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Microwave Drying of Jerusalem Artichoke (*Helianthus tuberosus L.*)

Erkan Karacabey[1], Cem Baltacıoğlu[2,3], Mete Çevik[2,4]

[1]Food Engineering Department, Engineering and Architecture Faculty, Süleyman Demirel University, Isparta, Turkey
[2]Department of Food Engineering of Faculty of Engineering, Middle East Technical University, Ankara, Turkey
[3]Department of Food Engineering, Faculty of Agriculture, Selcuk University, Konya, Turkey
[4]Agriculture and Fisheries Directorate, Ministry for EU Affairs, Ankara, Turkey

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✉ *Corresponding author (Yazışmalardan Sorumlu Yazar): erkankaracabey@sdu.edu.tr (E. Karacabey)*
✆ +90 246 211 16 68 🖷 +90 246 237 04 37

ABSTRACT

The potential use of microwave technique in drying process of Jerusalem artichoke (*Helianthus tuberosus L.*) slices was investigated and the results indicated the improvement in drying characteristics of artichoke slices through microwave oven. In addition to better appearance of dried artichoke slices, more than 200 folds increase and almost 155 folds decrease were observed in drying rate and drying time, respectively, when microwave technology was utilized. Additionally, process conditions were found to possess high influences on the microwave drying, especially the power effect was crucial due to its superior and adverse effects on process and product quality, respectively. Kinetic analysis were carried out for better understanding and description of drying processes operated in conventional oven and microwave one. The regression results indicated the similar success of three models, Page, Logarithmic and Midilli equations, for these purposes.

Key Words: Microwave drying, Jerusalem Artichoke, Drying kinetics, Midilli equation.

Yer Elmasının (*Helianthus tuberosus L.*) Mikrodalga ile Kurutulması

ÖZET

Mikrodalga tekniğinin yer elması (*Helianthus tuberosus L.*) dilimlerinin kurutulması prosesinde potansiyel kullanım olanağı araştırılmış ve sonuçların değerlendirilmesi, mikrodalga fırın ile yer elması dilimlerinin kurutulma karakteristiklerinde ilerleme sağlandığını göstermiştir. Kurutulmuş yer elması dilimlerinin daha iyi görünümlerine ek olarak, mikrodalga teknolojisi kullanıldığında, kurutma hızında ve kurutma zamanında sırasıyla, 200 kattan fazla artış ve 155 kattan fazla azalış gözlenmiştir. Ek olarak, proses koşullarının, mikrodalga ile kurutma işlemi üzerinde yüksek etkiye sahip olduğu bulunmuştur. Özellikle mikrodalga gücü, proses üzerindeki üstün ve ürün kalitesi üzerindeki olumsuz etkilerinden dolayı çok önemlidir. Mikrodalga fırında ve geleneksel kurutma fırınında gerçekleştirilen kurutma işlemlerinin daha iyi anlaşılması ve tanımlanması için kinetik analizleri yapılmıştır. Regresyon analizi sonuçları üç modellin, Page, Logaritmik ve Midilli eşitliklerinin, bu amaç için birbirine yakın derecede başarılı olduğunu göstermiştir.

Anahtar Kelimeler: Mikrodalga kurutma, Yer elması, Kurutma kinetiği, Midilli eşitliği

INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus L.*) has attracted a growing interest motivated by potential of this plant as a feedstock for the synthesis of a diverse cross section of new products, and by awareness of its significant health benefits. Jerusalem artichoke, including above- and belowground parts, is utilizable for various applications, like the tops for biomass and animal feed and the tubers as a feedstock for food and non-food chemical products. Structural difference of Jerusalem artichoke compared to other crops has created a pronounced influence on its economical value and utilization. Storage form of carbon is the difference of Jerusalem artichoke relative to the majority of crops storing carbon as starch, whereas inulin, a fructose polymer, is a carbon form of Jerusalem artichoke, primarily in tubers [1-3]. Distinctive properties and particular value of inulin is attributed to its nutritional contributions and low-calorie sweetener property [1,4]. This carbohydrate form is also included in diabetic foods, since inulin ingestion slightly influences blood sugar compared to other carbohydrates [1,5]. Besides to its positive contributions in food industry, inulin stands as a limiting constituent towards to the shelf-life of this plant material and its storage. It has been reported that storage of tubers promoted the degradation of inulin to some extent depending on the storage conditions. Additionally the degradation of inulin has also been observed as a result of the activity of inulase [6-8]. As a consequence the processing of this plant material has gained high importance. In this extend preservation techniques have become key points. One of the oldest and most cost-effective preservation methods for grains, crops and foods of all varieties is drying technology, which has been extensively examined in a wide range and new techniques have been developed. Microwave, relatively a new addition to the existing techniques, has been considered as a potential method for obtaining high quality dried food products, including fruits, vegetables and grains in this extent. Current studies have exhibited that drying of food material with microwave technology offers rapid, more uniform process and significant energy savings with a potential reduction in drying times of up to 50% and additionally avoiding undesired excessive surface temperature of treated material [9-11]. Some fruits and grains have been successfully dried by microwave technique and by a combination of microwave with other ones [9,10,12]. Studies have continued to improve and to optimize possible microwave applications in drying of food materials due to its high potential.

