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Original Research Article

Effect of Microwave and Hot-Air Drying Techniques on the Color Properties and Specific Energy Requirement of Madimak Plants (*Polygonum cognatum Meissn*.)

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ABSTRACT

***Polygonum cognatum Meissn*. is a wild edible plant and is known as madimak in Turkey. It's young shoots are cultivated in spring and used as vegetable. The present work evaluates the effect of different drying treatments on the color attributes of madimak plants, which were dried using two different methods: hot- air and microwave-drying. The treatments in air drying were carried out at 60, 70 and 80 °C. Microwave drying were done using four different microwave power levels ranging between 160 and 750 W. Microwave drying of the madimak was faster than hot air drying. Drying time decrease greatly with improved microwave power. Drying processes were completed between 0.058 and 0.308 h depending on the microwave power level, while between 2.583 and 4.166 h in hot-air drying. Microwave drying did not affect the color quality of the samples as much as hot air drying did. Chlorophyll a, chlorophyll b and total chlorophylls contents of microwave dried plants were significantly retained. Both color and chlorophyl attributes indicated that microwave drying for madimak plants is higher suitable than hot-air or ambient temperature drying. It was found the lowest colour change and the highest chlorophyll contents at 750 W microwave powers. In addition, minimum specific energy requirements were found as 44.58 kWh/kg and 107.00 kWh/kg for 80 °C hot air drying and 160 W microwave power level, respectively. The results showed that there was no significant difference of specific energy requirement between hot air drying temperatures while the important difference between microwave power levels.**

Keywords: Madimak, Microwave, Hot air, Color, Specific energy, Edible plants, Chlorophyll

INTRODUCTION

Chlorophyll is the most widely distrubed plant pigment, and importance of chlorophylls *a* and *b* in food technology derives from their part in the green color vegetables (King et al., 2001). Chlorophyll *a* and chlorophyll *b* are the main forms and are typically found in higher plants commonly utilized for food, and they occur in an approximate ratio of 3:1. Both chlorophylls a and *b* are magnesium containing derivatives of the tetrapyrrole phorbin. Chlorophyll *a* and chlorophyll *b* also differ in perceived color and thermal stability. Chlorophyll *a* appears blue-green and chlorophyll *b* yellow-green (Cui et al., 2004). They are highly susceptible to degradation processing and storage. The conversion of chlorophyll to pheophitins and other derivatives results in a change from bright green to dull olive-green or olive-yellow, which ultimatelly is perceived by the consumer as a loss of quality King et al., (2001) and Ahmed et al (2001). Chlorophyll retention is very important in determining the final quality of thermally dehydrated green plants. Under higher temperature and acidic conditions the central magnesium in the chlorophyll ring is replaced by two hydrogen ions and green chlorophylls are converted to olive-brown pheophytins. At lower temperatures of approximately 60–80 ºC, chlorophyllase activity increases to form the green chlorophyllides and then the chlorophyllides are susceptible to magnesium loss so that olive-brown pheophorbides are formed (Cui et al., 2004). Color is an important quality attribute of plant products, and chlorophylls have been used as an indicator of quality for green vegetables (Guan et al., 2005).

Polygonum cognatum Meissn. is a wild plant called 'madimak' in Turkish. This edible plant is a perennial of slender woody stock. It grows on roadsides, slopes and cliffs at altitudes of 720-3000 m. The young shoots with leaves are collected in spring (Yildirim et al., 2003). The fresh leaves and the stem of plant are consumed as vegetables. The dried plant is used as a medical plant (Ozbucak et al., 2007). In Turkish folk medicine it has been used for various purposes, such as its diuretic effect and for the treatment of diabetes mellitus (Yildirim et al., 2003).

