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Effects of pre-treatments on drying kinetics and energy consumption, heat-mass transfer coefficients, micro-structure of jujube (*Zizyphus jujuba* L.) fruit

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Abstract

In this study, jujube fruits were investigated effects on drying kinetics and energy consumption (total-specific), heat-mass transfer coefficients, micro-structure of pre-treatments 2% ethyl oleate, 540 W microwave and freeze-thaw + 720 W microwave. Initial moisture of fruit from 0.75 ± 0.2 g (water).g^{-1} (dry matter) to 0.15 ± 0.1 g (water).g^{-1} (dry matter). The shortest drying durations were observed in 2% ethyl oleate pre-treated samples. The greatest total power consumption (1.502 kW) was observed in control samples The greatest specific energy consumption (158.98 kW.kg^{-1}) was observed in freeze-thaw pre-treated samples. The effective diffusion values varied between 9.53 x 10^{-8}-5.26 x 10^{-8} m^2.s^{-1}. Lewis and Jena-Das models the best estimated time-dependent moisture ratios in freeze-thaw pre-treated samples. The average speed values was determined between 0.0025-0.0005 (gr db.minute^{-1}) at the beginning of the drying and decreased to about 0.0005 (gr db.minute^{-1}) at the lasting of the drying. The largest mass transfer coefficient value was found depending on the time varied between 1.035 x 10^{-7}-8.256 x 10^{-12} m.s^{-1}. in the samples dried by dipping into a 2% ethyl oleate solution. The average heat transfer coefficient value is calculated 0.204 W.m^2 °C^{-1}. With regard to micro-structure of the dried samples, 2% ethyl oleate pre-treatments yielded the least deformations and had the closest structure to fresh samples.

Keywords: drying process; drying pre-treatments; effective diffusion; energy values.

Practical Application: The aim of this study is to dry the jujube fruit under the most suitable conditions. While doing this, the effect of some pre-treatments (2% ethyl oleate, 540 W microwave and freeze-thaw) on energy analysis and quality characteristics was investigated originally from the literature. The highest energy consumption was determined in the drying process of the samples applied freeze-thaw pretreatment. The quality feature was determined in the drying of the samples dipped in 2% ethyl oleate solution.

1 Introduction

Freshly harvested agricultural products generally have quite high moisture content (75-95%). Therefore, physical, chemical and nutritional attributes can easily be influenced by surrounding environments. Such products are generally preserved by drying (Doymaz, 2011; Ghanbarian et al., 2020). With the drying of the products, the losses in nutritional and visual quality properties are reduced to a minimum and food safety is ensured (Moloto et al., 2021).

Throughout the process of drying, various physical and chemical changes occur at different levels based on drying temperature, duration and moisture content to be achieved. Therefore, drying methods and pre-treatments should be so selected as to control undesired conditions and to keep the final quality values at desired levels (Wang & Brennan, 1995; Rubinskienė et al., 2015; Majdi & Esfahani, 2019). Producers generally lay out the agricultural products over trays or concrete surface to dry them through moisture diffusion by the heat generated with the photons coming from the sun (Wojdyło et al., 2014; Panagopoulou et al., 2019). In such natural drying processes at open spaces, drying takes quite a long time, products are exposed to solar heat for longer durations, thus significant losses in quality parameters are experienced. With these methods, it is impossible to get dry and healthy products in a short time (Doymaz & Pala, 2003; Özgen, 2015; Polatcı & Taşova, 2018). On the other hand, to eliminate such problems experienced in open-space drying processes and to control drying conditions, more sensitive scientific drying approaches were developed for the best preservations of quality and nutritional attributes of agricultural products. Such approaches include oven, vacuum, microwave, vacuum-microwave and freeze-drying methods (Wojdyło et al., 2014; Panagopoulou et al., 2019).

It is quite significant to preserve final quality of dried products. However, drying methods are expected to be reliable and economic in energy consumption. Therefore, some physical and chemical pre-treatments are applied to products to enlarge pores and accelerate the moisture removal rates and ultimately to shorten drying durations. Shortened drying durations will also reduce energy consumptions, reduce the impacts of non-enzymatic reactions, thus improve final quality parameters. Rojas & Augusto (2018a); used chemical-dipping pre-treatments and reported reduced drying durations in pumpkins (Rojas & Augusto, 2018b); bananas (Corrêa et al., 2012); rice and pea powder mixtures (Tatemoto et al., 2015). It was reported that

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electromagnetic pre-treatments shortened drying durations in apples (Brncic et al., 2010) and pears (Yao, 2012).

Jujube is a fruit of Chinese origin and has been cultivated for 4000 years. It is thought to be one of the 5 most valuable fruits in China such as peach, apricot, plum and pear. It is widely grown in Russia, India, Middle East, Anatolia, Southern Europe and North Africa after China (Yao, 2012; Gulcuoglu & Başpınar, 2020). Approximately 90% of jujube production in the world is made in China (Li et al., 2005; Wang et al., 2016). In Turkey, production is made around 1772 acres of the 960 tons. The highest production is in Amasya with 281 tons and Antalya with 204 tons (Kaplan & Okcu, 2020).