The objective of the present study was to examine one of the potential application areas of microwave energy, which was the drying of Jerusalem artichoke tubers. Drying characteristics of treated material were evaluated. Conventional oven drying of tuber was carried out to compare microwave with this method to establish the feasibility of replacing existing system with microwave drying.

MATERIALS and METHODS

Fresh Jerusalem artichoke tubers were supplied from market and stored in storage room at 4°C. Tubers were thoroughly hand peeled prior to dehydration process and sliced to desired thickness by using an adjustable knife. Sliced tubers were immediately weighed and placed into the dryer. All slices were sized in 30 mm × 40 mm dimensions to avoid the influence of change in an upper surface on process. Initial moisture content of Jerusalem artichoke was determined by placing tubers in a conventional oven at 105°C till no further change in weight of sample was observed. The initial average moisture content of Jerusalem artichoke tubers was determined as 81.77±0.89 %.

Drying

Conventional Oven Drying

Jerusalem artichoke slices (2 mm thickness) were placed into the preheated oven (Nüve EN 400, Ankara, Turkey) at air temperature of 50, 70, 80, and, 90°C to evaluate the influences of temperature on drying process. Tuber samples were sliced at 2, 4 and 6 mm in thickness and dried in the preheated oven at 70°C to evaluate the influences of slice thickness on the drying characteristics of treated material. Tuber slices were spread as a single layer on the tray attached to the balance (KERN (EW) EW-1500-2M with sensitivity of 0.01g, Germany). During drying, weight of sample was recorded at a regular time interval. Drying process continued until desired moisture content was achieved (<10%, w/w).

Microwave Drying

A programmable domestic microwave oven (Samsung-MW71E, Malaysia) with maximum output of 800 W and wavelength of 2450 MHz was used for drying of slices. The dimensions of the microwave cavity were 307×185×292 mm. Preweighed tuber slices were spread in a glass dish (dried and weighed before use) as a single layer and placed on the centre of a turntable of microwave cavity. The sample was hold in the microwave oven under determined conditions for a specified time interval, while drying took place. The sample was taken out at every 60 s interval by switching off the microwave oven and after weight of sample was recorded, it was replaced in the oven. Drying process proceeded until desired moisture content was achieved (<10%, w/w). Three slice thicknesses (2, 4, and 6 mm) and three power level (100, 200, and 300 W) were examined to determine their effects on drying.

Kinetic Modeling

The experimental drying data obtained through conventional oven drying and microwave oven drying were tried to explain by using empirical and semi-empirical models commonly used for the description of drying curves in literature (Table 1). The experimental moisture content data were expressed as the following dimensionless form, dimensionless moisture ratio (MR), (1);

$$MR = \frac{X_t - X_e}{X_0 - X_e} \quad (1)$$

where X_t is the moisture content at any time t (kg/kg dry solid); X_0 is the initial moisture content (kg/kg dry solid), and X_e is the equilibrium moisture content (kg/kg dry solid). The values of X_e are relatively small compared to X_t and X_0, hence the error involved in the simplification by assuming that X_e is equal to zero is negligible [13]. The drying rate is expressed as the amount of the evaporated moisture over time. The drying rates (DR, kg moisture/kg dry solid min) of Jerusalem artichoke tubers were calculated using the following equation (2):

$$DR = \frac{X_{t+dt} - X_t}{dt} \quad (2)$$

The proposed models were fitted to the experimental drying data (MR vs. time). Model adequacies were checked by nonlinear regression analysis performed by statistical software (Sigma Plot 2000, Version 6.00, Chicago, IL, USA). The goodness-of-fits of the models were assessed using adjusted determination coefficient (R^2 *adj*) and root mean square error (*RMSE*).

RESULTS and DISCUSSION

Drying of Jerusalem artichoke was investigated and microwave oven drying and conventional one were compared to represent the potential application of microwave technology in drying of artichoke tubers. Compared to the conventional process, microwave technology exhibited high potency as a drying technique with valuable results like shorter drying time, higher drying rate and product quality. Drying time required to reduce moisture content of artichoke slice under 10% (w/w) was decreased almost 155 folds by operating microwave oven at power of 300 W compared to drying in conventional oven at 50°C. The improvement of drying rates by microwave technique varied from 20-folds to more than 200-folds relative to conventional one. Visual examination also displayed that microwave technology was superior to conventional oven drying in terms of the appearance of dried material. Color, brightness and structure of dried tubers were found to be better. Color of the dried material was found to be similar to raw material with maintained brightness, whereas tubers dried in conventional oven was exposed to color change like cooked color and even burned regions. For product quality, shrinkage is an important structural change which takes places in drying process and not desirable due to its negative effect on drying and rehydration processes. As a part of shrinkage, size reduction in pore dimensions might be significant handicap for the movement of water molecules throughout the solid matrix. Microwave technique also exhibited a succeeding improvement in the plant structure having weak shrinkage.

