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Research Article

Drying of White Nectarine Puree Through Various Methods and an Analysis of Their Effects

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Abstract

The influence of various drying techniques, including microwave, hot air, infrared, and freeze drying (F.D.), on key parameters such as drying time, drying rate, color, energy consumption, and specific energy consumption of white nectarines was systematically examined. In a comparative analysis of drying methods, microwave drying at 300 W exhibited the shortest drying time, completing the process in 15 minutes, whereas freeze-drying required the longest time, extending to 360 minutes. Besides, the highest drying rate (0.55 g water / g dry matter) was obtained by microwave drying at 300 W. Although freeze drying resulted in the best color retention when compared to fresh samples, it also exhibited the highest levels of energy consumption and specific energy consumption. Overall, freeze drying is advised primarily for preserving quality parameters, though it may not be the most efficient option in terms of energy consumption.

Keywords: Color, drying rate, drying time, energy consumption.

Beyaz Nektarin Püresinin Farklı Yöntemler ile Kurutulması ve Etkilerinin Analizi

Öz

Mikrodalga, sıcak hava, kızılötesi ve dondurarak kurutma gibi çeşitli kurutma tekniklerinin; beyaz nektarinde kurutma süresi, kurutma hızı, renk, enerji ve özgül enerji tüketimi gibi temel parametreler üzerindeki etkisi sistematik olarak incelenmiştir. Kurutma yöntemlerinin karşılaştırmalı analizinde, 300 W mikrodalga kurutma 15 dakika ile en kısa sürede kurutma işlemini tamamlarken, dondurarak kurutma 360 dakika gerektirerek kurutma süresini uzatmıştır. Diğer yandan, en yüksek kurutma hızı (0.55 g su / g kuru madde) 300 W mikrodalga kurutma ile elde edilmiştir. Dondurarak kurutma, taze örneklerle karşılaştırıldığında en iyi renk korunmasını sağlasa da en yüksek enerji tüketimi ve özgül enerji tüketimi de göstermiştir. Genel olarak, dondurarak kurutma kalite parametrelerini korumak için öncelikle tavsiye edilebilir, ancak enerji tüketimi açısından en verimli seçenek olmayacaktır.

Anahtar Kelimeler: Renk, kuruma hızı, kuruma süresi, enerji tüketimi.

Introduction

White nectarine is an endemic fruit of the Çanakkale region of Türkiye and is internationally recognized by receiving a Geographical Indication Registration under the name "Bayramiç Beyazı" (Anamur and Türkmen, 2021; Gür and Eroğul, 2018). It is also locally called " Tüysüz Beyaz Şeftali " or " Evciler Tüysüzü " and is a shiny, hairless, hard fruit with a thin yellow-green skin and white flesh (Serbes, 2024; Gür, 2012). The fruit is classified in the same class as peach and named Prunus persica var. nucipersica Schneid. or Prunus persica var. nectarine Maxim (Kaynaş and Kesmen, 2018). However, the main feature that distinguishes white nectarines from peaches and other nectarines is their flavor (Serbes, 2024). The size of the fruit, the average fruit weight, and the proportion of fruit flesh vary between 40-50 mm, 30-62 g, and 87-91%, respectively (Kaynaş and Kesmen, 2018). The white nectarine ripens between the end of July and the beginning of September (Gür and Şeker, 2014).

Harvested fruits can be provided directly to the market with a shelf life of 12-15 days, or they can be stored in cold storage at 0°C and 85-90% relative humidity for up to 4 weeks (Serbes, 2024). Nevertheless, long-term storage affects the taste, nutritional quality, and shelf life of the products (Temizkan, 2017).