It was also reported that jujube fruits had healing effects on lung diseases. Due to its texture and water content, it is a delicate fruit and can remain at room temperature for up to a week without shrinking or darkening (Moradinezhad et al., 2018). Therefore, jujube fruits are mostly consumed as dried. There are studies investigating the effect of pre-treatments applied before drying for jujube fruit (Wojdyło et al., 2019); they investigated the most suitable method in terms of final quality values by drying the jujube fruit in vacuum microwave (480, 120 W) and hot air dryer (50, 60 and 70 °C). They found that the process performed at a temperature of 50 °C in a hot air dryer was better in terms of color, polyphenol and antioxidant properties. However, they found that the energy consumption was several times higher than the vacuum microwave dryer (Tepe & Ekinci, 2021); they investigated the effect of temperature values on water-soluble vitamin, total phenol and atotal antioxidant properties by drying jujube fruit with a hot air dryer (50, 60 and 70 °C). Water-soluble vitamins, total phenolic content, and antioxidant capacity were significantly reduced by the drying process. Degradation of water-soluble vitamins increased with the drying temperature, although total phenolic content and antioxidant capacity were not significantly affected by temperature (Niu et al., 2021); they dried the jujube fruit at three different air velocities (3, 6 and 9 $m.s^{-1}$) in a hot air dryer (55, 60, 65 and 70 °C). They investigated the effects of drying conditions on vitamin C, drying pattern and activation energy values. They reported that vitamin C is broken down by drying processes and the activation energy varies between 36.48-153.51 $kJ.mol^{-1}$.

The primary purposes of this study are: (i) comparing the drying durations of three drying pre-treatments with relation to the kinetics, (ii) selecting the most favourable thin-layer drying model and lastly, (iii) determinating effects of effective diffusion (*Deff*) values to drying pre-treatments, (iiii) identifying the variations between the dried samples regard to last moisture content and specific energy consumption, total energy consumption features, micro-structure.

2 Material and method

2.1 Sample preparation

Wild jujube fruits to be used in present experiments were supplied from Aksaray province/Turkey. Samples were brought to laboratory under reliable conditions and preserved in a fridge at +4 ± 0.5 °C until the time of analysis. Drying experiments were conducted at drying laboratory of Tokat Gaziosmanpaşa University Agricultural Faculty. To get wet basis moisture content, about 30 ± 0.5 g sample was taken, dried in an oven at 70 °C until a constant mass and reweighed (Yağcıoglu, 1999).

2.2 Drying pre-treatments

Some pre-treatments were applied to jujube fruits before the drying process to reduce drying durations and energy consumption values and preserve micro-structure. Pre-treated fruits were dried separately and compared with the control fruits. There are studies on the effects of pre-treatments applied to jujube fruit (Table 1).

Present pre-treatments included; 1) Immerse into 2% ethyl oleate solution for 10 min; 2) Intermittent microwave application of 540 W for 2 min; 3) Intermittent microwave application of 720 W to freeze-thawed samples for 1.5 min. Fruit pores were enlarged with these pre-treatments to accelerate mass diffusion and to increase drying rates.

2.3 Drying equipment and process

Şımşek Laborteknik-brand ST-120 (Turkey) type oven was used in drying experiments. Drying air temperatures were controlled with PID controllers on dryer. About 28 ± 0.5 g fresh fruits were used in drying processes. Pre-treated and control samples were dried constant 65 °C drying air temperature. In many studies, jujube fruit has been dried at temperatures of 50, 60 and 70 °C (Izlı & Polat, 2019); in the study, they determined the optimum drying temperature at 60 °C in terms of rehydration, color and microstructure analysis.

2.4 Theoretical thin layer drying models

Time-dependent dimensionless moisture ratio (MR) released from the pre-treated and control samples at different drying pre-treatments were calculated with the aid of Equation 1 (Maskan, 2000).

$$\mathrm{MR} = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

where;

MR: Moisture ratio

M_t: Instant moisture content

$M_{e:}$ Equilibrium moisture content

$M_{o:}$ Initial moisture content

The drying speed values at different drying pre-treatments were calculated with the aid of Equation 2.

$$\mathrm{DS} = \frac{N(t) - N(t + \Delta t)}{\Delta t} \tag{2}$$

where;

DS: Drying speed

N_t: Moisture content t time

$_{\Delta t:}$ after t time

Table 1. Effect of various pretreatment processes on the drying characteristics and quality of jujube.