Conventional Drying

Four levels (50, 70, 80, and 90°C) were examined to figure out the temperature influence on drying. Dehydration process of raw material (2 mm thickness) continued till moisture content dropped under 10% (w/w). Drying times of Jerusalem artichoke slices in the conventional oven system were measured as 540 min, 300 min, 240 min, and 210 min for temperature levels of 50, 70, 80, and 90°C, respectively (Figure 1). The improvement in drying period could be attributed to the temperature effect on drying rate. Faster heat flux through the solid matrix, in other words faster water diffusion to the drying surface occurred as a consequence of the vapor pressure increase in the solid matrix with temperature. However the superior effect of temperature was found to be limited. In other words a reduction in process time remained less than expectation when varying from moderate to elevate temperatures (Figure 1). This might be due in part to a surface hardening effect as a consequence of quicker initial rate of evaporation of moisture from the surface occurred at elevated temperatures.

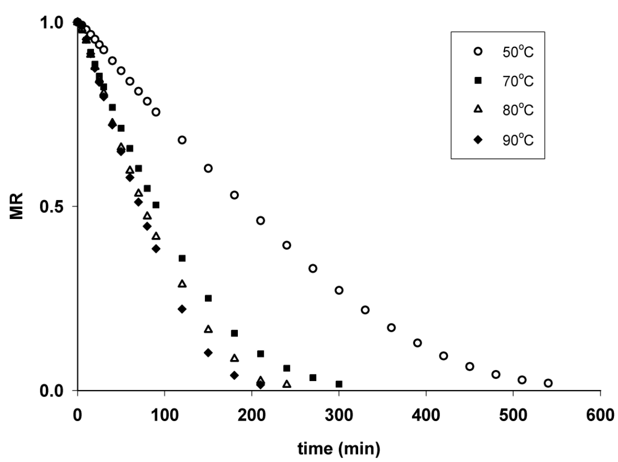


Figure 1. Moisture profile for conventional oven drying of Jerusalem artichoke slices under the effect of temperature change

Tubers sliced at different thicknesses were also processed in conventional oven system at 70°C to lower their moisture level under 10% (w/w). Drying times for this purpose were measured as 300 min, 480 min and

450 min for 2, 4, and 6 mm thicknesses, respectively (Figure 2). Diffusional movement of water molecules throughout the solid surface was adversely affected by an extension in pathway as a result of a change in the slice thickness. However, a slight decrease in drying time was observed in the case of drying of 6 mm –slices relative to 4 mm ones. This case could be attributed to the change of surface area from which drying took place. As slicing Jerusalem artichoke tubers in 6 mm thickness instead of 2 mm, collateral area of slice was extended by 3 folds corresponding to 70% of its upper surface area (30×40 mm), whereas that proportion remained only at the level of 23% in the case of 2 mm. As a consequence of this extension in the drying areas of 6 mm-slices possible side diffusion might occur, and taking this effect into account, the removal of moisture in thick slices might be enhanced, whereas the edge effect was negligible in the case of thinner slices (2 and 4 mm). In addition, the hardening effect on drying phenomena might take into account, when thin slices (4 mm) were considered relative to thick slices (6 mm).

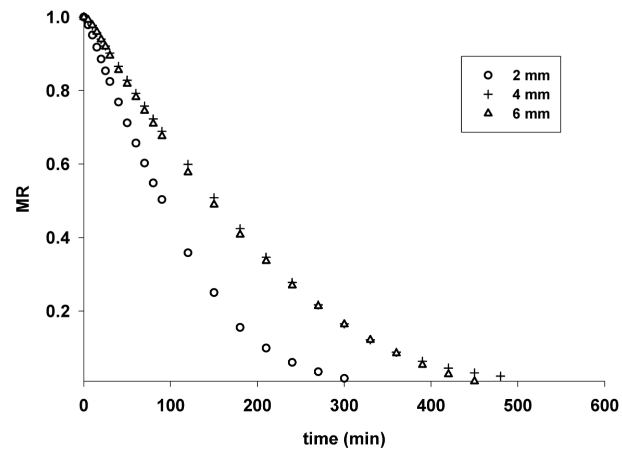
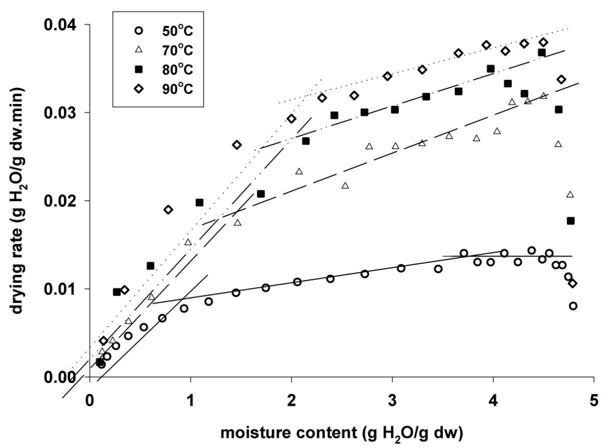


