0.005^{et}	29.96±0.05^{aw}	16.63±0.05^{aw}	2.10±0.13^{at}	15.18±0.25^{aw}	16.76±0.32^{aw}	44.05±0.45^{aw}
		360	4.95±0.05^{cx}	0.265±0.010^{ct}	30.74±0.10^{bw}	17.63±0. 53^{bw}	2.02±0.45^{aw}	16.01±0.18^{bx}	17.74±0.40^{bw}	44.64±0.12^{ax}
		540	3.33±0.02^{bx}	0.230±0.006^{bt}	35.94±0.19^{dx}	18.53±0.12^{cw}	4.14±0.05^{cw}	21.16±0.21^{cx}	19.08±0.50^{bw}	47.07±0.20^{bw}
		720	4.84±0.09^{dw}	0.292±0.006^{dt}	34.17±0.14^{cx}	19.53±0.10^{dw}	3.58±0.05^{bx}	19.54±0.45^{cx}	19.95±0.23^{cw}	49.24±0.12^{dx}
		900	2.56±0.01^{at}	0.203±0.013^{at}	40.12±0.05^{ey}	21.63±0.18^{ew}	5.07±0.26^{dw}	25.60±0.31^{dy}	21.24±0.24^{cw}	48.12±0.22^{ct}
	12	180	5.39±0. 44^{dt}	0.356±0. 035^{bt}	32.79±0. 27^{aw}	16.63±0. 63^{aw}	3.56±0. 24^{ct}	17.90±0.13^{aw}	17.00±0.25^{aw}	45.59±0.21^{cw}
		360	3.73±0. 17^{cw}	0.268±0. 106^{at}	32.57±0. 23^{ax}	17.63±0. 13^{bw}	1.81±0. 20^{aw}	17.84±0.20^{ay}	17.72±0.19^{bw}	41.58±0.28^{aw}
		540	3.99±0. 36^{cy}	0.338±0. 037^{bx}	35.47±0. 42^{bx}	18.79±0. 10^{cw}	6.09±0. 15^{dt}	20.81±0.16^{bx}	19.60±0.45^{cw}	54.40±0.27^{ey}
		720	2.96±0. 13^{bt}	0.312±0.061^{bt}	37.62±0. 16^{cy}	19.68±0. 09^{dw}	2.82±0. 11^{bw}	22.98±0.24^{cz}	19.83±0.19^{cw}	42.57±0.13^{bt}
		900	2.59±0. 19^{at}	0.250±0. 010^{at}	35.09±0. 09^{bw}	20.63±0. 17^{ew}	3.12±0. 12^{ct}	20.64±0.22^{bt}	20.86±0.35^{dt}	48.20±0.24^{dt}
	15	180	5.36±0. 08^{bt}	0.350±0. 022^{ct}	26.53±0. 07^{at}	16.63±1. 13^{aw}	2.43±0. 05^{cw}	11.73±0.15^{at}	16.81±0.24^{aw}	50.82±0.22^{bz}
		360	2.96±0. 10^{at}	0.343±0. 081^{ct}	27.65±0. 12^{bt}	17.63±0. 20^{bw}	2.31±0. 07^{bx}	12.92±0.24^{bt}	17.78±0.32^{bw}	50.51±0.27^{by}
		540	3.03±0.06^{aw}	0.340±0. 082^{cx}	29.02±0. 13^{ct}	18.93±0. 16^{cw}	5.48±0. 25^{dy}	14.37±0.23^{ct}	19.42±0.24^{cw}	63.74±0.28^{dz}
		720	2.97±0. 34^{at}	0.253±0. 092^{bt}	31.90±0. 07^{dt}	19.63±0. 16^{dw}	1.05±0.06^{at}	17.54±0.32^{dt}	19.65±0.29^{cw}	43.46±0.37^{aw}
		900	2.74±0. 06^{aw}	0.188±0. 090^{at}	33.76±0. 32^{et}	20.73±0. 25^{ew}	5.46±0. 15^{dw}	19.39±0.27^{et}	21.34±0.36^{dw}	58.37±0.25^{cx}
	18	180	5.37±0. 21^{dt}	0.348±0. 061^{bt}	33.86±0. 18^{ay}	11.43±0. 24^{at}	3.12±0. 12^{bx}	19.63±0.29^{by}	11.85±0.40^{at}	32.89±0.38^{bt}
		360	3.90±0. 08^{ct}	0.345±0. 090^{bt}	33.54±0.06^{by}	16.60±0. 12^{ct}	1.15±0. 05^{at}	18.85±0.24^{az}	16.64±0.27^{dt}	36.41±0.34^{ct}
		540	3.22±0. 12^{bw}	0.340±0. 094^{bx}	34.63±0. 06^{cw}	14.67±0. 19^{bt}	1.20±0. 23^{at}	20.00±0.28^{bw}	14.72±0.32^{bt}	32.04±0.12^{at}
		720	3.01±0. 13^{bt}	0.327±0. 101^{bt}	35.31±0. 13^{dx}	14.69±0. 16^{bt}	5.20±0. 21^{czz}	20.53±0.28^{cy}	15.58±0.30^{ct}	44.44±0.35^{dw}
		900	2.48±0. 12^{at}	0.187±0. 032^{at}	39.50±0. 46^{ey}	18.23±0. 13^{dt}	8.47±0. 16^{dy}	25.08±0.34^{dy}	20.10±0.47^{et}	55.89±0.43^{ew}
	21	180	5.20±0. 13^{ct}	0.387±0. 036^{ct}	29.96±0.06^{aw}	16.63±0. 16^{aw}	2.94±0. 34^{ax}	15.10±0.24^{az}	16.80±0.35^{aw}	47.31±0.27^{ay}
		360	3.06±0. 09^{bt}	0.268±0. 021^{bt}	30.79±0. 24^{bw}	17.63±0. 03^{bw}	4.12±0. 37^{by}	15.40±0.26^{aw}	18.11±0.36^{bw}	52.61±0.42^{dz}
		540	2.62±0. 03^{at}	0.258±0. 095^{bw}	34.42±0. 26^{dw}	18.63±0. 22^{cw}	4.50±0. 18^{bx}	19.66±0.26^{cw}	19.17±0.24^{cw}	50.33±0.30^{bx}
		720	2.73±0. 36^{at}	0.266±0. 052^{bt}	32.97±0. 13^{cw}	19.50±0. 23^{dw}	3.80±0. 09^{by}	18.36±0.35^{bw}	19.99±0.26^{dw}	51.73±0.28^{cy}
		900	2.63±0.06^{aw}	0.172±0. 020^{at}	37.01±0. 18^{ex}	20.89±0. 28^{ew}	7.36±0. 33^{c}	22.77±0.30^{dw}	21.90±0.34^{ew}	59.86±0.40^{ey}

Different letters (a–e) in the same column indicate significant difference between the microwave powers $P < 0.05$.
Different letters (t-z) in the same column indicate significant difference between the amounts of samples at $P < 0.05$.

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