While the search for environmentally friendly and low-cost preservation methods continues, the nutritional value and quality of food products must be protected (Erbay & Küçüköner, 2008; Temizkan, 2017). Drying is one of the most widely used methods due to its advantage of allowing long-term preservation (Günaydın et al., 2022). Moreover, numerous drying technologies are available across the food, agriculture, and textile industries. These technologies utilize alternative energy sources, such as microwaves, ultrasonic waves, and infrared radiation (Walters et al., 2014). Considering the drying method challenges, the puree drying process offers a relatively inexpensive and straightforward approach, requiring shorter drying times and lower drying temperatures (Polat et al., 2021). Dried products obtained with the above method are consumed in different areas such as instant soup, baby food, and ready-made meals (Erbay and Küçüköner, 2008).

This study aimed to analyze the impact of microwave, hot air, infrared, and freeze drying on drying time, drying rate, color, energy consumption, and specific energy consumption of white nectarine. The main objective of puree drying is to overcome the knowledge gap regarding the use of white nectarine as an ingredient for various foods and to have energy-efficient rapid drying requirements in the industry.

Material and Method

Drying Equipments and Drying Procedure

White nectarine samples were sourced from a local market in Bursa, Türkiye, and stored at a temperature of 4 ± 0.5 °C until the drying experiments were conducted. The initial moisture content of the fresh white nectarine samples was determined to be 5.63 (g water/g dry matter) on a dry basis (d.b.) through oven drying at 70 °C for 24 hours using an M3025P model (Electromag, Turkey).

The drying experiments were conducted using an oven (Arçelik, KMF 833, Türkiye), with the hot air drying performed at temperatures of 80 ºC and 90 ºC, while the microwave drying was carried out at power levels of 200 W and 300 W. The infrared drying process was performed using a custom-designed dryer that featured a 1500 W halogen infrared lamp positioned longitudinally above the products. The spacing between the lamp and the product was configured to be 12 cm. Power settings of 300 W and 400 W were implemented in continuous infrared drying modes (PR1). A laboratory-scale freeze dryer (Alpha 1–2 LD Plus, Osterode am Harz, Germany) was utilized, operating at a processing temperature of −50 °C and maintaining a constant pressure of 52 Pa within the drying chamber. The process conditions for the drying methods were determined based on literature review (Chen et al., 2015; Motevali et al., 2011; Kocabiyik and Tezer, 2009 and Taskin et al., 2021).

The peeled samples, each weighing 50 g, were pureed with a home-type blender (800, Tefal, France). The monitoring of moisture loss in the samples occurred at different intervals depending on the drying method employed: 3 minutes for microwave drying, 9 minutes for hot air drying, 6 minutes for infrared drying, and 30 minutes for freeze drying. Using a Radwag balance (Radom, Poland) with an accuracy of ± 0.01 g, measurements were taken until the samples reached a final moisture content of 0.1 on a dry basis (d.b.).

Drying Curves

In the course of the drying experiments, the moisture content (MC) and drying rate (DR) were determined using Equation (1) and Equation (2), respectively. In this context, W_w represents the weight of the wet sample (g), W_d denotes the weight of the dry sample (g), M_t+d_t refers to the moisture content at time t+d_t (g water/g dry matter), Mt represents the moisture content at a specific time (g water/g dry matter), and t signifies the drying time (min) (Thorat et al., 2012).

$$MC = \frac{(W_w - W_d)}{W_d} \tag{1}$$

$$DR = \frac{M_{d+dt} - M_t}{dt} \tag{2}$$

Color Measurement

The color analysis of both fresh and dried white nectarine samples was performed with five measurement using a color analyzer (MSEZ-4500L, Hunterlab, USA), following calibration against standard black and white surfaces. The color attributes were expressed using the L, a, and b parameters: L indicates lightness or darkness, a represents the balance between greenness (−) and redness (+), while b denotes the balance between blueness (−) and yellowness (+). The reference values for the fresh samples are designated as L_0, a_0, and b_0. To evaluate the changes in color, Equations (3), (4), and (5) were utilized to compute the chroma (C), hue angle (α), and total color difference (ΔE) (Atmaca and Büyükcan, 2022).

$$C = \sqrt{(a^2 + b^2)} \qquad (3)$$

$$\alpha = \tan^{-1}\left(\frac{b}{a}\right) \qquad (4)$$

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \qquad (5)$$

Energy Aspect

Energy consumption (Ec) values in the dryers were measured in kilowatt-hours (kWh) using a power meter (EU TS-836A; Floureon, China), as reported by Orikasa et al. (2018). The specific energy consumption (E_{cs}), defined as the energy required to evaporate a unit mass of water from the sample, was calculated using Eq. (6) (Motevali et al., 2012).