Figure 2. Moisture profile for conventional oven drying of Jerusalem artichoke slices under the effect of slice thickness change

As can be seen from Figure 3a, drying process carried out at 50℃ was determined to follow two successive falling rate periods being after constant rate one (Figure 3a). However constant rate period was disappeared when other temperature levels (70, 80, and 90℃) were examined. Figure 3b represented the presence of two falling rate periods for each slice thickness dried in conventional oven at 70℃ (Figure 3b). Drying rates were determined for the processes operated under the studied temperatures and thicknesses. Calculated results were indicated that the drying rates increased with elevating process temperature from 50 to 90℃. Drying rates of Jerusalem artichokes was found to be favored with decreasing slice-thickness from 4 mm to 2 mm, however no difference was detected in between rates calculated in the drying processes progressed for 4 mm and 6 mm slice-thicknesses (Figure 3b). Adverse effect of increasing thickness on dehydration rate and thus on drying time could be compensated by the enhancement of removal of moisture due in part to side diffusion from extended collateral area which might be significant (Figure 3b).



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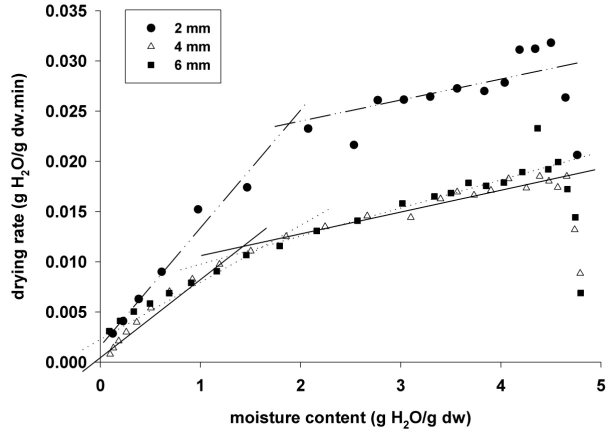

b

Figure 3. Drying rate curves for Jerusalem artichoke slices as a function of moisture content a) temperature effect b) slice thickness effect.

Microwave Drying

Microwave technology displayed a high success for the drying process of Jerusalem artichoke slices relative to the conventional method. Graphical representations of the change in moisture content with drying time at different microwave output powers and slice-thicknesses were illustrated in Figure 4 and 5. The drying process could be characterized as a continual decrease in moisture content with time. Time requirement to reduce the moisture content of tuber slice under 10% (w/w) was measured only as a couple of minutes for all trials except that for output power of 100 W (Figure 4 and 5). Additionally, visual inspection indicated that the color quality of treated material was maintained by microwave oven drying. Compared to conventional drying size change remained at an insignificant level in microwave drying, since volumetric heating was valid in latter method, whereas heat was moved from surface to internal matrix of treated material in the case of conventional oven drying and, thus, surface and slight depth of matrix was permanently exposed to high temperature along process which resulted in crust formation and shrinkage in the structure.

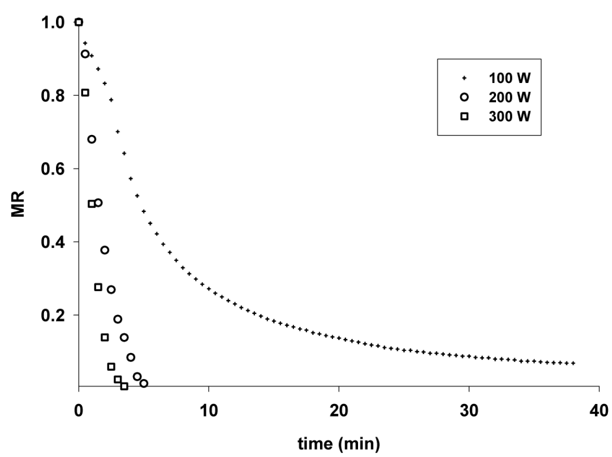

Figure 4. The influence of power on the moisture profile for microwave drying of Jerusalem artichoke