Dehydration is one of the oldest methods of food preservation and it represents a very important aspect of food processing. Thermal damage incurred by a product during drying is directly proportional to the temperature

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and time involved. The high temperature and long drying time associated with conventional hot-air drying often causes heat damage and adversely affects texture, color, flavor and nutritional value of products (Lin et al., 1998). The desire to eliminate this problem, prevent significant quality loss, and achieve fast and effective thermal processing has resulted in the increasing use of microwaves for food drying. Microwave drying is rapid, more uniform and energy efficient compared to conventional hot air drying. In this case, the removal of moisture is accelerated and, furthermore, heat transfer to the solid is slowed down significantly due to the absence of convection. In recent years, microwave drying has gained popularity as an alternative drying method for a wide variety of food products such as fruits, vegetables, snack foods and dairy products (Wang and Xi., 2005)

The purpose of this study was to compare the effects of the different drying methods on the color properties and specific energy requirement of madimak plants (*Polygonum cognatum* Meissn).

MATERIAL AND METHODS

Material

Madimak young shoots with leaves were harvested in May in the Black Sea region of Turkey (Kavak, Samsun). It was cleaned, and stored at a temperature of 4±0.5 °C until drying process. In the fresh plants, moisture, lightness (L^*), greenness ($-a^*$), yellowness ($+b^*$), hue angle, chlorophyll *a*, chlorophyll *b* and total chlorophylls were determined as 88.05±0.50% (733% dry basis), 30.56±1.60, -6.72±0.53, 12.62±0.42, 118.09±2.63, 3805.76±142.98 mg/kg (in dry weight), 1475.86±8.20 mg/kg (in dry weight), and 5281.62±151.17 mg/kg (in dry weight), respectively.

Drying Experiment and Drying Methods

Drying experiments were conducted using two different drying methods such as hot air drying and microwave drying. Three different temperatures such as 60, 70 and 80 °C were used for hot air drying method. Ambient air temperature and relative humidity were found as 20 °C (±1) and 60% (±3), respectively for hot air drying. Besides, four different power levels such as 160W, 350W, 500W and 750W were also used for microwave drying of madimak plants.

Convective dehydration

The plants were dehydrated by hot air drying technic using the dehydration system developed by (Koyuncu et al., 2003) at 60, 70 and 80 ºC with air flow rates of 0.30 m/s to achieve moisture content of 8-10%.

The convective dryer equipped with an electric heater (air heating duct), temperature adjuster, centrifugal fan (blower), air speed adjuster (regulator of variable transformer), corrosion resistant chromium mesh, corrosion resistant chromium sheet, glass wood insulator, a 0.01 g sensitive Precisa BJ 600 D digital balance, RS232 connection, a PC, specially designed Balint data processing software, drying air inlet and outlet channels as well as thermostat, temperature indicators, wattmeter and free wheels (Fig. 1). The microwave oven dryer mainly consists of magnetron tube (source of radiation), oven cavity, filter, step-up transformer, power plug, wave guide, mode stirrer and oven tray (Fig. 2). The products were placed on the chromium mesh as a thin layer. In order to produce different temperatures and fix up the velocity, the electric current of the heater and the rotation of the fan were adjusted manually. The system was also controlled by the thermostat automatically. To measure the power consumption, air speed, relative humidity and drying air temperatures at different points, several digital devices such as watt meter, hot-wire anemometer having in the measurement sensitive of 0.1 m/s, Testo AG 309 type relative humidity and temperature sensors and thermocouple were connected to the drying system. In addition, it must be noted that the experimental drying studies we conducted showed us that the maximum length of the drying chamber was approximately 1 m depending on the drying air temperature distribution during the length of the dryer. Thus, the drying chamber was selected less than 1m long. During these studies, it was also seen that when the length of the drying chamber more than 1 m, there were important temperature and relative humidity differences between the beginning and the end of the drying chamber (Koyuncu et al., (2003) and Koyuncu et al., (2004)) The moisture content (percentage dry basis) of fresh products, at harvest was approximately 733% (Eq. 1) (Ekechukwu,1999).

