Current Trends in Natural Sciences
Vol. 11, Issue 22, pp. 53-58, 2022
https://doi.org/10.47068/ctns.2022.v11i22.007

Current Trends in Natural Sciences (on-line)
ISSN: 2284-953X
ISSN-L: 2284-9521

Current Trends in Natural Sciences (CD-Rom)
ISSN: 2284-9521
ISSN-L: 2284-9521

ENERGY ASPECTS AND EFFECTIVE MOISTURE DIFFUSIVITY OF RED PEPPER: CHANGE IN CULTIVARS AND DRYING METHODS

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Abstract
The drying methods have been performed successfully for many years in product processing and preservation. The moisture content of the products has been reduced to desirable levels with the use of this method. In the present study, the effect of different drying methods on specific moisture extraction ratio, specific energy consumption, effective moisture diffusivity, energy, and thermal efficiency of Pinar and Bozok red pepper cultivars were determined. Red peppers were dried eight different drying methods of six drying techniques. According to findings the shortest and longest durations were recorded in freeze and microwave (600 W) drying respectively. The greatest specific energy consumption values were found in freeze drying. Both 300 W and 600 W had the highest thermal efficiency, energy efficiency, and specific moisture extraction ratio, values. Generally, the greatest effective moisture diffusivity values were determined in microwave drying, while the lowest ones were determined in natural conditions such as open-sun, shade, and greenhouse drying.

Keywords: Pepper, energy consumption, moisture, durations, thermal efficiency

1. INTRODUCTION

Red pepper is extensively utilized as food component such as sausages, stews, soups, cheeses, pizzas (Arimboor et al., 2015). However, peppers have high moisture contents, for this reason they quite short shelf life. Red peppers highly sensitive to microbial deterioration and are also quickly spoiled textures (Montoya-Ballesteros et al., 2014). The drying methods have been performed successfully for many years in product processing and preservation. The moisture content of the products has been reduced to desirable levels with the use of this method (Çetin, 2022).
Drying process also is important for the food commodities as its transportation costs, reduces packaging and extends shelf life of products. The other importance of this process is that it allows the reach of products out of season (Gümüşay et al., 2015). The different convective methods are commonly used for agricultural products. However, it has long drying times and high energy consumption. Freeze-drying is an effective for retaining nutrients, although expensive aboriginal cost (Tan et al., 2021). For many years, open sun technique is used because of low operating costs

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and availability (Hussein et al., 2020). Microwave drying provides homogeneous heat and energy distribution, prevents thermal degradation, and offers energy saving (Pinar et al., 2021).
The heating mechanism and conditions inside the material differ in different drying conditions. Effective moisture diffusion must be known to model mass transfer processes such as adsorption, dehydration, and desorption of moisture during storage (Sharma and Prasad, 2004). In addition, the effective moisture diffusivity is one of the most important material properties and its value depends on the conditions within the product such as physical structure, moisture content, and temperature of the product. In this study, the effects of eight different drying methods on effective moisture diffusivity, specific moisture extraction ratio, specific energy consumption, thermal and energy efficiency of two red pepper cultivars were investigated.

2. MATERIALS AND METHODS

2.1. Materials

In the present study, 'Bozok' and 'Pinar' red pepper varieties were used. Drying processes were performed in a hybrid (air convective+microwave) dryer (Arçelik KMF 833 I, Turkey). Fresh products were brought to the drying laboratory in the portable type of refrigerator in order to prevent moisture loss and were kept in the refrigerator of +4 ° C during the drying period.

2.2. Methods

2.2.1. Processes

Eight different methods of six drying techniques (open-sun, shade, greenhouse, microwave, air-convective, and freeze drying) were applied. To determine initial moisture, samples were dried in an oven (Memmert UN55, Germany) at 105 °C for 24 h. Convective, microwave, and hybrid drying processes were performed by hybrid dryer (Arçelik KMF 833I, Türkiye). In microwave drying was performed at 600 and 300 W. In convective drying was performed at 60 and 80 °C temperatures. In open-sun, shade, and greenhouse drying, samples were laid out on drying papers (50 × 50 cm). The peppers were dried at 25.8 °C mean temperature and 48.75 % mean relative humidity in open-sun drying. Shade drying was carried out at room temperature at 24 °C. In the greenhouse drying, mean temperature, and relative humidity were recorded as 34.55 °C and 34.20 %, respectively. Freeze drying were performed with lab-scale freeze dryer (Christ ALPHA 2–4 LSCplus, Germany). In the tests, 140 ± 5 g samples were used, and the initial moisture of the samples were 82.59 and 84.65 % (w.b.) for Bozok and Pinar, respectively (Pinar et al., 2021).

