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EFFECT OF SOLAR COLLECTOR DRYING ON THE NUTRITIONAL PROPERTIES OF ÇAKILDAK HAZELNUT

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ABSTRACT

This study investigated the effects of drying hazelnut in shell with husk samples from the 'Çakıldak' cultivar (*Corylus avellana*) using hot air heated by solar panels at different speeds (3.0 m s^{-1}, 4.0 m s^{-1}, 5.0 m s^{-1}) on hazelnut properties. The hazelnuts were dried and their drying curve was determined by measuring their mass losses at regular intervals. Additionally, the total phenolics, DPPH radical scavenging activity, FRAP, free fatty acidity, peroxide value, and moisture content. For comparison, some of the samples were dried in the sun. The drying rate increased as the air speed increased and hazelnut samples dried the fastest at 5.0 m s^{-1} air speed. As a result of drying treatments, the total phenolic content ranged from 264.11 to 376.91 mg GAE 100 g^{-1}, while the free fatty acidity ranged from 0.337% to 0.374%. The DPPH value ranged from 1.64 to 2.72 μg TE mg^{-1}, and the FRAP value ranged from 1.23 to 2.29 μg TE g^{-1}. The peroxide value ranged from 1.87 to 4.24 meq O_2 kg^{-1}, and the moisture content ranged from 3.43% to 5.18%. The hazelnut samples dried with an air speed of 3.0 m s^{-1} had the highest total phenolics, DPPH and FRAP values, as well as the lowest free fatty acidity and peroxide value. These values were statistically significantly different ($p<0.05$) from those of the sun-dried hazelnut samples. The study found that drying with a solar collector was more effective in preserving fruit quality. Additionally, the drying process was significantly impacted by different flow rates.

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1. Introduction

Hazelnut (*Corylus avellana* L.) is a hard-shelled nut produced on 996,196 hectares of orchard in temperate regions worldwide. In Türkiye, 68% of the world's hazelnut production comes from 728,381 hectares of orchard, primarily in the Black Sea region (TUIK, 2021). The main hazelnut-producing provinces in Türkiye are Ordu, Giresun, Samsun, Sakarya, Düzce, and Trabzon (TUIK, 2021). In these provinces, hazelnut harvesting starts in August and continues until mid-October, although it varies from year to year. Hazelnut harvesting generally starts after August 1-10 in the coastal line (0-250 m), August 10-20 in the middle section (250-500 m) and after August 20 in the high (500-750 m) areas (Kontaş, 2022). The drying of the harvested hazelnuts by different methods is called threshing, where hazelnuts with high moisture content are sorted by threshing machines after withering for 3-5 days. The nuts after sorting are generally laid on soil, concrete or grass and dried in the sun for 5-15 days. Harvesting operations in the middle and high section often coincide with the end of summer and the middle of autumn, exposing the region to heavy rain and fog. Rainfall can make hazelnut harvesting and threshing difficult, and also lead to a decrease in nut quality. Hazelnuts can be damaged in terms of quality parameters during the drying process, depending on the prolonged process and climatic factors. When hazelnuts are dried in sun dried, there is a risk of pathogen contamination, microbial spoilage, aflatoxin formation, deterioration in antioxidant and fatty acids, as well as quality and yield losses (Kontaş, 2022). Hazelnuts are a food with strong antioxidant properties. Antioxidants can prevent or delay oxidation in the human body, which can help prevent diseases such as cancer, heart disease, diabetes, and lung disease (Cornelli, 2009; Alasalvar and Bolling, 2015). Hazelnuts contain not only the main components of fat, carbohydrates, and protein but also secondary metabolites with antioxidant properties, such as phenolic acids, flavonoids, vitamins that are water and fat-soluble, and tannins. The presence of these properties is dependent on the conditions of harvesting and drying.