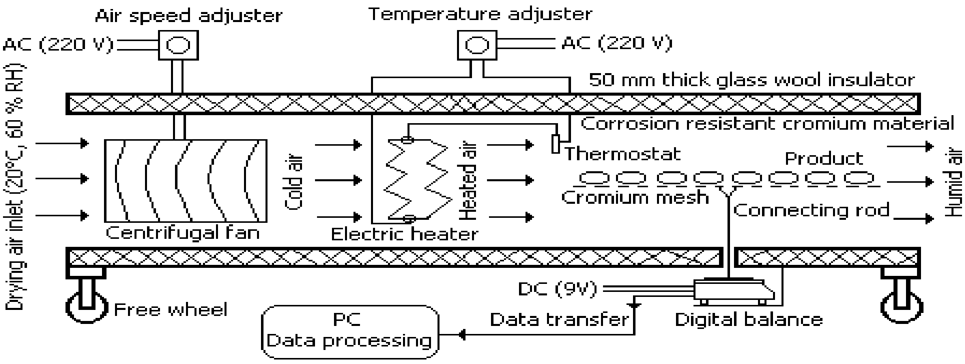

Figure 1. Schematic presentation of the computer connected parallel air flow type dryer.

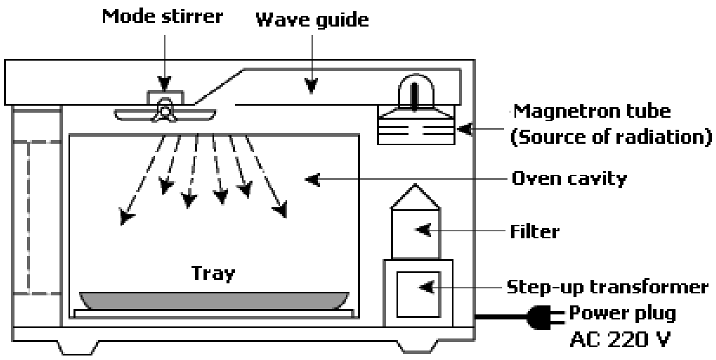

Figure 2. Schematic presentation of the microwave oven dryer.

For safe long-term storage, the moisture content should preferably be less than 10%. For that reason, the fresh products with moisture content of 733% was dehydrated until the moisture content becomes 8…10% in the dryer. During drying time, the mass of *Polygonum cognatum Meissn* leave samples were weighted automatically by the balance per 5…10 minutes and all test were replicated three times. The dryer was installed in conditions that were a relative humidity of 60% (±3) and a temperature of 20 °C (±1). This air was heated by the heater and directed to the drying chamber. Three different temperatures such as 60, 70 and 80 °C and a selected air velocity of 0.30 m/s were used for experimentation. This is coming from the fact that it was understood from the preliminary studies that the temperature less than 50 °C and the air speed more than 0.30 m/s extremely increase the drying time and energy requirement for these products. In addition, four power levels (160, 350, 500 and 750 W) of microwave oven dryer were also used for products drying. During experiments, drying characteristics, total drying time, total energy needed for drying of one charge of the dryer, total energy requirement for drying 1 kg of wet product (specific energy requirement) and color retention for different convective drying temperatures and for microwave drying power levels were found (Eq. 2, 3, 4 and 5) (Holman., 1994).

$$PM_{db} = \left[\frac{W_o - W_d}{W_d}\right] \times 100 \quad (1)$$

$$E_{t(c)} = A.v.\rho.c.\Delta T.D_t \quad (2)$$

$$E_{t(m)} = \frac{U.I}{1000}.D_t \quad (3)$$

$$E_{kg(c)} = \frac{E_{t(c)}}{W_o} \quad (4)$$

$$E_{kg(m)} = \frac{E_{t(m)}}{W_o} \qquad (5)$$

A Drying air flow surface area, m^2

c Specific heat of air under adiabatic conditions, kJ/(kg K)

D_t Total drying time, h

$E_{kg(c)}$ Energy requirement for drying 1 kg of product and for convective drying, kWh/kg

$E_{kg(m)}$ Energy requirement for drying 1 kg of product and for microwave drying, kWh/kg

$E_{t(c)}$ Total energy requirement for a charge of the convective dryer, kWh

$E_{t(m)}$ Total energy requirement for a charge of the microwave dryer, kWh

I Electric current, A

PM_{db} The moisture content on dry basis expressed as percentage, %

U Electric voltage, V

v Drying air speed , m/s

W_d Weight of dry matter in product, kg

W_o Initial weight of undried product, kg

ΔT Temperature differences, K

ρ Air density, kg/m^3

Microwave dehydration

The programmable, multifunctional, domestic microwave oven used in the study (Arcelik MD581, Turkey) has the technical features of 230 V, 50 Hz, and 2550 W. The power produced by the oven in microwave function was continuous. The oven can be operated at microwave output powers of 160, 350, 500 and 750 W.