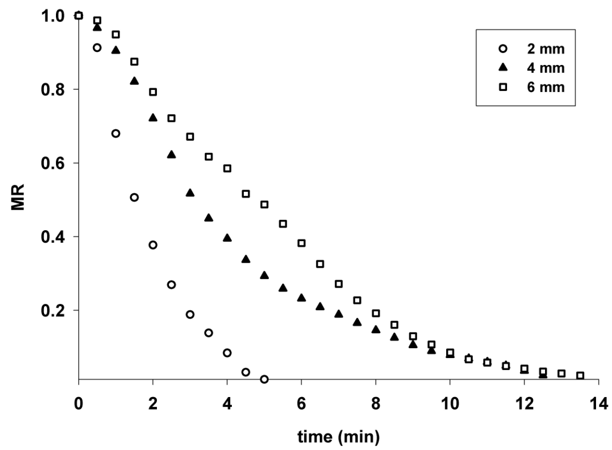

Figure 5. The influence of thickness on the moisture profile for microwave drying of Jerusalem artichoke.

Investigation of the microwave power effect on drying time indicated the presence of adverse relation which was to be a decrease in drying time with increasing power level. Drying times for finalization of process were found to be a couple of minutes, however, in a case of 100 W, even drying more than 30 min was found not to be sufficient to reduce moisture content level under 10% (w/w) (Figure 4). Superior effect of output power can be associated with its relation with generated heat. Higher power of microwave caused faster increase in internal temperature of entire volume, as a result more efficient diffusion of water molecules [20].

Figure 5 displayed the effect of slice-thickness on drying time and indicated that thin artichoke slices was dehydrated faster than thick one by microwave oven. This could be associated with the thickness dependency of pathway through which diffusion of water molecules took place. Three thicknesses were investigated and results exhibited a presence of a non-linear relation between thickness and drying time (Figure 5). Although 5 min application at 200 W output power was enough to reduce the moisture content level of 2 mm slices under 10% (w/w), more than 2 fold increment required in drying time (12.5 min) for the case of 4 mm slices. Slight increase of only 1 min was detected in the drying time, when thickness was adjusted as 6 mm compared to 4 mm. This unexpected reduction in the effect of slice-thickness in drying time when shifting from 4 mm- to 6 mm-thickness might be attributed to the improved edge effect on dehydration. In this case, in addition to the moisture removal from upper-surface (30 mm × 40 mm), side diffusion of water could take place in drying process unlike to other two thicknesses (2 mm and 4 mm).

Response of drying rate towards the change in the output power and the slice-thickness during microwave drying was investigated and results were illustrated in Figure 6a and 6b. It can be observed that an increase in the microwave power substantially increased drying rate and thus decreasing drying time. Increasing thickness, however, decreased drying rate. In general of microwave trials, three distinct periods were identified by the examination of Figure 6a and 6b. The initial stage was a short warming-up period corresponding to solid heating and consequently to non-isothermal drying conditions. This was followed by successive constant rate and falling rate periods. As can be seen from Figure 6a, after short warming-up stage, two distinct drying rate periods were observed in the dehydration in microwave oven operated at 100 W power and 2 mm thickness. When output powers of 200 W and 300 W were employed, constant rate period was disappeared, although it was expected due to high moisture content of Jerusalem artichoke slices. After warming-up stages, only falling rate periods were observed during drying processes under this conditions (200 W and 300 W powers) (Figure 6a). This might be attributed to the instant drying of slices as a consequence of rapid heating by microwave operated at the studied output power levels more than 100 W. Wang and Sheng [20] and Giri and Prasad [10] have also stated to the similar results observed during microwave drying of peaches and microwave-vacuum drying of mushrooms, respectively. Despite of the high differences between drying rates at the very beginning of treatments among different output powers, moisture content of slices decreased to such a low level that those differences were diminished towards to the end of drying process (Figure 6a). Decrease of drying rate and its intensity can be attributed to the variation of dielectric constant and loss factor depending on the moisture content of drying material and consequently to the amount of microwave energy absorbed. Mudgett [21] has also stated a strong relation between the amount of microwave energy absorbed by the treated material and its dielectric properties and electric field strength. The material absorbs more microwave power and heating is faster at high moisture content since high moisture content causes higher dielectric constant and loss factor. As drying progresses, a fall in drying rate occurs as a result of the decrease in the absorption of microwave power due to the moisture loss in the product [9, 10, 22, 23].

A graphical representation of change in drying rate with slice-thickness (Figure 6b) revealed that the drying of artichoke slices by microwave progressed and finalized in two successive periods (constant rate and falling rate periods), being after a warming-up period, except 2 mm thickness where constant rate was diminished due to the fast increment of heat in the tuber slices. As can be seen from Figure 6b, the differences in the calculated drying rate values for slice-thickness of 2 mm and 4 mm were able to clearly distinguished; however it almost disappeared in between 4 mm and 6 mm.