Various techniques have been developed to prevent hazelnuts from deteriorating due to threshing conditions and to dry them quickly and efficiently with minimal energy consumption. Conventional dryers are commonly used for this purpose, where the flow rate, temperature, and humidity of the mass transfer fluid are adjusted. New technologies such as infrared, microwave, heat pump, LED dryers, and hybrid dryers, where two or more drying systems are used together, are becoming increasingly popular in drying systems (Gürlek et al., 2015; Akgün et al., 2018; Aksüt et al., 2018).

Nuts, including hazelnuts, walnuts, almonds, and peanuts, require drying and storage. Hazelnuts are typically grown in rainy and humid regions, making them more challenging to sun-dried than other fruits. Therefore, an environmentally friendly drying system is necessary to preserve fruit quality, minimize energy costs, and be accessible to producers (Danso-Boateng, 2013; Topdemir, 2019). Recently, there has been a growing emphasis on drying methods that utilize energy from solar panels and the design of such systems (Ceylan et al., 2006; Mohana et al., 2020).

This experimental study investigates the drying of 'Çakıldak' hazelnuts, harvested with hazelnut husks, before and after patching. The study examines the effects of air heated by air-type solar collectors, at different flow rates, on hazelnut drying times and nut traits.

2. Material and methods

This experimental study was conducted at sea level in Altınordu district of Ordu province (in Türkiye), not at high altitude where hazelnuts are harvested. Following the harvest, the hazelnuts were transported to a lower altitude where the climatic conditions were more suitable for drying.

2.1. Plant materials

'Çakıldak' (*Corylus avellana* L) is intensively grown in Gölköy district of Ordu province, which is located in the high section growing area, was used as plant material in the study. The initial moisture content of hazelnut varies between 30.7% and 33.3%, while the initial moisture content of hazelnut husk varies between 70.4% and 76.3%. Hazelnuts used as drying material are not classified by size. 'Çakıldak' cultivar is suitable for high section.

Figure 1 shows a picture of 'Çakıldak' hazelnuts being harvested by hand from the branch. The harvest period for this variety of hazelnut is between August 20th and September 30th, during which time the high section experience significant rainfall and fog. Due to the unique characteristics of hazelnuts, they should be sun-dried by laying them on the ground to separate them from their husks. The drying time for hazelnuts varies between 3 and 10 days depending on the climate. Shelled hazelnuts are dried in the sun until they reach 6% humidity, but this process can take a long time (5-15 days) due to rain and fog. Unfavorable drying conditions can also lead to the formation of aflatoxins in hazelnuts.

Figure 1. Picture of undried 'Çakıldak' cultivar with husks

2.2. Drying equipment

In the drying process, 4 air type solar collectors designed and manufactured by us were used as heat source (Figure 2). The collector radiation surface is 80 x 125 cm. Air flow rate adjustable fans were placed at each collector inlet. Fan speeds were measured with a thermo-anemometer at the inlet of the hazelnut drying box. Air temperature was measured from the collector inlet and outlet in a time dependent manner. Temperature measurement was carried out with a K-type thermocouple. The heated and accelerated air passing through the collector leaves the environment through the spiral pipe through the nuts laid on the net in the Polyfoam boxes (Figure 3). The hazelnuts in the polyfoam box are covered with a perforated cover through which air can pass so that the hazelnuts are not exposed to the sun.

