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Drying of olive leaves in a geothermal dryer and determination of quality parameters of dried product

H. U. Helvaci[a,*,†], A. Menon[b], L. Y. Aydemir[c,†], F. Korel[c], G. G. Akkurt[d]

[a]*Energy Engineering Program, Izmir Institute of Technology, Gulbahce Campus, Urla, 35430 Izmir, Turkey*
[b]*Brunel University London, Institute of Energy Futures, RCUK Centre for Sustainable Energy use in Food chains (CSEF), Uxbridge, UB8 3PH, United Kingdom*
[c]*Department of Food Engineering, Izmir Institute of Technology, Gulbahce Campus, Urla, 35430 Izmir, Turkey*
[d]*Department of Energy Systems Engineering, Izmir Institute of Technology, Gulbahce Campus, Urla, 35430 Izmir, Turkey*

Abstract

In this study, a cabinet type geothermal dryer was designed, operated and tested for drying olive leaves with minimum losses of phenolic content and antioxidant capacity by optimization of drying conditions. Two factors; face centered central composite design was applied and response surface methodology was used to optimize the drying conditions of olive leaves. The results indicate that phenolic content stability were mainly affected by air temperature, whereas antioxidant capacity is affected by both air temperature and velocity ($p<0.05$). The optimal drying conditions were found to be at 50°C of air temperature and 1 m/s of air velocity for the minimum losses of determined quality parameters, where 88.8% of phenolic content and 95.3% of antioxidant capacity were recovered.

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Keywords: Antioxidants; dehydration; phenolics; drying kinetics;

* Corresponding author. Tel.: +44 (0)1895 268288
E-mail address: Huseyin.Helvaci@brunel.ac.uk

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Nomenclature

A	Area, m^2
AC	Total antioxidant activity loss, %
M	Moisture content, g water g-1 dm
m	Mass, kg
N	Number of experiment
PC	Total phenolic content loss, %
T	Temperature, (°C)
TAC	Total antioxidant capacity
TPC	Total phenolic content
Subscripts	
da	Drying air
exp	Experimental

1. Introduction

Olive leaves have many beneficial effects on human metabolism, such as combating fever and other diseases due to their phenolic compound content [1]. Besides giving colour and sensory characteristics to a plant, phenolic compounds are also important for their antioxidant activities which delay the oxidation reactions and formation of free radicals in metabolism [2, 3]. Oleuropein and hydroxytyrosol are the most abundant phenolic compounds with high antioxidant activity in olive leaves and they prevent cardiac and tumoral diseases as well as diabetic neuropathy [4-6]. Dehydration is an essential process prior to the extraction and consumption of olive leaves [7]. Among all the methods, open air sun drying is not an appropriate way of drying of herbal plants due to the several drawbacks such as contamination with dust and insects and uncontrollable drying parameters which can cause over-drying as well as loss in quality of dried product. Therefore, drying in a closed and controlled environment should be preferred [8]. Garcia and Alcaide determined the effect of different drying procedures such as freeze, air and oven on the nutritive value of olive leaves and they stated that air-drying could be a suitable and simple solution for drying of olive leaves. Drying characteristics and the effective moisture diffusivity of four varieties of olive leaves were studied and drying air temperature was found to be the main parameter in the drying process [9]. Erbay and Icier evaluated the main effects of drying air temperature, drying air velocity and drying time on the product quality of dried olive leaves and determined the optimum process conditions for drying of olive leaves in a tray drier. They reported that 51.16 ºC of temperature and 1.01 m/s of velocity were the optimum drying conditions [10]. Erbay and Icier also studied the main effects of the same process variables (drying air temperature and velocity) on product quality in heat pump drying of olive leaves [11]. Furthermore, Bahloul et al. investigated the effects of solar drying conditions (drying air temperature and velocity) on drying time and quality parameters such as colour, total phenols and radical scavenging activity of four varieties of olive leaves and optimized the conditions. They showed that the total phenols and radical scavenging activity were influenced mainly by drying conditions and tended to decrease with increased drying time [12]. In order to enhance the quality of dried product, the controlled conditions such as hot air drying is important, but it needs a considerable amount of thermal and electrical use. Therefore, renewable energy sources such as geothermal energy could be an important alternative for the controlled drying methods [13]. An industrial dryer using geothermal hot water from a geothermal power plant in Thailand was designed and tested by [14]. Kumoro and Kristanto conducted a study on the drying of tobacco leaves using geothermal steam as a heat source. The effect of the steam velocity on the drying rate of tobacco leaves was also investigated. The results showed that the increase of the steam flow rate can improve the drying performance [15].