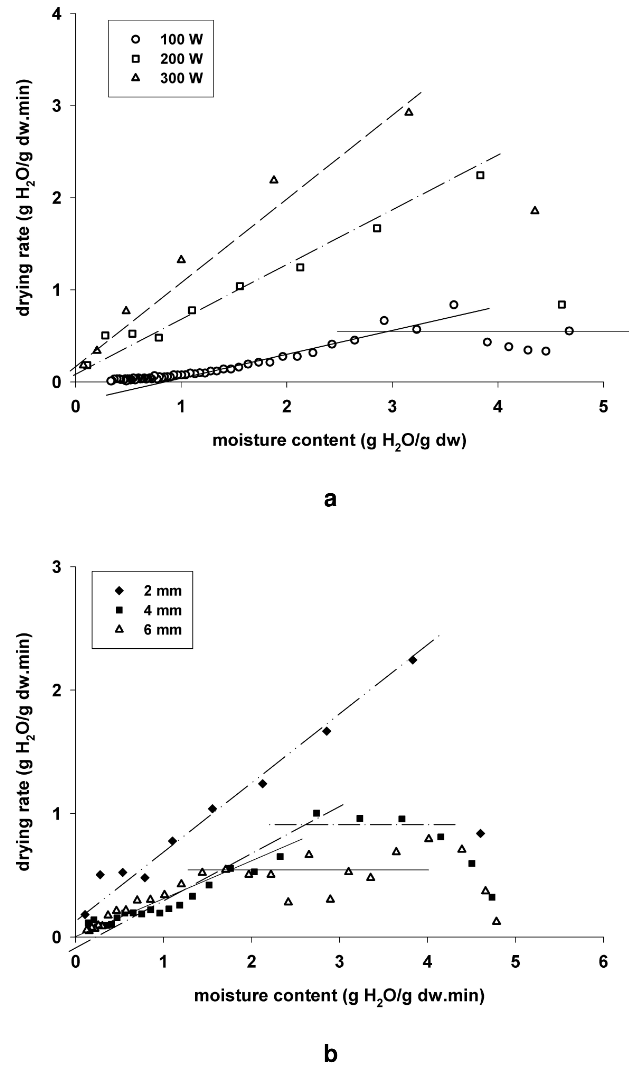

Figure 6. Drying rate curves for Jerusalem artichoke slices as a function of moisture content a) microwave power effect b) slice thickness effect.

Drying Kinetics of Jerusalem Artichoke Slices

Six well-known equations were employed to explain the drying kinetics of the conventional and microwave oven treatments. Models and their calculated model parameters and goodness-of-fit values were summarized in Tables 1 and 2. Selected equations were fitted to the experimental data obtained by proposed drying methods by non-linear regression analysis. Assessment of goodness-of-fits was performed by comparing mean square error values (*MSE*) and adjusted determination coefficient (R^2_{adj}). The assessment of goodness-of-fit emphasized to three employed models, Page, Logarithmic and Midilli equations; with high successes irrespective of drying methods and treatment conditions (Tables 1 and 2). These three models displayed similar successes to describe the experimental results of drying methods.

Midilli equation was determined as the best describing model for conventional drying of Jerusalem artichoke slices, however, logarithmic and Page's equations also described the conventional drying process with high successes and slight losses in the goodness of fits relative to Midilli's one. Additionally, Midilli equation displayed the highest success to explain the microwave drying of artichoke slices carried out under studied conditions except 100 W power level in which logarithmic equation was found to be most suitable one (Table 1). Page's equation also showed high performance to describe the microwave drying. Although Midilli equation could be the best-describing model for microwave and conventional oven drying methods (Table 2), its number of terms could be considered as a handicap. Compared to other equations having more terms makes that equation more complicated. When viewed from this aspect, advantage of Page's model was to need less term to explain the drying process compared to other ones. Logarithmic and Midilli equations, respectively, possessed three and four terms in contrast to Page's one having just two terms (Tables 1 and 2). This advantage can put Page's equation one step forward depending on the application purpose.

Table 1. Mathematical models applied to the microwave drying of Jerusalem artichoke and the results of regression analysis