Figure 2. Solar collectors used in the system

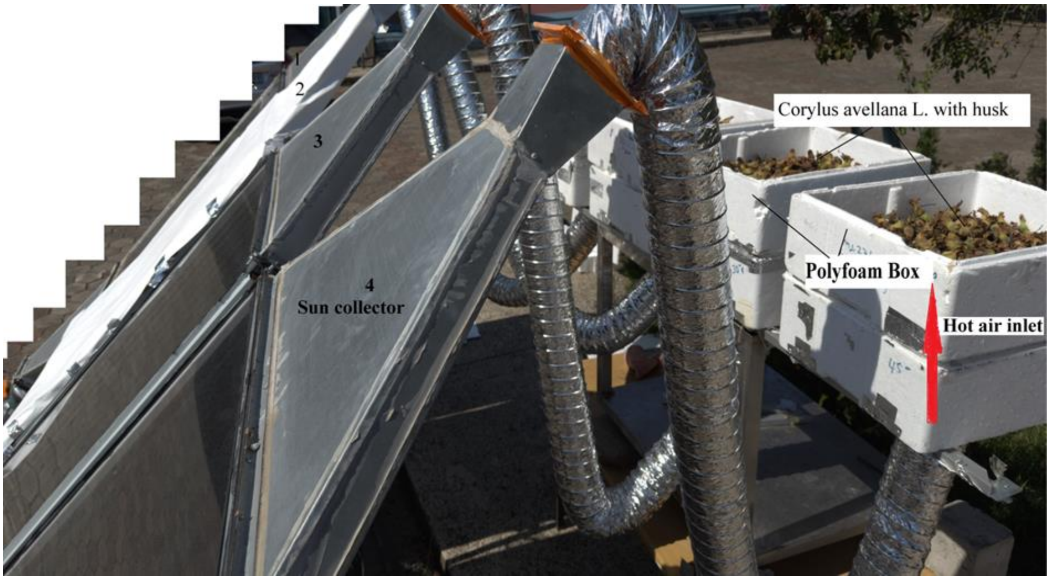

Figure 3. Experimental setup

2.3. Methods

Hazelnuts harvested from the orchard were weighed without separation and placed in Polyfoam boxes, with 3 kg per treatment. The air velocities passing over the hazelnuts were 3.0 m s^{-1} for Collectors 1 and 2, 5.0 m s^{-1} for Collector 3, and 4.0 m s^{-1} for Collector 4. Collector 2's radiation surface was covered, and hazelnuts dried with ambient air temperature. The drying process was carried out using hot air obtained from Collectors 1, 3, and 4. For comparison, hazelnuts were also sun-dried (S).

Mass losses were measured by weighing at regular intervals during drying. When the mass losses of the samples with the husks were approximately constant, they were manually sorted and separated from the husks and the moisture content of each sample was measured. The sorted fresh hazelnut samples were weighed and placed in Polyfoam boxes again with 1.5 kg per treatment and mass losses were determined by weighing every hour.

The nuts in each treatment were weighed using a 0.01 g precision scale at the start of the drying process and at hourly intervals. During sun drying, the surface temperature of the hazelnuts was measured with an infrared thermometer. Hazelnut moisture was determined using an infrared moisture meter of the Precisa XM60. After the drying process, the fruit quality characteristics associated with the drying conditions were evaluated.

2.3.1. Oil extraction

Cold extraction procedure was applied for oil extraction from hazelnut samples (Dordoni et al., 2019; Çakır et al., 2023). Hexane was added to the homogenized hazelnut samples at a ratio of 1:5 and mixed in a shaker (MR-12 Rocker-Shaker, Biosan, Latvia) at 50 rpm for 2 h at 20 °C and then the mixture was centrifuged at 3000 g for 10 min (Nüve 800R, Türkiye). The resulting supernatant was filtered through a filter paper (Whatman 595) and collected in a measuring flask. The hexane in the hexane-oil mixture was removed by means of a rotary evaporator (Heidolph Laborota 4000, Germany) at 45 °C. The oil obtained was used for free fatty acidity and peroxide value analysis.

2.3.2. Free fatty acidity

2.0 g of hazelnut oil obtained by the cold extraction method was mixed with 12 mL of diethyl ether:ethanol (1:1, v:v) mixture. Then 2-3 drops of 1% phenolphthalein indicator were added to the mixture and titration was carried out with 0.01 N ethanol-KOH solution until a pink color was obtained. The results were expressed in terms of oleic acid (AOAC, 1990).

