Effect of Sun and Microwave Drying on the Antioxidant Potential and Hydroxymethylfurfural Formation of Damson Plum (Prunus domestica subsp. Insititia)

Dilay Yıldız  
Manisa Celal Bayar University

Özlem Çağ込んだ (ozlem.cagindi@cbu.edu.tr)  
Manisa Celal Bayar University

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Abstract

In this study, the antioxidant potential and hydroxymethylfurfural formation of damson plum were investigated using different drying methods. Before drying, the samples were immersed in 1% NaOH at 55°C for 1 min and divided into two groups (half and whole) and dried under the sun and using different microwave power levels (450, 720, 900 W) to reduce the moisture content to 18%. Total dry matter, drying period, total monomeric anthocyanin, total flavonoid, total phenolic, antioxidant capacity and hydroxymethylfurfural values were determined. The sun-drying period of whole plums found to be about four times longer than half plums. Similarly, at different microwave power levels (450, 720 and 900 W), the drying period of whole plums was also longer than half plums, but the sun drying for whole plums was more than 500 times longer and 150 times longer than microwave drying for half plums. Also, the increase in microwave power level shortened the time. The total anthocyanin, total flavonoids, total phenolic and antioxidant capacity values of sun-dried samples were lower than those of microwave-dried samples. It was observed that hydroxymethylfurfural values in microwave-dried samples increased. It is thought that microwave drying at 900 W, where the antioxidant properties of plums dried at three power levels are better preserved, can be recommended with little difference in drying period in 720 W microwave application.

1. Introduction

Plum is the common name of some edible tree species of the genus Prunus, family Rosaceae. Plum is a temperate climate fruit species and has many uses according to different consumption habits of societies. In addition to fresh consumption, it can be utilized in various ways such as drying, fruit juice concentrate, jam, marmalade, canned and ice cream. Plum is a potential fruit that will make a significant contribution to human nutrition because it is rich in fiber and antioxidants [1–3]. Prunes are one of the important crops for the dried fruit industry with worldwide production [3]. Only varieties originating from Prunus domestica L. can dried without fermentation due to their high sugar content [4]. Since the moisture content of fresh plums can reach 80%, drying plums is costly and accounts for almost a quarter of total production costs [5]. Prunes are also used in many different areas as sweetener, coloring and flavoring, binder for cereal bars, moisturizer (to keep cakes and cookies moist), healthy snack and diet snacks, muesli, a mixture of cereals and breakfast products, desserts, pudding and chocolate, biscuit-cake, sweet and salty foods, chocolate covered prunes, beverages, fermented beverages, stewed fruits, rice pudding, soup, stuffed vegetables, cake and ice cream. With new drying studies to be conducted, prune production and consumption can be increased, and its use can be realized in many different areas [6].

Drying, one of the oldest food preservation methods, has been used in the food industry over many years to maintain food quality and prevent spoilage and contamination during storage [7, 8]. Foods whose moisture and water activity contents are reduced below a certain amount by drying become more resistant to chemical, enzymatic and microbiological spoilage, thus increasing the shelf life of the food [9, 10]. In addition, because of the decrease in product weight drying, storage and transportation costs are
also reduced [11, 12]. During the drying process, losses in phenolic compounds, vitamins and colour occur and as a result, the physical, chemical, and sensory properties of the products are affected. For this reason, studies are carried out on different drying conditions to decrease the losses during the drying process [13]. Among many drying methods, the microwave is seen as an efficient drying method and has been intensively studied in recent years. Since the internal temperature is much higher than the external temperature during the microwave drying of foods, the drying rate increases, and the drying period is shortened [14]. It is also preferred for drying fruits due to its relatively low energy consumption and preservation of heat-sensitive compounds [15]. In microwave drying technology, it provides very rapid heating by acting on the polar (mainly water) and ionic compounds it contains. As a result of the comprehensive literature review, it is seen that Michalska et al. 2016 [16] conducted a study on drying plums with microwave technology. Since different plum types and different microwave application methods were used in these studies, it is thought that the current study will contribute to the literature. Sun drying, cabin drying, oven-vacuum oven, tunnel dryer, freeze drying, convection drying oven, heated air, microwave-assisted heated air, and infrared radiation-assisted heated air methods are used for drying plums [16–22]. In the literature, a study examining the drying of damson plum with both microwave and sun drying has not been found within the knowledge of the researchers. It has a unique value as it is the first research on this subject.