2.2.2. Effective Moisture Diffusivity

Effective moisture diffusivity (Deff) values were calculated with the use of Eq. (1) (Crank, 1975; Çetin et al., 2022):

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp\left(-\frac{(2n-1)^2 \pi^2 D_{eff} t}{4L^2} \right) \tag{1}$$

where; D_{eff} is effective moisture diffusivity (m^2 sec^{-1}), L is half thickness of sample (m), t is drying duration.
For long drying times, the first term of the above equation is used (Çetin, 2022).

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

The slope of the graph of ln (MR) versus drying time gives the k_0 in the equation below.

$$k_0 = \frac{\pi^2 D_{eff}}{4L^2} \tag{3}$$

2.2.3. Energy Aspects

For determination of energy consumption (E_c), a digital watt-meter (Tt Technic PM-001, Turkey) was used (Taskin, 2020). The specific moisture extraction rate (SMER), specific energy consumption (SEC), energy efficiency (η_{en}) were calculated using the Eq. 4-6 (Motevali et al., 2016)

$$SEC = \frac{E_c}{m_w} \tag{4}$$

$$SMER = \frac{m_w}{E_c} \tag{5}$$

$$\eta_{en} = \frac{m_w \lambda_{wp}}{E_c} \tag{6}$$

$$\frac{\lambda_{wp}}{\lambda_w} = 1 + 23\exp(-0.4X) \tag{7}$$

where, m_w is evaporated water mass (kg), X is moisture content (kg water kg dry matter^{-1}), λ_w is water latent heat (J kg-1) and λ_{wp} is sample latent heat (J kg^{-1}).

2.2.4. Thermal Efficiency

In the present study, thermal efficiency were determined by Eq 8 (Beigi, 2016):

$$\eta_{th} = \frac{P\,A\,\lambda_w (M_o - M_e)}{F\,t\,(100 - M_e)} \tag{8}$$

where, λ_w is latent heat of evaporation of water (kJ kg^{-1}), A is the area of drying tray (m^2), P is product amount (kg m^{-2}), F is heating capacity (kW), M_e is amount of water evaporated from sample (kg), and t is drying time.

3. RESULTS AND DISCUSSIONS

In this study, drying time and effective moisture diffusivity values were presented in Table 4. The greatest drying time was determined as 10080 min in shade drying. The microwave drying as 600 W power level had the lowest drying time. Generally, the greatest effective moisture diffusivity values were determined in microwave drying, while the lowest ones were determined in natural

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conditions such as open-sun, shade, and greenhouse drying. Effective moisture diffusivity values ranged from 6.30x10^{-13} m^2s^{-1} (60 °C) to 4.29x10^{-11} m^2s^{-1} (600 W) for Bozok cultivar, and from 9.37x10^{-13} m^2s^{-1} (Shade) to 1.27x10^{-10} m^2s^{-1} (300 W) for Pinar cultivar. The greatest effective moisture diffusivity values were obtained 600 W for Bozok and 300 W for Pinar. In addition, the lowest values were found in 60 °C for Bozok, and Shade for Pinar. Decrement of moisture content on sample surface increment the moisture gradient at the surface and center of the material. In addition, this phenomenon allows the moisture to move faster through the sample, thus increasing the D_{eff} (Çetin et al., 2022). İncedayı et al. (2020) reported D_{eff} values for red pepper for different pre-treated assisted convective drying (60 and 70°C) between 6.11x10^{-10} and 9.31x10^{-10} m^2s^{-1}. In contrary to present study, Scala and Crapiste (2008) indicated effective moisture diffusivity ranging from 5.01 to 8.32x10^{-10} m^2s^{-1} for red pepper at 50, 60 and 70 °C.

Table 1. Drying time and effective moisture diffusivity

Drying Conditions	Drying Time (min)		D_{eff} (m^2s^{-1})	
	Bozok	Pinar	Bozok	Pinar
Open-sun	4800	4800	3.29x10^{-13}	1.29x10^{-12}
Shade	10080	10080	1.64x10^{-13}	9.37x10^{-13}
Greenhouse	4800	4800	4.38x10^{-13}	1.41x10^{-12}
300 W	24	42	4.33x10^{-11}	1.27x10^{-10}
600 W	24	21	4.29x10^{-11}	1.72x10^{-10}
60 °C	1800	2070	6.30x10^{-13}	3.51x10^{-12}
80 °C	810	810	1.59x10^{-12}	5.03x10^{-12}
Freeze	4320	4320	2.47x10^{-13}	1.05x10^{-12}