2.3.3. Peroxide value

The peroxide values of hazelnut oil samples were determined using the titrimetric method (AOAC, 2000). To do this, hazelnut oil samples (2.0 g) obtained by cold extraction were dissolved in 25 mL of a chloroform and glacial acetic acid mixture (2:3, v/v). Next, 1 mL of saturated potassium iodide solution was added, and the mixture was kept in the dark for 5 min. After that, 75 mL of distilled water was added to the mixture and titrated with a 0.002 N solution of sodium thiosulfate. The titration used a 1% starch indicator. The results are presented in meq O_2 kg^{-1} oil.

2.3.4. Bioactive component

For the extraction of bioactive compounds from hazelnut samples, defatted hazelnut samples were treated with a 1:10 (w/v) methanol-distilled water mixture (80:20 v/v) and subjected to extraction for 6 h at 50 rpm on a shaker (MR-12 Rocker-Shaker, Biosan, Latvia) at room temperature. Then, the mixture was centrifuged at 3500 g for 10 min (Nüve 800R, Türkiye) and the supernatant was separated. This procedure was repeated for the residue and the combined extracts were used for total phenolic matter and antioxidant activity analysis.

2.3.5. Total phenolics

Total phenolics was determined according to the Folin-Ciocalteu test. Accordingly, 1 mL of sample extract transferred to the test tube was mixed with 500 µl Folin-Ciocalteu solution and 250 µL sodium carbonate (20% w/v) and the total volume was adjusted to 10 mL with distilled water. The resulting mixtures were kept in the dark at room temperature for 30 min and the absorbances were read at 760 nm in a spectrophotometer (Shimadzu UV mini- 1240, Japan). The results were calculated as mg gallic acid equivalent (GAE) 100 g^{-1} dry weight from the standard curve obtained using gallic acid (Singleton et al., 1999).

2.3.6. Antioxidant activity

The antioxidant activity of hazelnut samples was determined by two different in vitro antioxidant tests. The results of DPPH and FRAP tests were calculated as µg Trolox equivalent (TE) mg^{-1} dry weight (dw) and µg TE g^{-1}, respectively.

For DPPH free radical reducing activity, 100 µL of sample extract was transferred into a test tube and treated with 2900 µL of DPPH solution (0.1 mM). After vortexing, the mixtures were incubated at 30 °C for 30 min and at the end of incubation, absorbance measurements against the control were performed at 517 nm (Brand Williams et al., 1995).

FRAP (ferric ion reducing antioxidant power) assay was performed following the method described by Benzie and Strain (1996) with some modifications. First, FRAP reagent was prepared by mixing TPTZ (10 mmol L^{-1}), $FeCl_3.6H_2O$ (20 mmol L^{-1}) and acetate buffer (0.3 mol L^{-1}, pH 3.6) solutions in appropriate volume ratios (1:1:10 v/v). The absorbance values of the mixture prepared with the sample extract and FRAP reagent were then measured at 593 nm in a spectrophotometer after a 4 min incubation at 37 °C.

2.4. Statistical analysis

Statistical tests were performed using SAS-JAMP v. 10.0 (SAS Institute Inc., Cary, North Carolina, USA). Statistical differences were assessed using the Tukey multiple comparison test. The difference between the results was determined at the $p<0.05$ level.

3. Results and discussion

In this section discusses the results of the study in two parts: the drying of hazelnuts and the changes in kernel quality attributes resulting at the end of the drying process.

3.1. Hazelnut drying

The time-dependent mass loss change in 'Çakıldak' during pre-drying (wilting) for the purpose of removing the hazelnut from the husk is given in Figure 4. In the given mass loss curves, the discontinuous part represents the night and the curves represent the mass losses occurring in sunny moments. The pre-drying process was completed in 1.5 days.