This study, which was designed to enable the drying of damson plums in a shorter time with different drying techniques and to obtain high quality products, was aimed to dry whole and half damson plums under the sun and at 3 different microwave power levels and to determine some quality characteristics in particular antioxidant potential and hydroxymethylfurfural formation.

2. Material And Methods

2.1. Material

Damson plum (Prunus domestica subsp. Insititia) obtained from Izmir wholesale market used in the study. Plum samples were kept in the laboratory at + 4°C and 80–90% relative humidity. Plums that were not suitable for drying were subjected to sorting. Plums were sized for even drying and those of the same size were selected. To remove the wax layer, plums were immersed in 1% NaOH solution at 55°C for 1 minute. After immersion, the plums were washed under running water for 1 min and after washing, the plums were placed in the strainer for 5 min to remove excess water. The washed plums were divided into two groups; the plums in the first group were treated whole and the plums in the second group were cut in half and the seeds were removed.

Some fruits such as grapes, cherries, plums, apples, and pears have a thin layer of wax on their skins. To remove this layer, which slows down the drying rate, the samples are immersed in a suitable solution this process is called immersion. When we look at the literature, the immersion process applied to plums is usually carried out at 60°C with the addition of NaOH at different ratios to water. However, in this study, it was observed that at this temperature, the peel surfaces of the plum samples disintegrated, and
excessive hardness occurred in the products. For these reasons, the temperature was then tried at 55°C and it was found that the processing temperature was more suitable at 55°C since no negative effects were observed in the product.

2.2. Methods

2.2.1. Drying process

Whole and half plum samples were dried in the sun and at different microwave power levels (SD: Sun drying; MW 900 W: 900 Watt microwave drying; MW 720 W: 720 Watt microwave drying; MW 450 W: 450 Watt microwave drying). In studies on the drying of plums, it is reported that drying is terminated when the final moisture content of the product is 16–20% [23–25]. Therefore, drying was continued until the final product reached 82% total dry matter (18% moisture content).

Sun drying: The plum halves were dried one day with the cut side up and the next day with the cut side down in the sun. The plums were kept in the sun between 09:00–21:00 between August 30 and September 20 and were moved to the laboratory to minimize moisture change in the evening/night hours. The highest and lowest temperature averages measured in Manisa between these dates were 33.7°C and 19.4°C, respectively. Whether the plums reached the final dry matter content (82%) was ascertained by monitoring their weight during the drying period. The sun-dried plums were kept cold at room temperature for a while, then transferred into a refrigerator bag, wrapped with aluminium foil and filled into capped glass jars and stored at -18±2°C until analyzed.

Microwave (MW) drying: A kitchen-type microwave oven (AR 245, Arzum, Turkey) was used for MW drying. The samples were dried at 3 different power levels (450, 720 and 900 W). All drying processes were carried out with 400 grams of fresh plums. The drying process was applied as 20 s power application and 20 s waiting. Power application and waiting times identified because of preliminary tests and the product weighed at the end of each 5-minute waiting time. Whether the plums reached the final dry matter content (82%) was identified by monitoring their weight during the drying period. The MW dried plums were kept cold at room temperature for a while, then transferred into a refrigerator bag, wrapped with aluminium foil and filled into capped glass jars and stored at -18±2°C until analyzed. During drying, the surface temperature distributions of the samples were measured at regular intervals with a thermal camera (Testo 880-3, Germany). Temperature distributions were determined using the image processing package program of the device. The temperature distribution in microwave drying was obtained by temperature measurements from different points of the samples during the drying process. For plum samples, MW 900 W power temperature range is 86–94°C, MW 720 W power range is 78–90°C and MW 450 W power range is 74–82°C on average. It is thought that the differences are due to the displacement of the plums and the intermittent drying process. Also, the surface temperature of the plums increased as the power increased.