Drying method & conditions	Kinetic model	Model coefficients	*Adj-R²*	*MSE*
MW-100W-2mm	Lewis	k = 0.1170 ± 0.0027	0.96	0.0023
	Page	k = 0.1839 ± 0.0103; y = 0.8036 ± 0.0220	0.98	0.0013
	Modified Page	k = 0.1216 ± 0.0026; y = 0.8036 ± 0.0220	0.98	0.0013
	Henderson & Pabis	k = 0.1106 ± 0.0035; a = 0.9523 ± 0.0208	0.96	0.0022
	Logarithmic	k = 0.1594 ± 0.0031; a = 0.9568 ± 0.0094; c = 0.0827 ± 0.0034	>0.99	0.0003
	Midilli & Kucuk	k = 0.1701 ± 0.0121; a = 1.0533 ± 0.0168; c = 0.0021 ± 0.0002; y = 0.9108 ± 0.0284	>0.99	0.0004
MW-200W-2mm	Lewis	k = 0.5050 ± 0.0338	0.97	0.0040
	Page	k = 0.3629 ± 0.0165; y = 1.4138 ± 0.0503	>0.99	0.0004
	Modified Page	k = 0.4882 ± 0.0081; y = 1.4138 ± 0.0503	>0.99	0.0004
	Henderson & Pabis	k = 0.5469 ± 0.0386; a = 1.0877 ± 0.0459	0.97	0.0031
	Logarithmic	k = 0.3733 ± 0.0510; a = 1.2522 ± 0.0691; c = -0.2007 ± 0.0776	0.99	0.0013
	Midilli & Kucuk	k = 0.3779 ± 0.0261; a = 1.0162 ± 0.0194; c = -0.0030 ± 0.0050*; y = 1.3510 ± 0.0884	>0.99	0.0004
MW-300W-2mm	Lewis	k = 0.8202 ± 0.0811	0.96	0.0056
	Page	k = 0.6716 ± 0.0070; y = 1.5813 ± 0.0200	>0.99	<0.0001
	Modified Page	k = 0.7775 ± 0.0042; y = 1.5813 ± 0.0200	>0.99	<0.0001
	Henderson & Pabis	k = 0.8704 ± 0.0963; a = 1.0714 ± 0.0672	0.96	0.0054
	Logarithmic	k = 0.6090 ± 0.1259; a = 1.2254 ± 0.0982; c = -0.1803 ± 0.1053*	0.98	0.0030
	Midilli & Kucuk	k = 0.6763 ± 0.0115; a = 1.0027 ± 0.0061; c = 0.0006 ± 0.0016*;y = 1.5809 ± 0.0320	>0.99	<0.0001
MW-200W-4mm	Lewis	k = 0.2283 ± 0.0071	0.98	0.0020
	Page	k = 0.1519 ± 0.0087; y = 1.2552 ± 0.0341	>0.99	0.0005
	Modified Page	k = 0.2228 ± 0.0031; y = 1.2552 ± 0.0341	>0.99	0.0005
	Henderson & Pabis	k = 0.2503 ± 0.0070; a = 1.0980 ± 0.0199	0.99	0.0010
	Logarithmic	k = 0.2237 ± 0.0133; a = 1.1265 ± 0.0223; c = -0.0460 ± 0.0224*	>0.99	0.0008
	Midilli & Kucuk	k = 0.1602 ± 0.0135; a = 1.0285 ± 0.0155; c = 0.0024 ± 0.0010; y = 1.2746 ± 0.0533	>0.99	0.0004
MW-200W-6mm	Lewis	k = 0.1775 ± 0.0085	0.95	0.0056
	Page	k = 0.0672 ± 0.0040; y = 1.5302 ± 0.0323	>0.99	0.0003
	Modified Page	k = 0.1713 ± 0.0016; y = 1.5302 ± 0.0323	>0.99	0.0003
	Henderson & Pabis	k = 0.2009 ± 0.0095; a = 1.1357 ± 0.0346	0.97	0.0035
	Logarithmic	k = 0.1198 ± 0.0107; a = 1.3716 ± 0.0517; c = -0.2985 ± 0.0599	>0.99	0.0010
	Midilli & Kucuk	k = 0.0723 ± 0.0074; a = 1.0013 ± 0.0123; c = -0.0024 ± 0.0012*; y = 1.4596 ± 0.0591	>0.99	0.0003

Table 2. Mathematical models applied to the conventional drying of Jerusalem artichoke and the results of regression analysis