At the end of 940 min of operation of the system (night was not added to the time), the mass loss of the hazelnuts with the husk was 3 (28.6%), 4 (27%), 1 (24%), S (19.8%) and 2 (17.5%) respectively. Sun drying lost 2.3% more mass than the system 2 with unheated air. The reason for this is that, as shown in Figure 5, the surface temperature of the hazelnut reached 40.6 °C in solar drying while the ambient temperature reached 29.4 °C in system 2. In addition, the fact that the environment was quite sunny and windy (average air speed 2.5 m s^{-1}) was also effective in sun drying. Under normal conditions, it was necessary for the moisture loss of the Sun and sample 2 to fall below 20% to complete the pre-drying, but the withering study was terminated to ensure that the experimental conditions were the same.

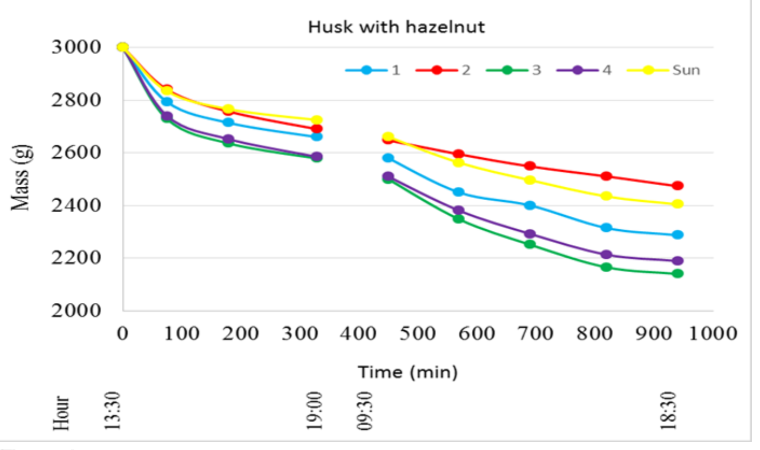

Figure 4. Time graph of mass loss of In-husk hazelnuts during pre-drying

After the initial drying process, the husk moisture content of sample 1 was 36%, while the hazelnut moisture content was between 24.8% and 25.2%. Sample 2 had a husk moisture content of 46%, and the hazelnut moisture content was between 30.6% and 32%. Sample 3 had a husk moisture content of 34%, and the hazelnut moisture content was measured as 26.6% to 27.6%. Sample 4 had a husk moisture content of 35%, and the hazelnut moisture content was between 28.3% and 29%. Finally, the sun sample had a husk moisture content of 44%, and the hazelnut moisture content was between 29% and 31.2%.

The variation of ambient temperature with time during pre-drying of hazelnuts is given in Figure 5. The temperature at night when the system was not operated was not measured and is given as intermittent in the graph. The high mass loss of samples 3 and 4 is due to the ambient temperature is higher than the others (41 °C) and the flow rates are high, as can be understood from the data in Figure 5. This result is similar with previous studies (Demirtaş, 1996; Akgün et al., 2017). As the temperature of the sun-dried hazelnut (max. 40.6 °C) was higher than the ambient temperature due to radiation, the sun treatment dried earlier than sample 2 (max. 29.4 °C, Figure 4).