Energy consumption and specific energy consumption (SEC) values were presented in Figure 1 and 2. The highest energy consumption was determined in freeze drying with the values of 4.32 kWh for both cultivars. The highest specific energy consumption values were found as 5.90 and 5.68 kWh kg^{-1} for Bozok and Pinar, respectively. The lowest energy consumption and specific energy consumption were determined in microwave drying.
SMER, η_{en} and η_{th} values are presented in Table 4. The highest SMER was found in 300 W (2.25 kg kWh^{-1}) for Bozok, and 600 W (1.48 kg kWh^{-1}) for Pinar. Freeze drying had the lowest SMER values as 0.17 kg kWh^{-1} for Bozok, and 0.18 kg kWh^{-1} for Pinar. Microwave dryer was determined the most efficient system with the η_{en} values of 45.42% (300W) and 49.73% (600W), for Bozok and Pinar, respectively. The 600 W microwave power level had the greatest thermal efficiency values as 21.82% and 24.27% for Bozok and Pinar, respectively. Nasıroglu and Kocabıyık (2007) reported specific energy consumption values for red pepper in infrared dryer (300, 400 and 500W) between 4.62 and 7.59 kWh kg^{-1}. Pal et al. (2010) found the SMER for red pepper dried in hot air dryer (30, 35, 40, 45, 55 and 65 °C) between 0.55 and 1.10 kg kWh^{-1}.

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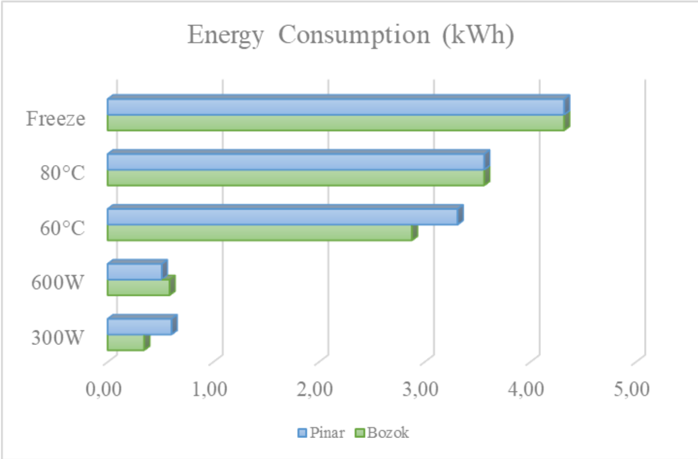

Figure 1. Energy consumption of drying methods

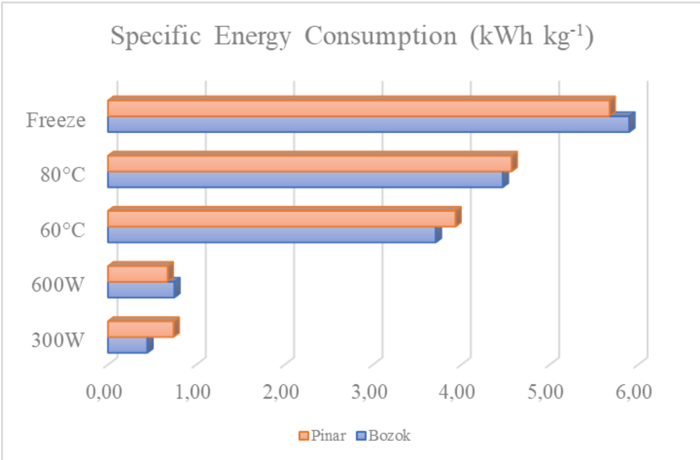

Figure 2. Specific energy consumption of drying methods

Table 2. Energy aspects of drying methods

Drying Conditions	SMER (kg kWh^{-1})		η_{en} (%)		η_{th} (%)	
	Bozok	Pinar	Bozok	Pinar	Bozok	Pinar
300 W	2.25	1.35	45.42	45.25	21.72	13.03
600 W	1.33	1.48	44.71	49.73	21.82	24.27
60 °C	0.27	0.25	10.59	9.99	2.03	1.92
80 °C	0.22	0.22	8.61	8.42	4.55	4.45
Freeze	0.17	0.18	6.73	6.99	0.86	0.89

4. CONCLUSIONS

In this study, drying of pepper cultivars was investigated for eight different drying methods. Findings showed that microwave dryer had the greatest drying times, effective moisture diffusivity and energy efficiency. The shortest drying time was found in microwave drying while the longest

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was found in shade drying. The highest E_c was obtained in freeze dryer while the lowest E_c was obtained in the microwave drying. However, the highest SMER was recorded in microwave drying, while the lowest was recorded in freeze drying. Microwave drying had the greatest D_{eff}. As a result, microwave drying has provided extremely significant advantages for drying time, energy aspects and thermal efficiency. Due to these advantages of microwave drying, it is recommended that its use in drying of peppers.

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