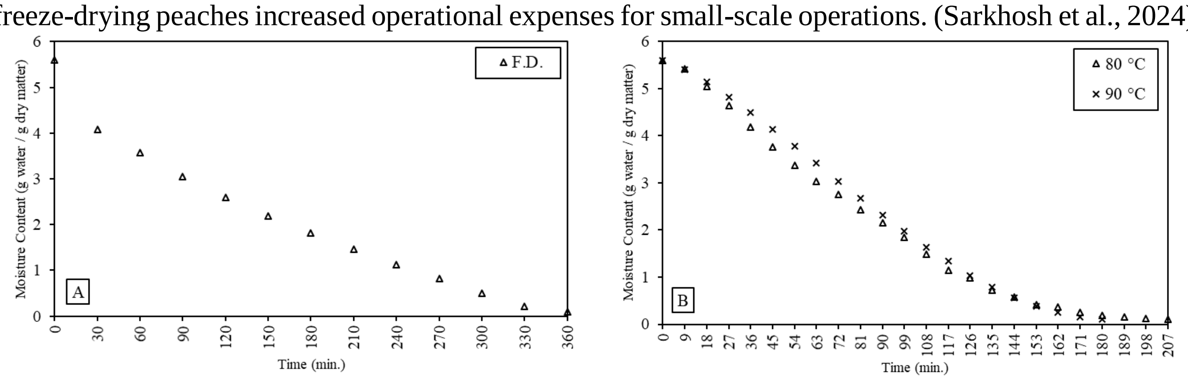
$$E_{cs} = \frac{E_c}{m_w} \qquad (6)$$

Statistical Analysis

The experiments were conducted in triplicate to ensure reliability and accuracy of the results. The data underwent analysis of variance (ANOVA) utilizing JMP software (Version 7.0; SAS Institute Inc., Cary, NC, USA). To compare the means at a significance level of 5% ($P < 0.05$), the least significant difference (LSD) test was employed.

Results and Discussion

Figure 1 presents the changes in moisture content of white nectarine samples over the drying time under various drying conditions. The drying conditions were defined by the total duration needed to attain the final moisture content. The longest drying time was observed with freeze drying, taking 360 minutes, whereas the shortest time was recorded with microwave drying at 300W, requiring 15 minutes. Additionally, a reduction in hot air, infrared, or microwave power levels led to an increase in drying time. The results indicated a decrease in drying time for white nectarine samples by 13.04%, 45.09%, and 61.53% when processed at 90°C, 400 W (PR1), and 300 W, respectively. The microwave drying method exhibited the greatest reduction in drying time, whereas hot air drying resulted in the smallest difference. Comparable findings regarding drying time have been reported in previous literature. Ismail et al. (2016) investigated sun, hot air, microwave, and infrared drying methods for nectarine. Among the various drying techniques evaluated, the microwave drying method proved to be the most effective for drying nectarines. Conversely, the extended processing time and limited scalability associated with freeze-drying peaches increased operational expenses for small-scale operations. (Sarkhosh et al., 2024).