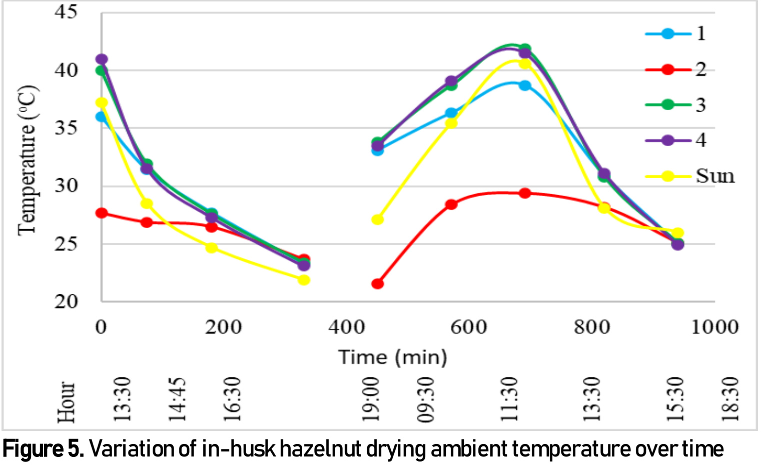

Figure 5. Variation of in-husk hazelnut drying ambient temperature over time

The time-dependent mass loss of shelled, which were separated from the husk and dried again, is given in Figure 6. As expected, sample 2 and sun drying were dried more slowly than the others. The drying curve of sample 2 shows that the hazelnuts dried for a longer time only by increasing the air velocity without heating. In rainy regions, passing air over the hazelnut under cover will prevent the hazelnut from spoiling and the hazelnut will dry in a shorter time.

The time-dependent mass loss of shelled hazelnuts with different moisture contents extracted from the husk is given in Figure 6. Sample 2 and the Sun sample had the highest mass loss on the first day due to their high moisture content. Sample 2, which was dried at normal air temperature, was the last to dry as expected. However, it dried faster than samples 1, 3, and 4 during sun drying. The reason for the difference in drying rates can be seen in Figure 7, which shows the temperature-time curves for the drying environment. The maximum surface temperature of the hazelnut during solar drying was 50 °C, while during collector drying, with air speeds of 3.0, 4.0, and 5.0 m s^{-1}, it was 44 °C. After four days (2240 min), sun drying resulted in a 21.7% loss of mass, while drying with air speeds of 3.0, 4.0, and 5.0 m s^{-1} (samples 1, 4, 3) resulted in losses of 17.4%, 17.6%, and 18.5%, respectively. The rates are similar. Sample 2, which was not exposed to high temperatures (maximum 34 °C) and dried with an air speed of only 3.0 m s^{-1}, experienced a 16.8% decrease in mass.

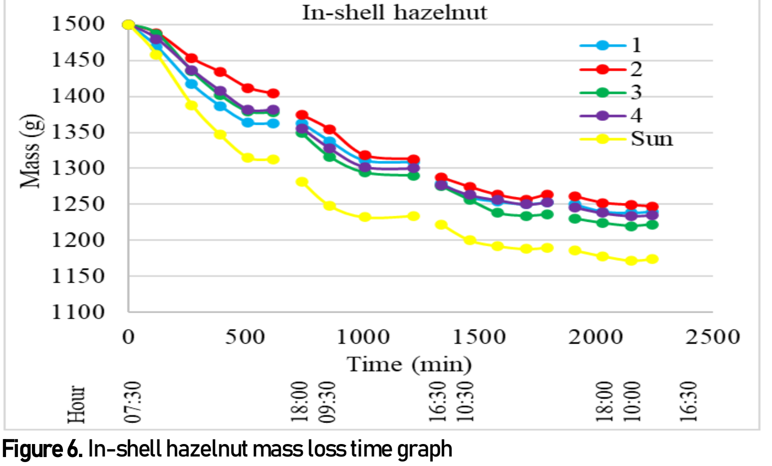

Figure 6. In-shell hazelnut mass loss time graph

After drying, the moisture levels of hazelnuts were measured and recorded as follows: Sample 1 (4.7% - 4.8%), sample 2 (8.6% - 9.3%), sample 3 (4.7% - 5.8%), sample 4 (4.6-5.5%), and Sun (4% - 4.9%). The difference in moisture values under the same treatment is largely due to the size of the hazelnut. Drying slows down as the size increases, and the nut is unable to inshell. At the end of the experiments, Sample 2 was not fully dried. Therefore, it was dried separately until it reached an equilibrium moisture level of 6%.