2.2.3. Total dry matter (TDM)
The moisture content of plum samples was found gravimetrically using a vacuum oven (Nube EV-018, Ankara). Total dry matter determination was carried out by keeping the samples in a vacuum oven until a constant weight was obtained [26]. For this purpose, plums were cut into small pieces and weighed approximately 3 g in glass containers and kept in a vacuum oven at 70°C and 600 mm Hg until a constant weight was reached. During the drying process, the dry matter content of the plums was monitored by weighing. A rapid moisture analyzer RADWAG (MAC 110 /NH, Poland) was used to establish the total dry matter content of the plums in a short time and to terminate the drying process. For rapid dry matter determination, plums were cut into small pieces and weighed approximately 2.5 g in aluminium weighing cups. The temperature of the apparatus (Radwag, MAC 110/NH, Poland) was set to 105°C and the samples were kept in the apparatus until a constant weight was reached (45–60 min).

2.2.4. Drying period

The drying period of the plum samples was identified by monitoring the decrease in the weight of the samples during the drying process. In each drying trial, approximately 400 g of fresh plums with known initial total dry matter content were placed in the dryer and the sample weight was monitored at 5 min intervals. The weight of the product was established by balancing the dry matter until the final product reached 82% TDM content (18% moisture). When the product reached this weight, the drying process terminated and period recorded.

2.2.5. Chemical Analysis

Extraction of phenolic compounds

Methanol extraction was applied for total monomeric anthocyanin, total flavonoid content, total phenolic content, and antioxidant analysis. The methods developed by Rodriguez et al. 2015 were modified [27]. To 2 g of homogenized prunes, 10 mL of methanol: water: acetic acid (300:100:10) was added and kept in a 100% ultrasonic water bath (Bandelin DK 102 P, Germany) at 21°C for 15 min. The samples were transferred to a centrifuge tube and centrifuged at 4100 rpm for 15 min and the supernatant was collected in a 50 mL volumetric flask. The residues were treated the same way 2 times and the supernatants were combined with methanol:water:acetic acid (300:100:10). Samples were stored in amber bottles at -18 ± 2°C until analysis.

Total phenolic content

The total phenolic content analysis was performed by the widely used Folin-Ciocalteu method proposed by Rodriguez et al. (2015) [27]. For this purpose, 250 µL of 10% 2N Folin-Ciocalteu reagent was added to 500 µL sample extract and after 30 seconds, 1250 µL (20%) saturated Na2CO3 was added to this mixture and vortexed. The samples were kept at room temperature and in the dark for 2 hours and the absorbance values were measured at 760 nm with a Multiskan Go Microplate Spectrophotometer reader (Thermo Scientific, USA). Total phenolic content was calculated as gallic acid equivalent (GAE) using the calibration curve for gallic acid (0.002–0.018 mg/mL) (y = 65.79x + 0.0108, R2 = 0.99881).
Total flavonoid content

The total flavonoid content analysis was performed using a modified method proposed by Rodriguez et al. in 2015 [27]. The 500 µL of the analysis sample was taken into a test tube, 1250 µL of distilled water was added followed by 75 µL of 5% NaNO2 and the mixture was stirred and left for 6 min. At the end of the time, 150 µL of 10% AlCl3 was added, mixed, and kept for 5 minutes. Finally, 500 µL of 1 M NaOH was added and mixed. The resulting mixture was kept at room temperature for 30 min in the dark and the absorbance of the color was read at 510 nm on a Multiskan Go Microplate Spectrophotometer reader (Thermo Scientific, USA). Total flavonoid content was given as catechin equivalent (CE) using the calibration curve for catechin (0.002–0.012 mg/mL) (y = 65.561x + 0.0142, R2 = 0.99795).

Total monomeric anthocyanin content

The total monomeric anthocyanin content was determined by pH differential method [28, 29]. First, 1 mL of the sample was transferred to a test tube and 1 mL of pH 1.0 buffer solution was added. Similarly, 1 mL of the same sample was transferred to another tube and 1 mL of pH 4.5 buffer solution was added. The absorbances of the samples were read at 528 and 700 nm with a Multiskan Go Microplate Spectrophotometer (Thermo Scientific, USA). Measurements were read against pure water as a witness and readings were completed 30 minutes after the solutions were prepared. The absorbance value was calculated after the measurement and the total monomeric anthocyanin content was determined according to Cemeroğlu, 2013 and AOAC, 2005b.