The madimak samples were 50 g (±0.10 g) in weight. Three replicated tests were conducted for each drying condition. The samples were removed from the oven periodically (every 30 s for microwave, and every 5 min for convective drying) during the drying period, and the moisture loss was determined by weighing the plate using digital balance.

Determination of Moisture Content

Dry matter was determined by heating in a vacuum oven (100 mmHg) at 70 °C until a constant weight was obtained (AOAC., 2000).

Determination of Color Values

Color of fresh and dried plants were evaluated by a colorimeter (Minolta CR 400, Japan). The results were expressed as L* (lightness/darkness), a* (+, redness/ -, greenness), and b* (+, yellowness/-, blueness) values. A white tile (No: 19633162) was used to standardize the instrument. Hue angle and total color difference (ΔE) values were calculated by followed equations (Eq. 6 and 7):

$$\mathrm{Hue}=\arctan(b^*/a^*) \qquad (6)$$

$$\Delta E= ((L^*-L_0^*)^2 + (a^*-a_0^*)^2 +(b^*-b_0^*)^2)^{1/2} \qquad (7)$$

Where, here subscript "0" refers to the colour reading of fresh madimak samples.

Chlorophyll Analysis

Chlorophyll contents of fresh and dried plants were determined according to Schmalko and Alzamora., (2001) and Cao et al., (2007). Plants (0.5 g) were extracted 10 mL of an acetone-water solution (80:20, V:V), and then introduced in an ultrasonic bath at 15 ºC for 5 minutes. Afterwards, the homogenate was centrifuged at 3000 rpm for 5 min, and supernatant was collected in a glass bottle. This process was repeated by adding acetone solution until the extract becomes colorless. Supernatants were collected and were colorimetrically at 647 and 664 nm to an UV-Vis spectrophotometer. The chlorophylls content was calculated using the equations from (Guan et al., 2005).

$$\text{Chlorophyll a} = 12.25A_{664} - 2.79A_{647} \quad (8)$$

$$\text{Chlorophyll b} = 21.50A_{647} - 5.10A_{664} \quad (9)$$

$$\text{Total chlorophylls} = 18.71A_{647} + 7.15A_{664} \quad (10)$$

Statistical analysis

Analysis of variance (ANOVA) was conducted using the SPSS 16.0 (SPSS Inc., USA). The calculated mean values were compared using Duncan's multiple range test with significance level of $p<0.05$.

RESULTS AND DISCUSSION

Drying characteristics and energy requirements

Drying curves for ambient air (room temperature) drying, microwave drying and convective drying are shown in Figures 3-5. The results regarding total drying time showed that there is significant difference between different drying methods. The fast drying is achieved for microwave drying while the slowest is obtained for room temperature. In addition, there is less difference between various temperatures of convective dryer while there is more significant difference between various power levels of microwave owen.

As a result, it is seen from Figures 3-6 that the total drying time substantially reduced with the increase in the temperature of hot air (Fig 3, 4 and 6) and reduced with the increase in the microwave power levels (Fig 5). The total drying times is varied from 3.5-2880 min. These minimum and maximum drying time is obtained for 750W power level of microwave drying and for room temperature drying, respectively. The total drying times are also given as hour (h) in Figure 6 to compare the different drying methods, temperature and power levels. As seen from this figure that the lowest and highest drying time are 0.058 h and 48 h for 750 W power level of microwave drying and for room temperature drying, respectively.