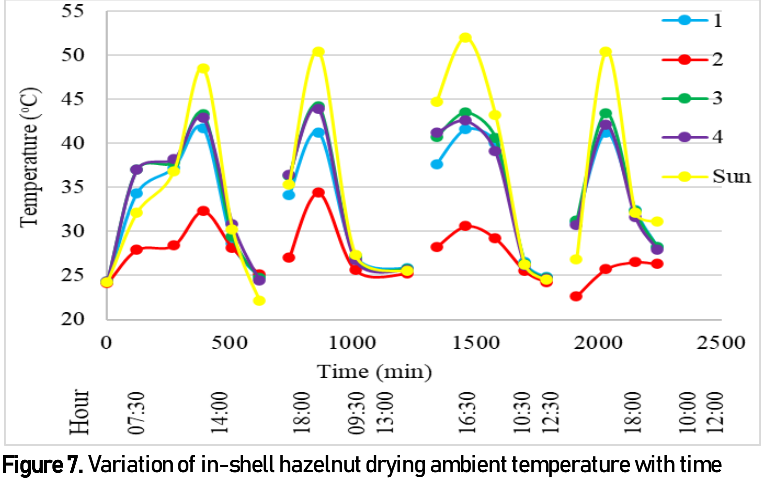

Figure 7. Variation of in-shell hazelnut drying ambient temperature with time

3.2. Nut traits

The study examined the impact of varying drying rates on oxidation parameters. Statistical analysis revealed that both free fatty acid and peroxide values were significant ($p<0.05$). Treatment 1 had the lowest free fatty acid value (0.337%, oleic acid) while treatment 3 had the highest (0.374%). Compared to the control conditions (0.356%), treatment 1 was able to maintain low levels of free fatty acid. Table 1 shows that the peroxide value of the sun-dried fruit samples was 3.67 meq O_2 kg^{-1}. Treatment number 1 resulted in a decrease to 1.87 meq O_2 kg^{-1}, indicating an improvement in nut quality.

Table 1. Effect of drying treatments on oil oxidation of hazelnut

Methods	Free Fatty Acidity (%)	Peroxide Value (meq O_2 kg^{-1})
S	0.356 ±0.01ab	3.67±0.57a
1	0.337±0.01b	1.87±0.68b
2	0.353±0.01ab	3.41±0.29ab
3	0.374±0.01a	4.24±0.57a
4	0.346±0.01ab	1.95±0.75b

a-b The difference between the means shown with different letters in the same column is significant (Tukey test; P<0.05)

Numerous studies have investigated oil oxidation in hazelnuts (Turan, 2018a-b; Turan, 2019; Cui et al., 2022; Gao et al., 2022; Sun et al., 2022). These studies have shown that oxidation parameters can vary significantly. For instance, Turan (2018a) found that oxidation parameters differed depending on the drying method of Ordu levant hazelnuts, but the peroxide value was 0.20 meq O_2 kg^{-1}. Turan (2018b) also reported that oxidation parameters varied according to the hazelnut variety. However, it was found by Turan (2019) that the free fatty acidity value of the 'Çakıldak' ranged from 0.06-0.12% (oleic acid). Additionally, Turan and İslam (2019) reported that the oxidation parameters of the 'Tombul' hazelnut variety varied depending on the drying method. The free fatty acidity value ranged from 0.15-0.28% oleic acid and the peroxide value ranged from 0.00-0.06 meq O_2 kg^{-1}. These findings suggest that hazelnut oxidation parameters are influenced by various factors. The study found that the levels of free fatty acids and peroxide in hazelnuts vary depending on the drying conditions. Therefore, it is crucial to optimize these conditions to ensure high nut quality.

The effect of different drying rates on total phenolics, radical scavenging activity (DPPH) and FRAP parameters of 'Çakıldak' was found statistically significant ($p<0.05$). When Table 2 was examined in detail, it was determined that the lowest value of total phenolics was found in treatment sample 3 (238.29 mg GAE 100 g^{-1}), the highest value was found in treatment sample 1 (376.91 mg GAE 100 g^{-1}) and the same statistical value was found in treatment sample 4 (360.82 mg GAE 100 g^{-1}). When compared with the control conditions (0.264.11 mg 100 g^{-1}), it is seen that sample 1 and 4 were able to keep the total phenolic high. When the radical scavenging activity (DPPH, µg TE mg^{-1}) values of the nut samples were analyzed (Table 2), it was determined that the sun-dried and sample 3 treatments were 1.90 and 1.64 µg TE mg^{-1}, respectively, while the sample 1 treatment was 2.72 µg TE mg^{-1} and gave the best result in terms of fruit quality.