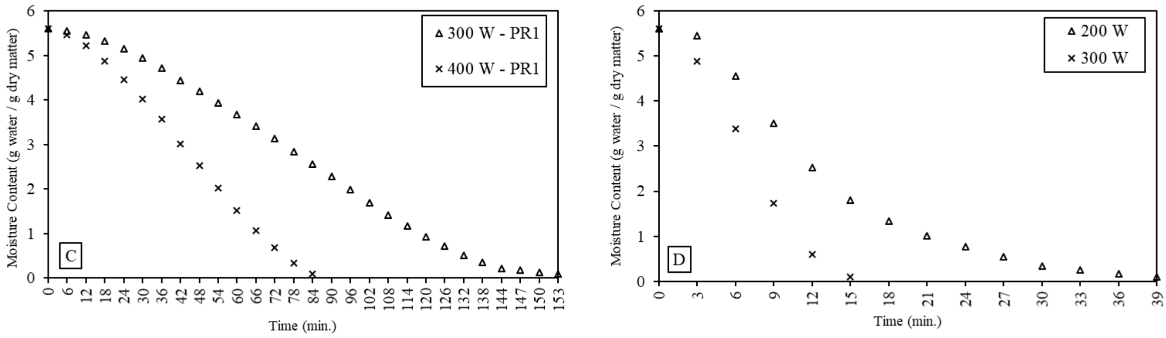


Figure 1. Changes in moisture content over time during the drying process

Figure 2 illustrates the correlation between the drying rate and the average moisture content of white nectarine samples. All experiments demonstrated that the drying rate decreased as the moisture content diminished. In contrast to hot air drying, an increase in infrared or microwave power resulted in a higher drying rate. In freeze drying, an increase in the drying rate was observed during the initial thirty minutes, followed by a period of constant drying rate for the remainder of the process. Experiments on drying of white nectarine puree show that the drying rates in the falling-rate period are dependent on drying method. Subsequently, the methods show that the drying rate in the falling-rate period depends on water concentration. A strategy aimed at enhancing the drying rate during the falling-rate period is developed building on this understanding. In a similar study, Ismail et al. (2017) investigated the drying of nectarines using infrared drying at 125 W and microwave drying at 180 W. The infrared drying process did not exhibit any periods of constant rate drying. Furthermore, the reduction in moisture content within the product resulted in decreased microwave power absorption, which, in turn, caused a decline in the drying rate as the process advanced. Additionally, Miraei Ashtiani et al. (2018) observed that there was no constant-rate period during the drying process for both hot-air and hybrid hot air-microwave drying. Instead, a falling-rate period was noted, attributed to the diffusion-controlled mechanism occurring within the nectarine.