In addition, the total energy requirement for one charge of the dryers and specific energy requirement (energy consumption for 1 kg of the product) is seen from Figure 7 and 8. The minimum specific energy requirements were found as 44.58 kWh/kg and 107.00 kWh/kg for 80 °C hot air drying and 160 W microwave power level, respectively. This figures also shows that there is no significant difference of specific energy requirement between hot air drying temperatures while the important difference between microwave power levels. In order to save the possible maximum energy while drying this agricultural product, the 80 °C hot air convective drying method should be preffered. Otherwise, by using the 750 W power level of microwave drying will increase the total and specific energy comsumption approximately 13 times more than 80 °C hot air convective drying method.

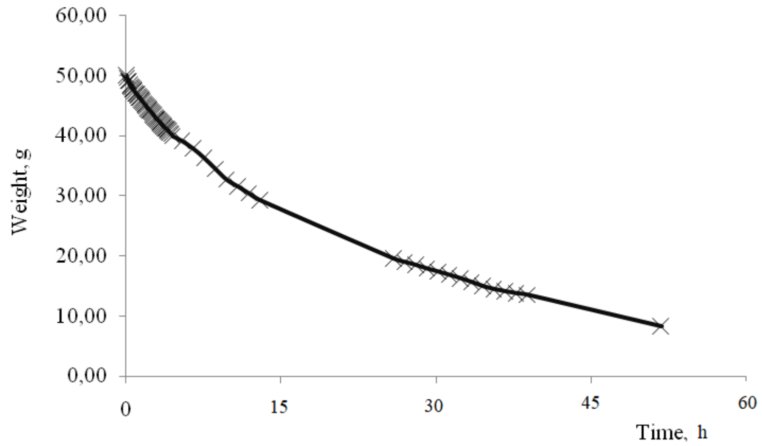

Figure 3. Drying curves of madimak dried at room temperature.

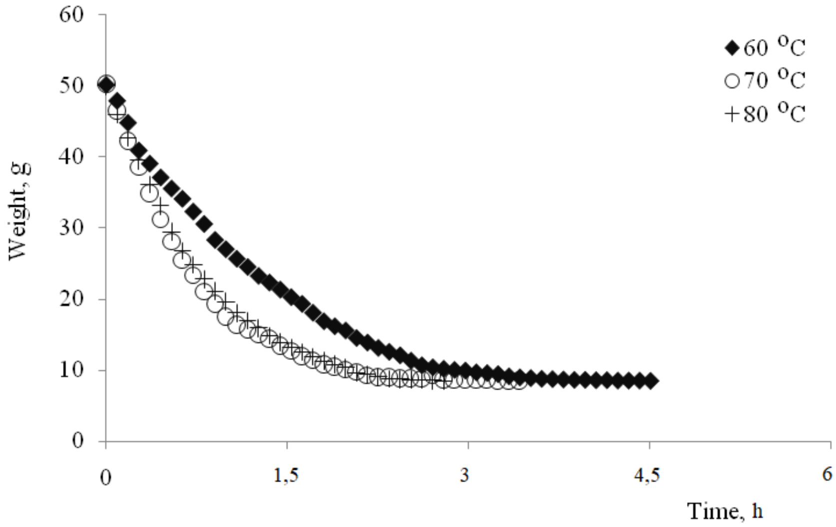

Figure 4. Drying curves of madimak dried using convective technique.

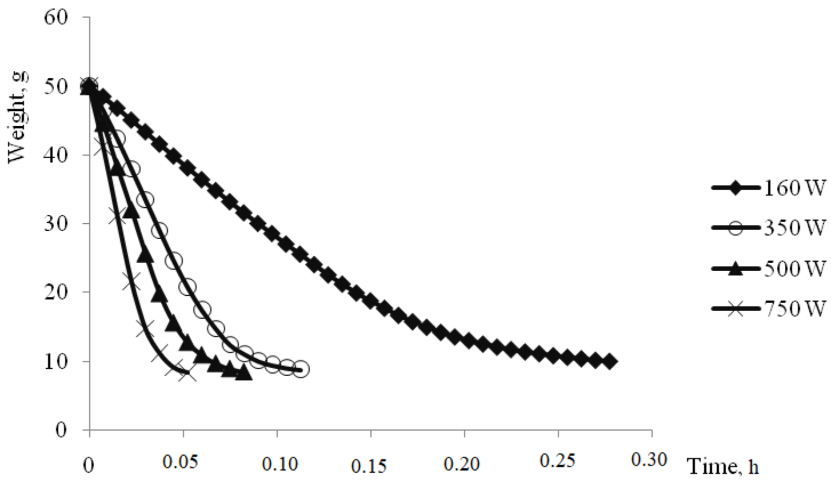

Figure 5. Drying curves of madimak dried using microwave technique.