Pre-treatment and application method	The advantage it provides	References
Cold plasma pre-treatment-Power 650 W, the gas flow 0.2 Mpa, working voltage of 5 kV and frequency of 40 kHz. Air is used to generate plasma at atmospheric pressure, and the flow rate of plasma afterglow was 135 $L.min^{-1}$.	The pre-treatment improved the contents of procyanidins, flavonoids, and phenolics by 53.81%, 33.89%, and 13.85% at most, respectively, and thereby enhanced antioxidant capacity by 36.85% at most.	(Bao et al., 2021)
Soaking pre-treatment-in a solution of 5% potassium carbonate and 0.5% olive oil	The pre-treatment positive effect on effective diffusion, total phenol, total antioxidant and total color change properties.	(Doymaz et al., 2016)
Soaking pre-treatment-ethyl oleate solution followed by slow freezing at -18 °C high pressure carbon dioxide (HPCD), and hot water blanching (HWB).	The method of AEEO + freeing pre-treatment damaged epidermis structure of jujube. This pre-treatment led to the moisture in jujube much more easily diffused and evaporated. The AEEO + freeing groups were the minimum and the HWB groups were the maximum.	(Dongsheng et al., 2017)
Carbon dioxide (CO_2) pre-treatment-containing 5% CO_2 and 95% N_2 by modified atmosphere packaging machine.	The pre-treatment changes the texture and aroma of jujube that caused an accumulation of acetaldehyde and ethanol.	(Chen et al., 2017)
Soaking pre-treatment-boiling treatment with 3% sodium chloride dipping treatment in glycerol.	The bulk density was highest with BTS. The soluble solids content was highest with. The titratable acidity was higher with DTG, and BTS showed the best browning-retarding effect.,	(Kim et al., 2013)
Soaking pre-treatment-dipping in 2% ethyl oleate plus 5% K_2CO_3 for 10 min.	Time-saving effect. The beneficial effect was considered based on its cuticle destruction. Activation energies decreased.	(Baomeng et al., 2014)
Pulsed electric fields (PEF) pre-treatment-1.5 $kV.cm^{-1}$, 1 Hz.	The pulsed electric fields (PEF) pre-treatment improved phenolic compounds extraction, especially for caffeic acid, morin and p-hydroxybenzoic acid.	(Xu et al., 2019)

Table 2. Thin layer drying models.

Models	Equation	References
Jena ve Das	$MR = hexp\left(-j\left(t^k\right)\right)+\left(mt\right)$	(Jena & Das, 2007)
Lewis	$MR = exp\left(-kt\right)$	(Lewis, 1921)

Jena and Das and Lewis equations were used to model drying curves generated for jujube fruits. Model equations are provided in Table 2.

2.5 Diffusion coefficient (D_{eff}, m^2/s)

The area in which the moisture released from pre-treated and control fruits during the oven drying process is difffused was calculated with the aid of Equation 3 (Crank, 1979; Türker & İşleroğlu, 2017).

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi}\sum_{n=0}^{\infty}\frac{1}{\left(2_n+1\right)^2}exp\left[\left(2_n+1\right)^2\frac{\pi^2}{4}\frac{Deff^t}{L^2}\right] \tag{3}$$

where; Deff: effective diffusion ($m^2.sn^{-1}$), L; half of slice thickness (m). Then, natural logarithm of the equation was taken and following equation (Equation 4) was obtained (Doymaz, 2007).

$$\ln ANO = \ln\frac{8}{\pi^2} - \frac{\pi^2 \cdot D_{eff \cdot t}}{4L^2} \tag{4}$$

Resultant moisture ratios (MR) were plotted against drying durations in a line-graph and Deff values were calculated from the slope of the resultant lines (Zakipour & Hamidi, 2011; Motevali et al., 2011).

2.6 Energy consumption values

Energy consumptions were determined for each drying process with the aid of Polaxtor-brand PLAX-15366 model power analyzer (Motevali et al., 2011); specific energy consumptions were calculated with the use of the changes in time-dependent mass loss (Equation 5).

$$SEC = TEEC / TWL \tag{5}$$

where;

SEC: Special energy consumption ($kW.kg\ water^{-1}$)

TEEC: Total elecric energy consumption (kW)

TWL: Total water loss (kg)

2.7 Convective mass transfer coefficient (h_m)

The effect of different drying pretreatments on the convective mass transfer coefficient (h_m) values of jujube fruit was calculated by Equation 6 (Lahsasni et al., 2004; Daş et al., 2021).

$$h_{m}=\frac{V}{A_{m.t}}\cdot\ln\left(MR\right) \quad (6)$$

where;

h_m: Convective mass transfer coefficient ($m.s^{-1}$)

V: Materiel volume (m^3)

A_m: Materiel surface area (m^2)

t: Time (s)

2.8 Convective heat transfer coefficient (h_c)

The effect of different drying pretreatments on the convective heat transfer coefficient (h_c) values of jujube fruit was calculated by Equations 7-14 (Lahsasni et al., 2004; Daş et al., 2021).

$$N_{u}=0.664.\sqrt{Re}.\sqrt[3]{\Pr} \quad (7)$$

$$N_{u}=\frac{hc.L}{Kv} \quad (8)$$

$$R_{e}=\frac{L.V.pv}{\mu v} \quad (9)$$

$$P_{r}=\frac{\mu v.Cv}{Kv} \quad (10)$$

$$pv=\frac{353.44}{Ti+273.15} \quad (11)$$

$$K_{v}=0.0244+\left(0.6773.10^{-4}.Ti\right) \quad (12)$$

$$C_{v}=999.20+0.1434.Ti+1.101.10^{-4}.Ti^{2}-6.7581.10^{-8}.Ti^{3} \quad (13)$$

$$\mu v=1.718.10^{-5}+4.620.10^{-8}Ti \quad (14)$$

2.9 Micro-structure analysis

Samples were taken from dried products and a longitudinal section was taken from the peals right from the center of product. The section was placed into distilled water between slide-lamella of Olympus-brand light microscope. The deformations in fruit peal cell walls were imaged under 400x imaging of light microscope (Eim et al., 2013).