Drying method & conditions	Kinetic model	Model coefficients	*Adj-R²*	*MSE*
CO-50C-2mm	Lewis	k = 0.0041 ± 0.0002	0.97	0.0032
	Page	k = 0.0006 ± 0.0001; y = 1.3566 ± 0.0299	>0.99	0.0004
	Modified Page	k = 0.0042 ± 0.0001; y = 1.3568 ± 0.0298	>0.99	0.0004
	Henderson & Pabis	k = 0.0044 ± 0.0002; a = 1.0598 ± 0.0181	0.98	0.0023
	Logarithmic	k = 0.0022 ± 0.0001; a = 1.5094 ± 0.0496; c = -0.4893 ± 0.0522	>0.99	0.0002
	Midilli & Kucuk	k = 0.0010 ± 0.0001; a = 0.9950 ± 0.0036; c = -0.0002 ± 0.0000; y = 1.2306 ± 0.0243	>0.99	<0.0001
CO-70C-2mm	Lewis	k = 0.0084 ± 0.0004	0.98	0.0025
	Page	k = 0.0021 ± 0.0002; y = 1.3001 ± 0.0213	>0.99	0.0029
	Modified Page	k = 0.0087 ± 0.0001; y = 1.3002 ± 0.0213	>0.99	0.0029
	Henderson & Pabis	k = 0.0091 ± 0.0004; a = 1.0596 ± 0.0196	0.99	0.0017
	Logarithmic	k = 0.0064 ± 0.0004; a = 1.2300 ± 0.0316; c = -0.2006 ± 0.0355	>0.99	0.0004
	Midilli & Kucuk	k = 0.0022 ± 0.0003; a = 0.9897 ± 0.0053; c = -0.0001 ± 0.0000; y = 1.2789 ± 0.0283	>0.99	0.0001
CO-80C-2mm	Lewis	k = 0.0097 ± 0.0005	0.97	0.0028
	Page	k = 0.0023 ± 0.0003; y = 1.3294 ± 0.0270	>0.99	0.0002
	Modified Page	k = 0.0103 ± 0.0001; y = 1.3295 ± 0.0269	>0.99	0.0002
	Henderson & Pabis	k = 0.0106 ± 0.0005; a = 1.0657 ± 0.0216	0.98	0.0018
	Logarithmic	k = 0.0063 ± 0.0004; a = 1.3920 ± 0.0441; c = -0.3622 ± 0.0475	>0.99	0.0002
	Midilli & Kucuk	k = 0.0035 ± 0.0003; a = 1.0049 ± 0.0036; c = -0.0004 ± 0.0001; y = 1.2057 ± 0.0210	>0.99	<0.0001
CO-90C-2mm	Lewis	k = 0.0104 ± 0.0006	0.96	0.0043
	Page	k = 0.0016 ± 0.0002; y = 1.4317 ± 0.0312	>0.99	0.0002
	Modified Page	k = 0.0111 ± 0.0001; y = 1.4318 ± 0.0312	>0.99	0.0002
	Henderson & Pabis	k = 0.0117 ± 0.0007; a = 1.0826 ± 0.0276	0.98	0.0027
	Logarithmic	k = 0.0069 ± 0.0007; a = 1.3969 ± 0.0685; c = -0.3526 ± 0.0746	>0.99	0.0006
	Midilli & Kucuk	k = 0.0020 ± 0.0003; a = 0.9984 ± 0.0065; c = -0.0003 ± 0.0001; y = 1.3589 ± 0.0385	>0.99	0.0001
CO-70C-4mm	Lewis	k = 0.0051 ± 0.0002	0.98	0.0026
	Page	k = 0.0010 ± 0.0001; y = 1.3045 ± 0.0200	>0.99	0.0002
	Modified Page	k = 0.0052 ± 0.0000; y = 1.3046 ± 0.0200	>0.99	0.0002
	Henderson & Pabis	k = 0.0055 ± 0.0002; a = 1.0605 ± 0.0164	0.99	0.0017
	Logarithmic	k = 0.0037 ± 0.0002; a = 1.2593 ± 0.0283; c = -0.2304 ± 0.0313	>0.99	0.0003
	Midilli & Kucuk	k = 0.0013 ± 0.0002; a = 0.9949 ± 0.0043; c = -0.0001 ± 0.0000; y = 1.2484 ± 0.0240	>0.99	0.0001
CO-70C-6mm	Lewis	k = 0.0052 ± 0.0002	0.98	0.0024
	Page	k = 0.0012 ± 0.0001; y = 1.2811 ± 0.0230	>0.99	0.0003
	Modified Page	k = 0.0053 ± 0.0001; y = 1.2811 ± 0.0229	>0.99	0.0003
	Henderson & Pabis	k = 0.0057 ± 0.0002; a = 1.0582 ± 0.0158	0.99	0.0015
	Logarithmic	k = 0.0036 ± 0.0001; a = 1.2879 ± 0.0184; c = -0.2631 ± 0.0202	>0.99	0.0001
	Midilli & Kucuk	k = 0.0021 ± 0.0001; a = 1.0047 ± 0.0021; c = -0.0002 ± 0.0000; y = 1.1526 ± 0.0111	>0.99	<0.0001

The proposed models labeled by numbers from 1 to 6 were from articles published by Lewis [14], Bruce [15], Overhults et al. [16], Henderson and Pabis [17], Yaldiz et al. [18], and Midilli and Küçük [19], respectively.

CONLUSION

The present study indicated that microwave technique can be used to dry Jerusalem artichoke slices as an alternative to conventional oven drying system. The results showed the improved drying characteristics of artichoke slices dried by microwave. Additionally, process conditions had a significant effect on the microwave drying rate, so they should be carefully considered to achieve optimal drying results. As a result optimization of microwave drying of Jerusalem artichoke slices are needed for improvement of this technique.

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