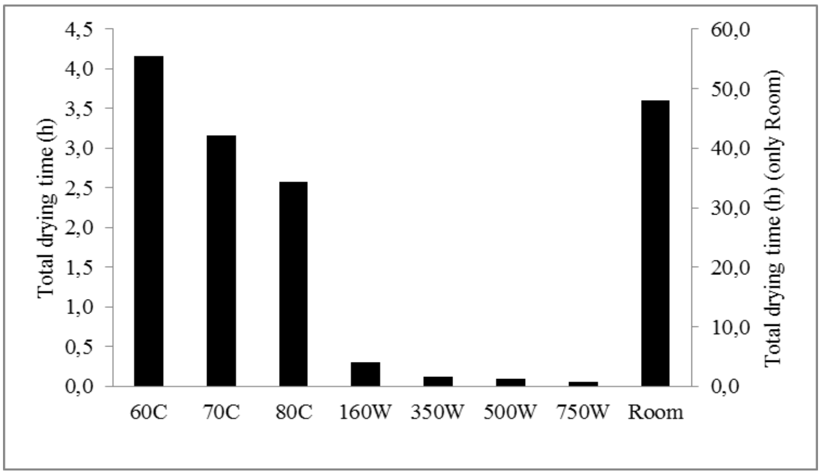

Figure 6. Drying times of dried samples by different techniques.

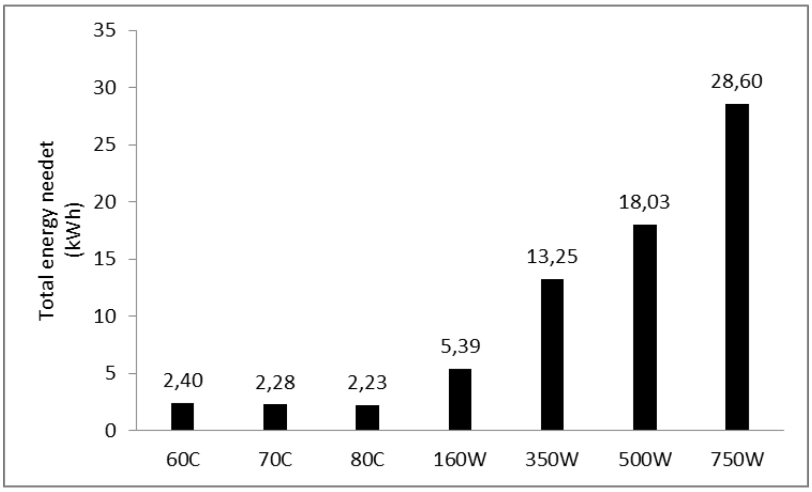

Figure 7. Total energy requirement for a charge of convective and microwave dryers at different temperatures and power levels.

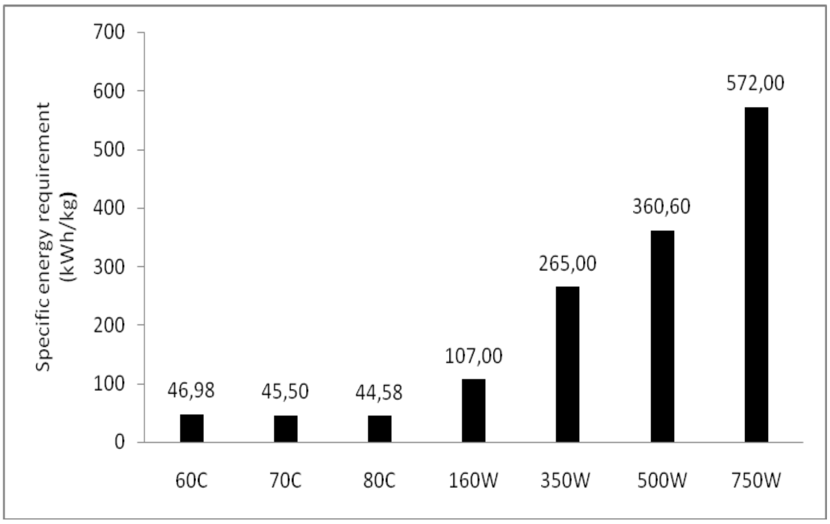

Figure 8. Energy requirement for drying 1 kg of product for convective and microwave dryer.