3 Results and discussion

3.1 Drying performance values

The wet-basis initial moisture content of jujube fruits was measured as 42.67% and fruits were dried to an average dry-basis moisture content of 0.15 ± 0.1 g (water).g^{-1} (dry matter). Drying durations of pre-treated and control fruits are provided in Table 3.

As can be inferred from Table 2, pre-treatments influenced drying durations. The longest drying duration (580 min) to bring the fruits to a desired range of moisture (10-15%) was observed in control fruits and the shortest drying duration (510 min) was observed in 2% ethyl oleate-treated fruits. Data showing the effect of pre-treatments on drying speed values is given in Figure 1.

Table 3. Mean drying performance values.

Pre-treatments	Mean wet-basis moisture content (%)	Mean drying duration (min)
Control	13.19	580
2% Ethyl oleate	12.09	510
540 W	13.26	540
Freeze-Thaw	14.77	535

Pre-treatments reduced drying times by 6.90-12.07% compared to control (An et al., 2019); when they dried the black mulberry fruit at 60 °C, the ethyl oleate pretreatment reduced the drying time by 17.17-40.70% (Izlı et al., 2017); in the drying process of mango samples at 60, 70 and 80 °C temperatures, the drying times were determined as 175, 140 and 95 min, respectively (Aydar, 2021). It has been determined that the increase in ultrasound pretreatment and power values in the drying process of olive leaves reduces the drying time by 42.50% on average. Data showing the effect of pre-treatments on % moisture content cumulative values is given in Figure 2.

3.2 Theoretical thin layer drying model values

Drying curve coefficients, R^2 and p values of thin layer drying models for jujube fruits are provided in Table 4.

As can be inferred from Table 3, among the thin layer drying models used in this study, Lewis and Jana-Das models the best estimated time-dependent moisture ratios during the drying process of jujube fruits. The R^2 value of these models was identified as 0.9988 and the best estimations were achieved in free-thaw pre-treated fruits.

3.3 Effective diffusion values

While calculating effective diffusion values of dried jujube fruits with different pre-treatments, required time-dependent ln MR values and the linear graph are presented in Figure 3 and effective diffusion coefficients are provided in Table 5.

As can be inferred from the equations of time-dependent ln MR lines, the greatest R^2 (0.9986) was observed in control samples and the lowest R^2 (0.9463) was observed in 2% ethyl oleate pre-treated samples. Effective diffusion coefficients for drying processes of control and pre-treated jujube fruits are provided in Table 5.

As can be inferred from Table 5, the greatest and the lowest effective diffusion coefficients were respectively observed in 2% ethyl oleate and control treatments. Pre-treatments influenced effective diffusion coefficients and increased the effective diffusion as compared to the control samples. It has been reported that pre-treatments performed improve the drying kinetics on fruits okra; (Tüfekçi & Özkal, 2017), kiwifruit; (Nowacka et al., 2014), shiitake mushrooms; (Zhao et al., 2019).

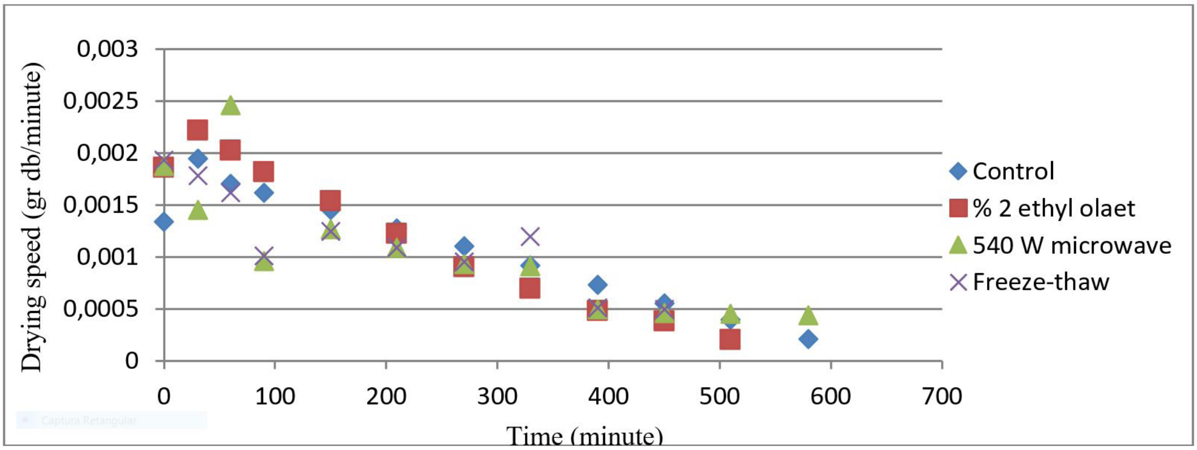


Figure 1. The drying speed values of dried samples.