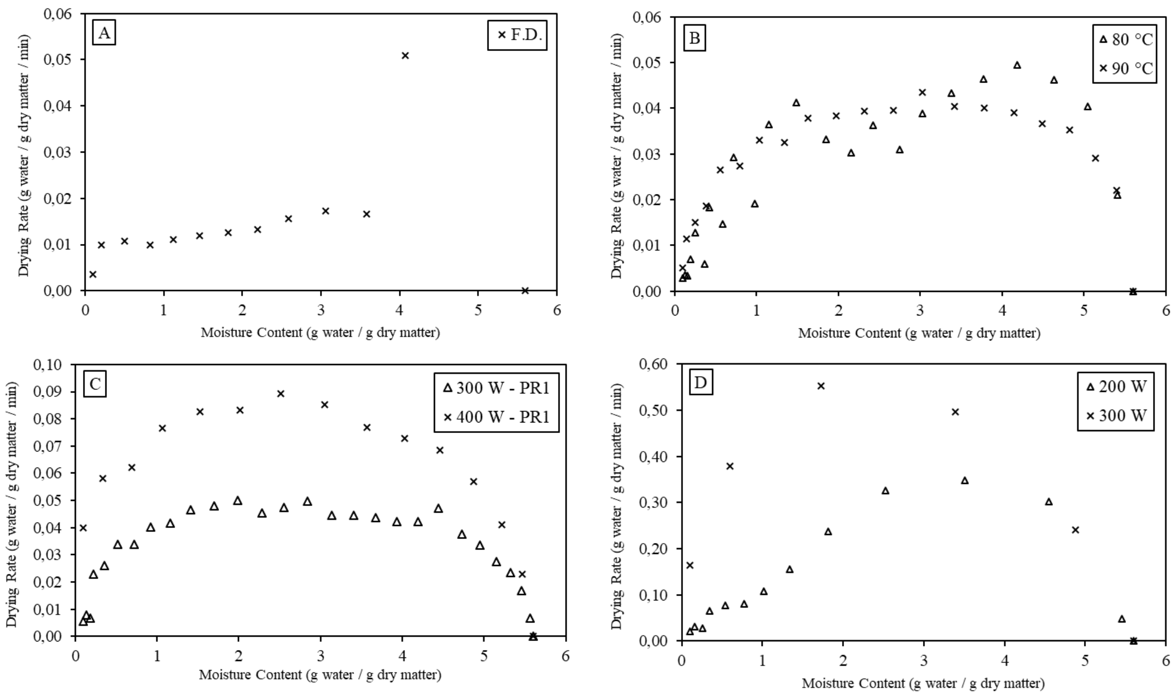


Figure 2. Correlation between drying rate and moisture content during the drying process

Table 1 displays the color parameters (L*, a*, b*, C, α, and ΔE) for both fresh and dried white nectarine samples. The white nectarine samples exhibited L*, a*, and b* values of 66.11 ± 0.09, -1.12 ± 0.08, and 25.96 ± 0.47, respectively. In all drying treatments, L* values showed a decline, while both a* and b* values exhibited an increase (P<0.05). The freeze-dried samples exhibited values that were closest to those of the fresh samples (P<0.05). The samples subjected to microwave drying at 300 W showed the greatest variation in chroma (C), while the highest variation in hue angle (α) was observed in samples dried at 90 °C using hot air. The smallest change in ΔE values was noted in the samples dried through freeze drying, while the greatest change occurred in the samples dried with microwave drying at 200 W. These findings align with previously reported values in the literature. Jahanbakhshi et al. (2020) investigated the drying of nectarine slices by hot air drying. Elevating the drying temperature resulted in increased ΔE levels, attributed to the Maillard reaction between sugars and proteins, which subsequently formed melanoidins. Additionally, da Silva et al. (2019) conducted an analysis of ultrasound-assisted vacuum drying techniques applied to nectarines. The color values of the fresh samples were recorded as 72.45 for L*, 9.43 for a*, and 40.25 for b*. It is essential to acknowledge that color differences observed between studies may be influenced by the variations between white and yellow nectarines.

Table 1. Color properties of white nectarine samples

Product	L	a	b	C	α	ΔE
Fresh	66.11±0.09 a	-1.12±0.08 h	25.96±0.47 g	25.98±0.46 f	92.48±0.23 a	*
F.D.	59.05±0.70 b	2.98±0.07 g	29.66±0.31 f	29.81±0.32 e	84.30±0.11 b	8.97±0.58 f
80 °C	51.19±0.65 c	9.06±0.04 e	31.05±0.26 e	32.34±0.25 d	73.77±0,15 d	18.77±0.59 e
90 °C	47.82±1.03 e	11.59±0.11 a	33.84±0.67 b	35.77±0.62 a	71.12±0.45 f	23.63±0.91 b
300W – PR1	48.25±0.10 e	9.34±0.09 d	32.01±0.25 d	33.35±0.26 c	73.77±0.07 d	21.57±0.09 c
400W – PR1	49.17±0.32 d	8.61±0.04 f	32.17±0.46 cd	33.30±0.44 c	75.05±0.51 c	20.50±0.27 d
200 W	43.04±0.31 g	9.67±0.07 c	32.76±0.96 c	34.17±0.91 b	73.57±0.51 d	26.37±0.27 a
300 W	44.90±0.21 f	10.82±0.06 b	34.61±0.14 a	36.27±0.14 a	72.68±0.09 e	25.83±0.23 a