Color properties and chlorophyll contents

One of the indicators of senescence in green leafy vegetables is loss of greenness with degradation of chlorophyll. Greenness (-a*) and yellowness (+b*) values loss occurred in the dried madimak plant compared with the fresh ones (Table 1). The lowest L* and a* values were found dried plants at 160 W of microwave power. It was found the highest L* values dried plants hot-air at 60°C; the lowest b* values at ambient temperatures; the highest greenness and yellowness values plants dried at 750 W. The color change index (ΔE) values for the microwave dried samples (except 160 W power) were statistically different from the hot air drying ($p<0.05$). The highest the color change index values was found dried samples at 60 °C; the lowest values was found at 750 W.

The colour values closest to that of fresh madimak values were obtained in the drying processes made using the energy levels of 750, 500 and 350 W. These results are consistent with those of (Ozkan et al., 2007). They investigated the colour change in spinach at microwave powers of 90, 160, 350, 500, 650, 750, 850 and 1000 W, and determined the lowest colour change at 500, 650 and 750 W microwave powers. The low values measured in L, a, and b colour criteria at 1000 W microwave power.

Soysal (2004), determined the colour change in parsley at microwave powers of 360, 450, 540, 630, 720, 810 and 900 W. He found that the change in colour values was not dependent on the microwave power.

According to Ozkan et al., (2007), high moisture bio-products undergoing microwave drying have the advantage. Microwave drying pushes liquid into the surface and the liquid is usually converted into the vapour. This process results in drying without causing surface overheating phenomena. Therefore, in terms of surface colour degradation, preservation of the product colour was good. It is estimated that the products are subjected to high temperature with the increasing power levels during microwave drying.

In addition, it was known fron a literature that microwave heating could be an effective treatment to inactivate oxidoreductases enzymes (de Ancos et al., 1999).

The total colour difference (ΔE) generally increased when microwave power decreased. The total colour difference values of dried samples with hot-air drying technique decreased when temperature increased. These results are not consistent with those of (de Ancos et al., 1999).

Table 1. Color properties of dried plants.

	*L**	*a**	*b**	Hue Angle	ΔE
Room	33.98±1.34abcd	-1.19±0.80abc	9.30±0.55b	97.10±4.28bcd	7.36±1.26ab
60°C	36.31±1.06a	-1.58±0.77bc	11.44±0.41a	97.88±3.84bc	7.88±0.53a
70 °C	35.24±1.21ab	-1.39±1.12abc	11.08±0.26a	97.01±5.48bcd	7.39±0.32ab
80 °C	34.44±1.34abc	-0.70±0.27ab	10.67±0.23a	93.76±1.38cd	7.47±0.87a
160 W	31.79±1.19d	-0.21±0.33a	10.18±0.83ab	91.20±1.99d	7.16±0.33ab
350 W	32.50±1.42cd	-2.38±0.43cd	10.99±1.06a	102.18±1.47ab	5.21±0.72c
500 W	33.634±0.48bcd	-2.39±0.13cd	10.55±0.51a	102.78±0.61ab	5.72±0.41bc
750 W	32.08±1.89cd	-2.89±0.81d	11.11±1.04a	104.43±2.87a	4.55±1.74c

[1]Significantly different in each group ($p<0.05$).

Chlorophyll retention is very important in determining the final quality of dehydrated green plants. In microwave dried plants at 750 W powers, chlorophyll a, chlorophyll b and total chlorophylls contents of plants were significantly retained (Table 2). Microwave heating could be an effective treatment to inactivate oxidoreductases enzymes as reported by (de Ancos et al., 1999).