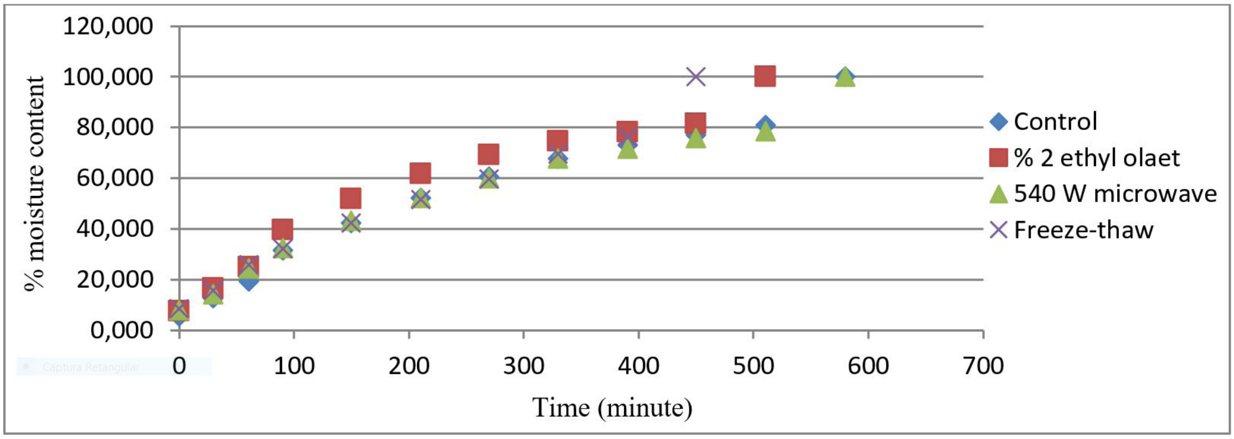


Figure 2. The % moisture content cumulative change values of dried samples.

Table 4. Values of mathematical models.

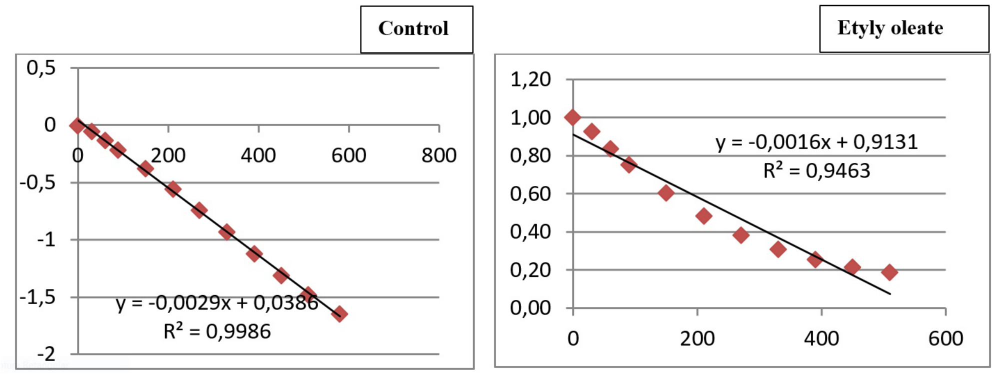
Pre-treatments	Models	k	h	j	m	R^2
Control	Lewis	0.0028	-	-	-	0.9957
	Jena-Das	1.0154	0.4053	0.8049	0.0117	0.9978
2% Ethyl oleate	Lewis	0.0034	-	-	-	0.9979
	Jena-Das	1.0107	0.4056	0.8043	0.0070	0.9987
540 W	Lewis	0.0028	-	-	-	0.9983
	Jena-Das	1.0030	0.4053	0.8050	-0.0015	0.9983
Freeze-thaw	Lewis	0.0027	-	-	-	0.9988
	Jena-Das	1.0009	0.4052	0.8050	-0.0039	0.9988

3.4 Energy consumption values

Total and specific energy consumption graphs for pre-treated and control samples are respectively presented in Figures 4-5.