[a,d] Values within a column with different superscripts differ significantly at P<0.05

The variations in energy consumption and specific energy consumption values are represented in Figures 3 and 4. The energy consumption associated with the drying processes was quantified for various methods: freeze drying accounted for 3930 Wh, hot air drying at 80 °C and 90 °C required 797 Wh and 807 Wh, respectively. In the case of infrared drying, energy consumption was recorded at 473 Wh for 300 W-PR1 and 445 Wh for 400 W-PR1. Finally, microwave drying utilized 273 Wh at 200 W and 190 Wh at 300 W. Reducing the drying temperature led to an increase in energy consumption, whereas variations in power levels for infrared and microwave drying did not demonstrate a comparable effect. Besides, the results for specific energy consumption revealed that freeze drying exhibited the highest value, which was 20.7 times higher compared to microwave drying at 300 W. According to Demirel and İsmail (2017), the energy consumption values associated with drying nectarine slices indicated that the microwave drying method resulted in the lowest energy consumption. This was followed by the hybrid drying method (microwave-hot air) and the hot air drying method. Tunçkal et al. (2024) conducted an investigation into the drying efficiency of nectarine slices using a heat pump drying system. Exergy efficiencies were found to be highest at 45 °C within a temperature range of 35 to 45 °C, recording values of 65.94% for the condenser, 77.95% for the dryer, and 80.53% for the compressor.

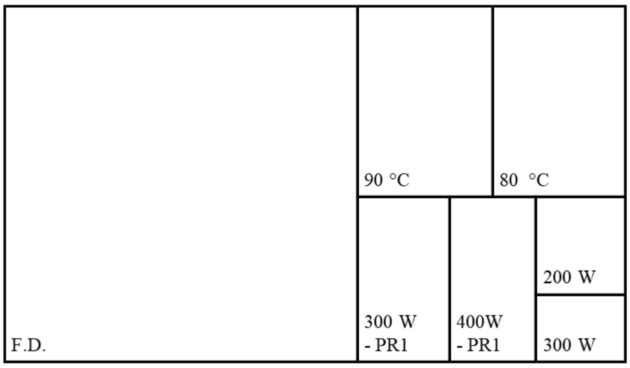


Figure 3. Energy consumption metrics associated with different drying techniques.

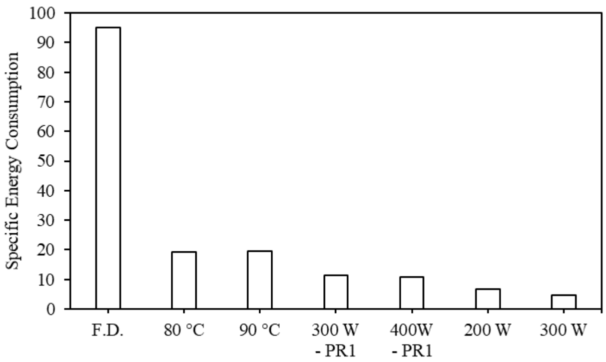


Figure 4. Specific energy consumption metrics for diverse drying techniques

Conclusion

Drying processes for white nectarine fruit provide effective methods to retain their nutritional value and natural flavor. The use of contemporary drying methods, including microwave, hot air, infrared and freeze drying, has led to the development of products with substantially extended shelf life. This study highlights the effectiveness of using these techniques on white nectarines, demonstrating their ability to extend shelf life and preserve quality, while also delivering important insights into energy efficiency for producers. The dried white nectarine provides consumers with an opportunity to enjoy this fruit throughout the year. In conclusion, it can be stated that freeze drying is an effective method for drying nectarine slices, particularly regarding color preservation. Nevertheless, future research should focus on enhancing the impact of drying time and improving drying efficiency.

Authors' Contributions

The authors declare that they have contributed equally to the article.

Conflicts of Interest Statement

The authors declare no competing interests.

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