Kostoglou et al. designed and tested a tunnel dryer which utilized geothermal energy in Greece. They also stated that the geothermal water could be used efficiently for air drying of several vegetables and fruits [16]. Andritsos et al. examined a tomato drying system in Greece, where the geothermal water flows into the water-air heat exchanger to heat the drying air. The possibility of using geothermal energy for drying traditional agricultural products in the

Aegean islands was also discussed in their work. They also highlighted that low-temperature geothermal energy could be used efficiently to dry many agricultural products. Such dryers also offered an alternative for drying process with reasonable cost and the system operation independent of weather conditions [17]. In this study, a cabinet type geothermal drier was designed, operated in geothermal field where the waste water of a district heating system was used as the energy source of the dryer, and tested for drying olive leaves to evaluate the effects of drying air temperature and drying air velocity on drying process and quality parameters such as total phenolic content and total antioxidant activity of olive leaves. The drying kinetics of olive leaves were evaluated, and the drying process was optimized by using statistical design.

2. Materials and Method

Olive leaves (*Olea europaea L.*) were collected from the trees grown in Izmir Institute of Technology Campus (Izmir, Turkey) and stored in air proof plastic tubes at +4 °C for 3-5 days. Olive leaves were cleaned with tap water and filtered through filter paper to remove the excess water from its surface before the experiments. The samples were dried in a drying oven at 105 °C until constant weight was reached to determine the initial moisture content of fresh olive leaves. The average initial moisture content was found to be 40 ± 2 % (w.b.)

2.1. Geothermal dryer

A cabinet type geothermal dryer was designed and constructed to conduct the drying experiments of olive leaves (Figure 1a and 1b). The geothermal dryer consisted of a fan section, a heating section and a drying tunnel section. In the fan section, ambient air was drawn in the dryer by a centrifugal fan and was sent to the water-to-air heat exchanger. In the heating section, the ambient air was heated as it passed the water-to-air heat exchanger and it reached the drying tunnel section. In this unit, there were six trays with a length of 600 mm and a width of 500 mm and there were also an air re-circulating unit to recover the exhaust air (Table 1).

Table 1. Dryer specifications.

Height of drier	mm	554
Width of drier	mm	1100
Length of drier	mm	2000
Width of tray	mm	500
Length of tray	mm	600
Thickness of each tray	mm	20
Distance between each tray	mm	100
Space of re-circulating unit	mm	210
Tray height from the floor	mm	720
Number of trays	-	6
Critical area of dryer	m^2	0.3474

The geothermal dryer was placed at Yenikale heat centre in Balçova-Narlıdere geothermal field where the geothermal district heating system was located. In Yenikale heat centre, geothermal fluid transferred its heat by primary plate type heat exchangers to the clean city water, which circulated through the city and provided heat to the buildings. The clean city water returned to the heat exchanger at a temperature of 62-65 °C where the dryer heat input was supplied through the dryer heat exchanger.