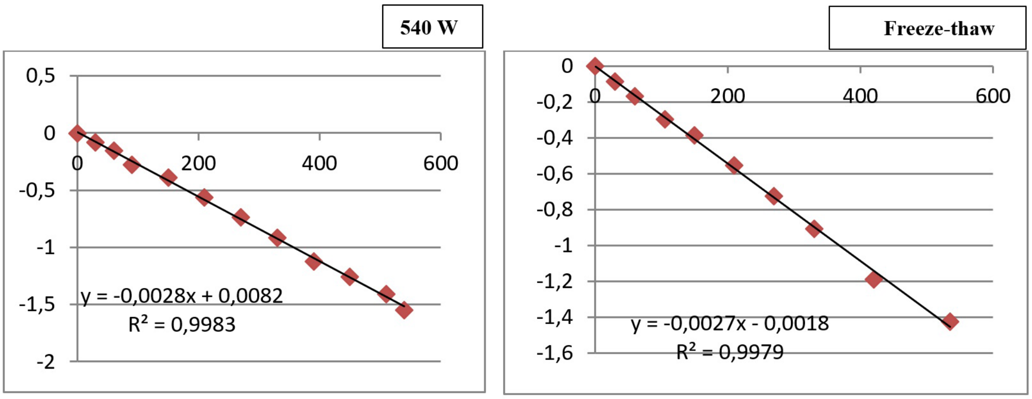
According to Figure 4, the greatest total power consumption (1,502 kW) was observed in control samples and the lowest total power consumption (1.352 kW) was observed in 2% ethyl oleate-treated samples. It was observed that pre-treatments influenced total power consumption values (Figure 5). It has been understood from the findings of the study that there is an inverse relationship between the drying temperature and the energy consumption values (0.31-0.43 kWh) (Alibas & Köksal, 2014).

As can be inferred from Figure 5, specific energy consumption of pre-treated samples continuously increased during the initial 100 min of drying process, then a parabolic decrease was observed



a) Control samples (without pre-treatments)

b) 2% ethyl oleate



c) 540 W microwave

d) Freeze-thaw and 720 W microwave

Figure 3. The ln MR values and line graph of dried samples.

Table 5. Effective diffusion coefficients.

Pre-treatments	Effective diffusion coefficients ($m^2.s^{-1}$)
Control	9.53×10^{-8}
2% Ethyl oleate	5.26×10^{-8}
540 W	9.20×10^{-8}
Freeze-Thaw	8.87×10^{-8}

in specific energy consumptions. Such a case revealed that initially power consumptions were greater than the removed moisture, then removed moisture was greater than power consumption. Convective mass transfer coefficient values depending on time are given in Figure 6.

3.5 Convective mass transfer coefficient (h_m)

The effect of drying pre-treatments on convective mass transfer coefficient was calculated (Figure 6).

According to Figure 6, it is seen that the effect of pre-treatments performed before drying on convective mass transfer coefficient values is significant. It changed the convective mass transfer coefficient values of the pre-treatment of dipping in 2% ethyl oleate solution more than other pre-treatments. The convective mass transfer coefficient values calculated for the control group samples varied between 1.162×10^{-7}-2.017×10^{-10} $m.s^{-1}$, while it varied between 1.035×10^{-7}-8.256×10^{-12} $m.s^{-1}$ for the 2% ethyl oleate group samples. These values for 540 W microwave and freeze-thaw pre-treated sample groups are respectively; 1.116×10^{-7}-2.107×10^{-10} $m.s^{-1}$, 1.054×10^{-7}-1.703×10^{-10} $m.s^{-1}$ (Bezerra et al., 2015); the mass transfer coefficients in drying of passion fruit peel were computed between 4.53×10^{-7} and 8.702×10^{-7} $m.s^{-1}$. It is thought that higher values are calculated as this will be faster and more practical than the passion fruit peel.

3.6 Convective heat transfer coefficient (h_c)

The effect of drying pre-treatments on convective heat transfer coefficient was calculated. It was determined that the average heat transfer coefficient value this study is calculated 0.204 $W.m^2$ °C^{-1} (Jain & Tiwari, 2004); cabbage and peas dried sera tip in a dryer to a certain amount of moisture. They calculated that the convective heat transfer coefficient took values between 0.16-0.36 $W.m^2$ °C^{-1} (Kaya et al., 2006); they calculated that the convective heat transfer coefficient varied between 4.33-96.16 $W.m^2$ °K^{-1} (0.016-0.37 0.16-0.36 $W.m^2$ °C^{-1}) in their drying studies. There are similar findings in the literature.

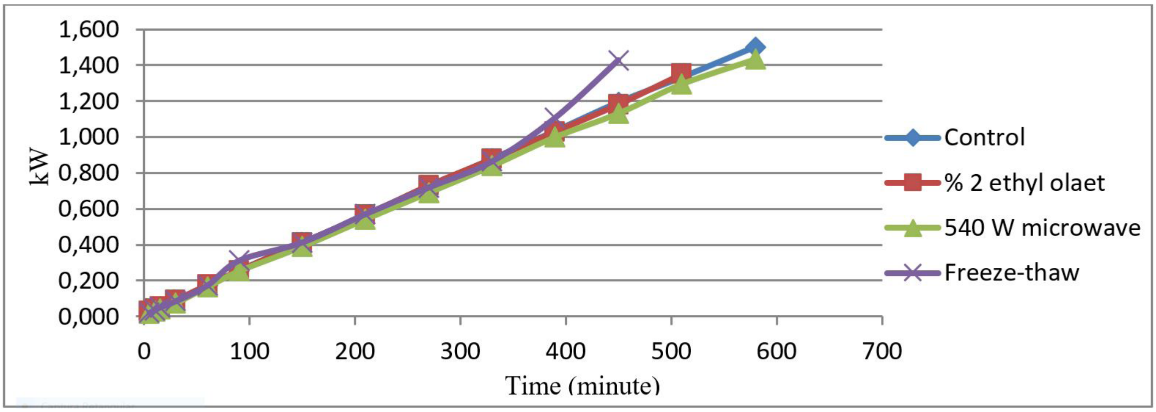


Figure 4. Total power consumption values.