Table 2. Total phenolic content and antioxidant activity of hazelnut

Method	Total Phenolics (mg GAE 100 g^{-1})	DPPH Radical Scavenging Activity (µg TE mg^{-1})	FRAP (µg TE g^{-1})
S	264.11±14.29 bc	1.90±0.07 c	1.32±0.03d
1	376.91±20.40 a	2.72±0.14 a	2.29±0.10 a
2	283.79±4.23 b	2.21±0.03 b	1.59±0.02 c
3	238.29±11.90 c	1.64±0.08 c	1.23±0.05d
4	360.83±2.29 a	2.50±0.17 ab	2.05±0.09 b

a-d The difference between the means shown with different letters in the same column is significant (Tukey test; P<0.05)

In previous studies, the 'Çakıldak' cultivar grown in Giresun ecological conditions was found to contain 246.0 mg of total phenolics 100 g^{-1} (Pelvan et al., 2012), while a subsequent study reported a higher amount of 741.0 mg GAE 100 g^{-1} (Balık et al., 2017). Yılmaz et al. (2019) conducted a study on hazelnuts grown under the same variety and conditions. The results showed that the total phenolic content varied between 662.3 (medium)-763.5 (small) mg GAE 100 g^{-1} depending on the size of the kernel.

The study suggests that the amount of total phenolics in hazelnuts is influenced by various factors. The total amount of phenolic substances, total flavonoid content and antioxidant capacity (according to FRAP and DPPH tests) in hazelnut kernel depending on the variety, nut size and extraction method (Yılmaz et al., 2019; Kurtça, 2021). In addition, ecological conditions, genotype, cultural practices, maturity of the nut, the region where it is grown, altitude and orientation have an effect on the chemical structure of hazelnuts (Cristofori et al., 2015; Tonkaz et al., 2017; Yaman, 2019). When the data we obtained from the research are examined; While it is between the values found by Pelvan et al., (2012) and the values found by Balık et al., (2017), it reveals the positive effects of drying practices on the total amount of phenolic substances in 'Çakıldak' cultivar.

4. Conclusion

The study investigated the impact of solar-heated air at varying speeds on 'Çakıldak' drying and the following conclusions were reached.

1. At the end of pre-drying, the mass loss of the husk (approximately 52%) was greater than the mass loss of the hazelnut (approximately 15%).
2. Although the drying process with accelerated air without heating took a long time, it made it possible to dry the hazelnuts without spoiling.
3. In pre-drying, the shortest drying process was achieved at 5.0 m s^{-1} air speed, as expected.
4. In drying with a solar collector, as the air speed increased, the drying time also shortened.
5. Drying the nut at an air speed of 3.0 m s^{-1} yielded the best results in terms of free fatty acidity and peroxide values. However, applying the same air speed gave the best results in terms of total phenolic substance amount, radical scavenging activity (DPPH), and FRAP values.

It is recommended to use solar collectors for drying hazelnuts, which have no energy costs, environmentally friendly air and preserve food properties.

Compliance with Ethical Standards

Conflict of Interest

The author of article declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authors' Contributions

Mithat AKGÜN: Design and manufacture of drying equipment. Evaluation of the data, article writing. **Mehmet AKGÜN**: Analyzing samples, obtaining data, article writing.

Ethical approval

Not applicable.

Funding

No financial support was received for this study.

Data availability

Not applicable.

Consent for publication

We humbly give consent for this article to be published.

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