In this study, chlorophyll b was lost in a smaller extent than chlorophyll a. These values for the loss of chlorophylls are similar to the ones reported in the literature for thermally processed green vegetables and plants (de Ancos et al., 1999 and Schmalko et al., 2001), who found that in peas, spinach, broccoli and Yerbá Mate, the a form of chlorophylls degraded more rapidly than the b form. Also, de Ancos et al., (1999), studied the effect of microwave heating on the colour and composition of strawberry, papaya and kiwi purees, reported chlorophyll b is the least heat-stable chlorophyll. They found that microwave heating of kiwi purees produced a signifficant decrease of chlorophyll a and b concentration due to chlorophyll degradation through transformation to chlorophyllide a, pheophorbide a and pheophytin b. As mentioned by Cui et al., (2004), chlorophyll a and chlorophyll b also differ in perceived color and thermal stability; chlorophyll a appears blue-green and chlorophyll b yellow-green. It is generally agreed that the b form is more resistant to heat treatment.

Ahmed et al., (2001) studied the drying behaviour and chlorophyll retention of coriander leaves. They found that chlorophyll retention in the dried product decreased with the increase in temperature and was at a maximum when coriander leaves were dried at 45°C.

Obviously, 60°C as the temperature for hot-air drying or 750 W as the power for microwave drying may be recommended for dehydration madimak plants as it gave the product with highest chlorophyll content.

In addition, (Alibas, 2007), studied on nettle leaves (*Urtica dioica* L.) for drying initial moisture by involving three different methods which are microwave, convective and vacuum drying. Experiments for energy consumption and color parameters were done according to four different microwave power levels (500, 650, 750 and 850 W) and air temperatures (50, 75, 100 and 125 °C). The semi-empirical Page's equation was used to reproduce the all experimental conditions. In this study, the optimum method with respect to the drying period, colour and energy consumption was the microwave drying at 850 W.

Kaya et al., (2007), studied on apple slices for varying values of the drying air parameters which are temperature, velocity and relative humidity. Experiments were done by using three different air tempratures (35, 45 and 55 °C) at different velocities (0·2, 0·4 and 0·6 m/s) and at different relative humidity values (40%, 55% and 70%). Mainly Henderson, Pabis, Newton and the two-term exponential model was used for expermiental initial mositure data. After confirmation according to literature, moisture diffusity, activation energy and sorption isotherms were determined.

Table 2. Chlorophyll contents (mg/kg, in dry weight) of dried plants.

	Chlorophyll a	Chlorophyll b	Total chlorophylls	Retention Total Chlorophyll %
Room	1691.43±76.29d	714.69±31.96bc	2406.13±108.25d	45.55
60 ºC	2399.11±13.99ab	817.31±32.25b	3216.43±46.24b	60.90
70 ºC	2217.97±50.26bc	800.14±29.23b	3018.12±79.49bc	57.14
80ºC	2201.77±35.46bc	700.09±27.91bc	2901.86±63.37bc	54.94
160 W	2037.39±264.62c	629.32±60.91c	2668.37±302.41cd	50.52
350 W	2327.19±29.32bc	690.57±106.56bc	3017.76±115.37bc	57.13
500 W	2500.54±8.34ab	818.46±13.62b	3319.01±5.28ab	62.84
750 W	2705.01±414.38a	1008.89±162.68a	3713.90±577.06a	70.32

CONCLUSIONS

It was seen from the results of this experimental investigation that total drying time, total energy consumption and specific energy requirement is considerably reduced with the increase in drying air temperature and microwave power levels. The minimum specific energy requirements were found as 44.58 kWh/kg and 107.00 kWh/kg for 80 °C hot air drying and 160W microwave power level, respectively. Otherwise, we concluded that 750 W is the optimum microwave power level in the microwave drying of madimak with respect to total chlorophyll content and colour criteria. The main conclusion of this study is that the 80°C hot air drying method and 750 W microwave power level should be preffered for minimum specific enery consumption or for high quality total chlorophyll content and colour criteria, respectively. It depends on the user choices.

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