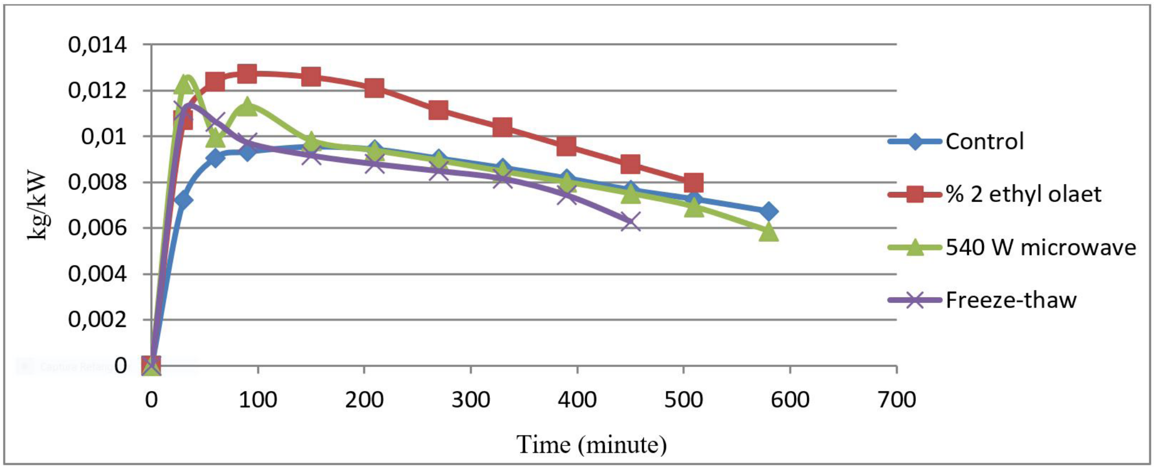


Figure 5. Specific power consumption values.

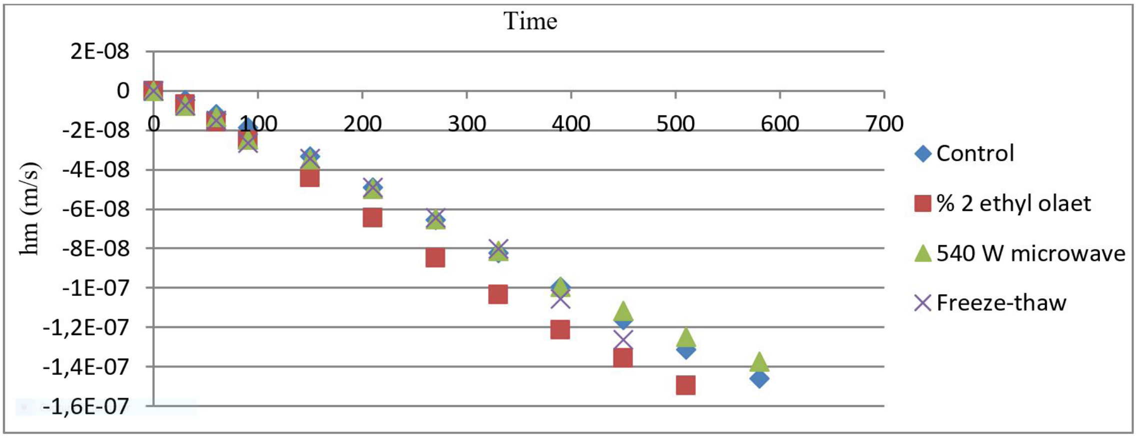


Figure 6. Convective mass transfer coefficient (h_m).

3.7 Micro-structure images

Micro-structure images of pre-treated and untreated control samples taken under light microscope are presented in Figure 7.