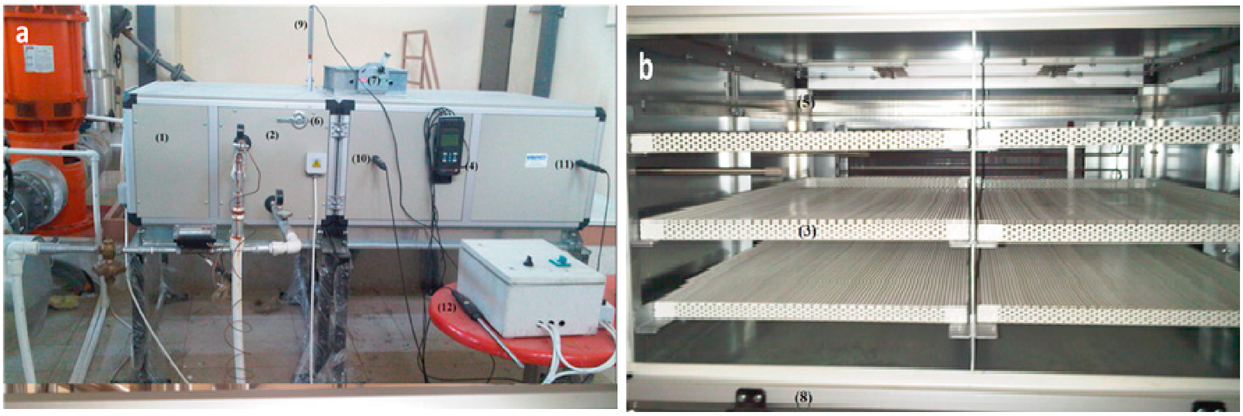

Fig. 1. The geothermal dryer (a) drying tunnel, (b) drying trays. Fan section (1), water-to-air heat exchanger (2), trays (3), drying tunnel (4), air re-circulating unit (5), discharger flap (6), chimney (7), door (8), velocity anemometer (9), Thermocouples (10-11-12).

2.2. Drying experiments

Drying experiments were carried out at different drying air temperatures of 40-50-60 °C and velocities of 0.5 – 1.0 - 1.5 m/s to evaluate the effects of drying conditions on drying characteristics and quality parameters of olive leaves. Approximately 150 g of the collected leaves were spread onto the trays as a thin layer and dried until the drying rate reached zero when the moisture content of the leaves was about 4-6% (dry weight basis). To set the drying air temperatures to 40, 50 and 60 °C, the mass flow rate of the clean city water was regulated by globe valve. The temperature and relative humidity of ambient, tray inlet and exit, and the velocity at tray inlet were measured and recorded by a data logger.

2.3. Quality measurements

Total phenolic content

Total phenolic content loss (PC) of olive leave extracts was determined using a spectrophotometer at 765 nm using Folin-Ciocalteu method [18]. Dried olive leaves was extracted with the method described in [19]. The average of the three measurements was used. PC was calculated as follows;

$$PC = \frac{TPC_{raw} - TPC_{dried}}{TPC_{raw}} \times 100 \tag{1}$$

Where, TPC represents the total phenolic content, raw indicates the olive leave before the drying, and dried represents the dried olive leaves.

Total antioxidant capacity

ABTS radical cation decolorisation assay was conducted following [20], with slight modifications. The reaction mixture was prepared by mixing 20 μl of olive leave extract with 2 ml of ABTS radical cation solution. The absorbance of each reaction mixture was kinetically monitored at 734 nm for 6 minutes, using a spectrophotometer. To calculate the area under curve (AUC), the percent inhibition / concentration values for the extracts and Trolox as standard were plotted separately against test periods. The division of the areas of curves for each extract to that of Trolox was applied to calculate the AUC value. All measurements were repeated three times and the total antioxidant capacity loss (AC) was calculated as follows;

$$AC = \frac{TAC_{raw} - TAC_{dried}}{TAC_{raw}} \times 100 \quad (2)$$

Where, TAC shows the total antioxidant content, raw represents the olive leave before the drying, and dried indicates the dried olive leave.

2.4. Experimental design and statistical analysis

In order to determine the main and interaction effects of the drying air temperature and the drying air velocity on quality parameters of dried olive leaves, two factors, face centred central composite design was applied and response surface methodology was utilised (Table 2 and 3). Statistical analysis was performed using Minitab 15 software.

Table 2. Variables in 32 central composite designs.

Independent Variables (coded)	-1	0	1
X_1 = Temperature (C)	40	50	60
X_2 = Air velocity (m/s)	0.5	1	1.5
Dependent Variables			
Y_1 = Total Phenolic content loss			
Y_2 = Total antioxidant capacity loss			

Table 3. Matrix of 3^2 central composite designs

Run	Drying air temperature (T)	Drying air velocity (v)
1	(0)	(1)
2	(1)	(0)
3	(-1)	(1)
4	(-1)	(0)
5	(-1)	(-1)
6	(0)	(-1)
7	(1)	(1)
8	(0)	(0)
9	(1)	(-1)

3. Results and Discussion

Total phenolic content (PC) and total antioxidant capacity (AC) loss for each experimental run were given in Table 4.

Table 4. Values of each response variable

Run	T (°C)	V (m/s)	PC (%)	AC (%)
1	50(0)	1.5(1)	11.34	9.43
2	60(1)	1(0)	33.8	42.94
3	40(-1)	1.5(1)	18.55	35.54
4	40(-1)	1(0)	28.68	24.88
5	40(-1)	0.5(-1)	29.59	37.6
6	50(0)	0.5(-1)	13.32	8.82
7	60(1)	1.5(1)	49.22	55.69
8	50(0)	1(0)	11.22	4.72
9	60(1)	0.5(-1)	41.05	47.34

To verify significant effects of independent variables on each response variable ANOVA was employed and coefficients obtained from the models and statistical significance of all main effects were investigated (Table 5). After elimination of insignificant variables (P>0.05), the relationship between response variables (PC) and (AC), and the independent variables (T) and (v) was evaluated through the following regression equations:

$$PC = 10.218 + 7.875T + 21.521T^2 \quad (3)$$

$$AC = 2.174 + 7.992T + 33.008T^2 + 8.223v^2 \quad (4)$$

Table 5. Evaluation of linear and quadratic terms of each variable for PC and AC

PC			AC		
Term	Coefficient	p value	Term	Coefficient	P value
T	7.875	0.037	T	7.992	0.005
V	-0.808	0.738	V	1.15	0.355
T×T	21.521	0.011	T×T	33.008	0.000
V×V	2.611	0.542	V×V	8.223	0.02
T×V	4.802	0.173	T×V	2.603	0.137

The linear and quadratic effects of drying air temperature on both PC and AC were significant. T and T^2 suggested an increase in PC and AC. Yet there was a change observed in PC values when the temperatures were kept constant and velocities varied from 0.5 to 1.5 m/s, PC was statistically not influenced by drying air velocity (p= 0,738). Furthermore, it was found that there was no significant interaction effect observed between T and v on both PC and AC. There was no significant effect of drying air velocity obtained on AC, whereas there was a relationship of a quadratic term of velocity on AC. The response surface plots demonstrated the maximum PC and AC values were obtained at 60 °C for all air velocities (Figure 2).This was due to temperature increment which might have caused a degradation, polymerisation or conversion of phenolic compounds resulting in loss of antioxidant capacity also. However, PC and AC were higher at 40 °C than those at 50 °C. The explanation for this phenomenon could be that lower drying air temperature resulted in longer drying period, which might have degraded the phenolic compounds and lowered the antioxidant capacity, similar findings were reported by several literatures [10, 21]. The optimal air conditions of drying of olive leaves for minimum PC (11.22 %) and AC (4.72 %.) were 50 °C of drying air temperature and 1 m/s of air velocity.

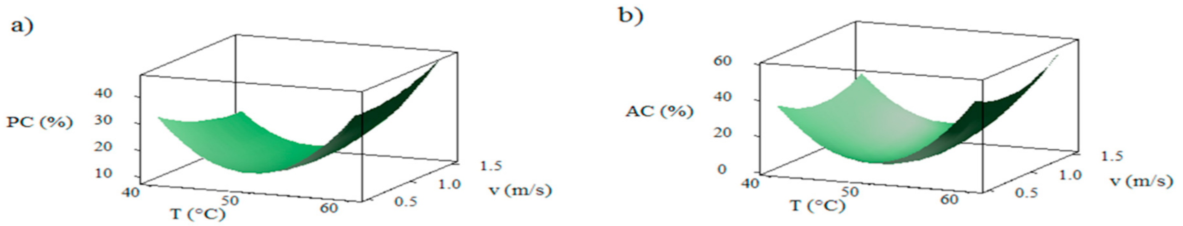

Fig. 2. Surface plots for the effects of T and v on (a) PC and (b) AC

4. Conclusions

This study investigated the effects of drying air temperature and velocity on the quality parameters of the dried product. A geothermal drier was constructed and tested in Balcova-Narlıdere geothermal field, Izmir where the clean city water (62-65 °C) of Balcova-Narlıdere district heating system was used as the heat supply of the dryer. Experiments were conducted at different drying air temperatures (40, 50 and 60 °C) and velocities (0.5, 1.0, 1.5 m/s). An optimisation study was carried out to investigate the optimal drying air conditions to evaluate minimum quality parameters loss from dried olive leaves. Optimisation results indicated that relatively high temperatures, as well as longer drying periods had an essential effect on total phenolic content and total antioxidant capacity loss. Drying air temperature of 50 °C and air velocity of 1 m/s was found to be the optimum drying air condition for the minimal total phenolic content and total antioxidant capacity loss.

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