Micro-structures presented in Figure 7, revealed direct information about rehydration of dried samples and indirect information about nutritional values. Image of fresh fruits revealed that jujube cells were full and intercellular spaces were distinctive. Images of control samples revealed deformations in upper epidermis cells and the underlying 2-3 rows of cell. The image of 2% ethyl oleate-treated fruits revealed that micro-structure of the treated fruits was close to fresh samples, slight

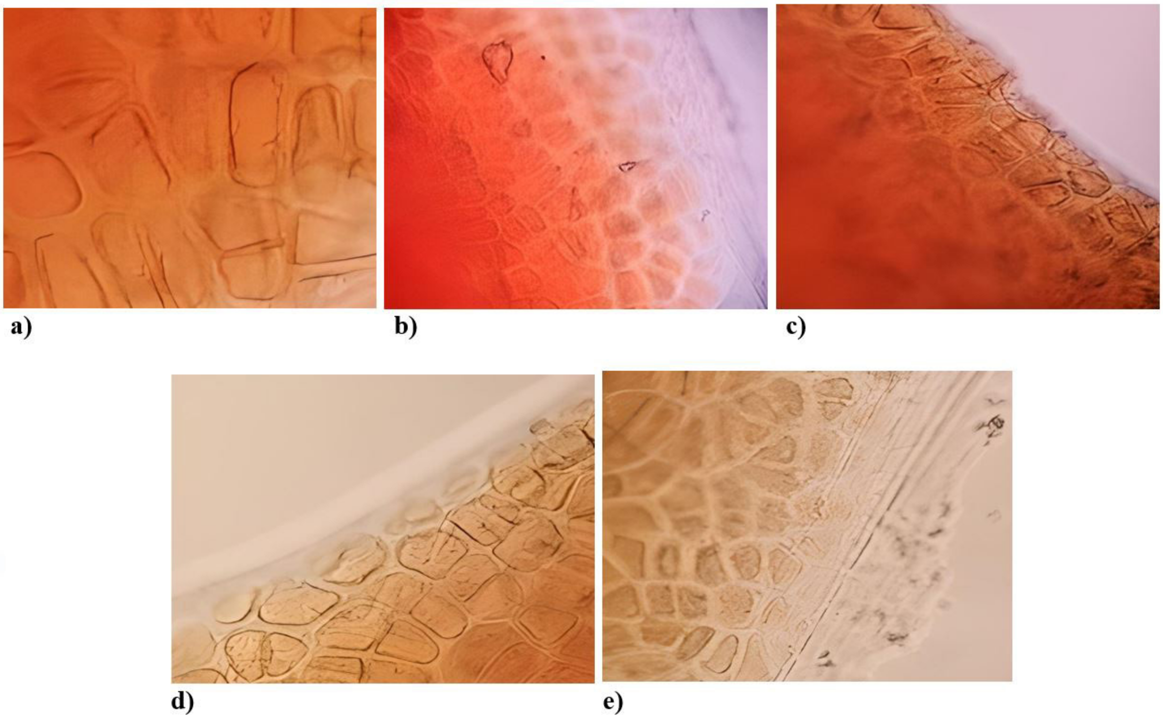


Figure 7. Micro-structure images of dried samples: a) Fresh, b) Control, c) 2%’Ethyl oleate, d) 540 W microwave, e) Freeze-thaw (720W).

shrinkage was observed in upper cells, but cellular disintegration was not observed at all (Ando et al., 2019); carrot dried in microwave and conventional ovens and at different temperatures. The freeze-thaw pretreatment determined that this pretreatment has a positive effect on the microstructure. Partial deformations were observed in upper epidermis cells of 540 W microwave-treated samples and these samples had the best micro-structure after 2% ethyl oleate-treated samples. For freeze-thaw samples, significant deformations were observed in upper epidermis cells and underlying 4-5 rows of cells. As compared to fresh and the other pre-treated samples, freeze-thaw pre-treatments the worst preserved micro-structure of the fruits.

4 Conclusions

In this study, effects of different pre-treatments (2% ethyl oleate, 540 W microwave and freze-thaw + 720 W microwave) on drying durations, power consumption and micro-structures of oven-dried (60 °C) jujube fruits were investigated. Better outcomes for investigated parameters were achieved with 2% ethyl oleate pre-treatments. The shortest and the longest drying durations were respectively observed in 2% ethyl oleate pre-treated and the control samples. Lewis and Jena-Das models the best estimated time-dependent moisture ratios in freeze-thaw pre-treated samples. The greatest power consumption (1.502 kW) was observed in control samples and the lowest power consumption (1.352 kW) was observed in 2% ethyl oleate pre-treated samples. It was determined that the average speed values started between 0.0025-0.002 (gr db/min) at the beginning of the drying and decreased to about 0.0005 with the decrease of the moisture content. The greatest effective diffusion value (5.26×10^{-8} $m^2.s^{-1}$) was observed in 2% ethyl oleate pre-treated samples and the lowest effective diffusion (9.53×10^{-8} $m^2.s^{-1}$) was observed in control samples without any pre-treatments. In the study, it was found that the largest mass transfer coefficient value depending on the time varied between 1.035×10^{-7}-8.256×10^{-12} $m.s^{-1}$ in the samples dried by dipping into a 2% ethyl oleate solution. It was determined that the average heat transfer coefficient value this study is calculated 0.204 $W.m^2$ $°C^{-1}$. With regard to micro-structure of the dried samples, 2% ethyl oleate pre-treatments yielded the least deformations and had the closest structure to fresh samples. It was concluded based on present findings that jujube fruits should be immersed into 2% ethyl oleate solution before drying and then dried accordingly to get shorter drying durations, lower power consumptions and better micro-structures.

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