Total antioxidant capacity by ABTS method

The Trolox equivalent antioxidant capacity (TEAC) method was applied to determine the antioxidant activity of the samples. In the determination of antioxidant activity, according to Cemeroğlu, 2010 [30], 7 mM ABTS solution containing 2.45 mM potassium persulfate was prepared and kept at room temperature and in a dark for at least 12–16 hours to form ABTS. + radical solution. The ABTS. + radical solution was diluted with phosphate buffer solution to give an absorbance value of 0.700 (± 0.02) at 734 nm before starting the analysis. Then, 10 µL of sample extract was added to 1 mL of ABTS. + radical solution and absorbance values were read 6 minutes after gently mixing. The per cent reduction of ABTS. + solution was calculated according to the beginning absorbance value and expressed as the inhibition ratio. This process was repeated twice, and inhibition rates were calculated. The same procedure was then replicated with 2.5, 5, 7.5 and 10 µL of sample and inhibition ratios were determined. The average per cent inhibition values were plotted against the sample concentrations and the curve for the sample and the equation describing this curve were obtained by linear regression analysis. The TEAC value of the sample was calculated as the ratio of the slope of the sample curve to the slope of the standard curve and given as µM Trolox/g [30].

Hydroxymethyl furfural (HMF)
High performance liquid chromatography (HPLC) method including 3 steps (extraction, identification, and calculation) was applied to determine the amount of HMF in prunes. For extraction, the method proposed by Zappala et al. was used [31]. Approximately 5 g (± 0.001 g) of the sample was taken and left to rehydrate in 20 mL distilled water at +4°C for 1 night. This mixture was then homogenized in the waring blender for 5 min at 1 min intervals. After washing the blades of the homogenizer with 20 mL of water, the resulting suspension was centrifuged at 4000 rpm for 10 min at 19°C. The clear supernatant phase in the centrifuge tube was taken directly into a 50 mL measuring flask and the volume was completed. A portion of the solution in the flask filtered through a 0.45 µm pore size polyvinylidene fluoride filter (Millipore, Bedford, Mass., USA) into 1.5 mL amber vials used in the high-performance liquid chromatography (HPLC) autosampler. HPLC (Agilent 1260 Series, USA) was used to identify and quantify HMF in prunes. C18 column (250 x 4.6 mm, 5 µm, Phenomenex, Los Angeles, CA, USA), DAD detector, methanol:water (10:90, v/v) mobile phase, 285 nm wavelength, 1 mL/min flow rate, column temperature 25°C, elution time 56 min and injection volume 20 µL were set as operating conditions. The HMF peaks obtained in the chromatograms were identified by comparing the retention time of the standard substance with the UV spectra obtained in the DAD detector. The amount of HMF in the sample was calculated from the standard curve obtained by injecting HMF solutions prepared at 6 concentrations of the standard substance into the HPLC.

2.2.6. Statistical Analyses

The results obtained were statistically evaluated using the SPSS (version 22) package program. A One-way analysis of variance was performed to determine the differences with Tukey's multiple comparison test. In addition, T-test was applied to compare the difference between whole and half dried samples. Data were analyzed at a 95% significance level. All experiments were performed in two replicates. The experimental data shown in the tables are given as mean ± standard deviation.

3. Results And Discussion

Total dry matter and drying period

Total dry matter and drying period values of whole and half plums in the sun and at three different powers (450, 720 and 900 W) are given in Table 1. This parameter is an important quality index, especially in dried fruits [32]. The total dry matter value, which was 18.08% in the fresh plum used, varied between 81.07 and 82.17% in the samples dried by both methods. The effects of different drying methods on the total dry matter content of whole and half-dried plums were found to be insignificant, respectively [F(0.946) = 0.437, p > 0.05; F(0.607) = 0.618, p > 0.05]. The effect of all drying types was insignificant (p > 0.05) for total dry matter content for whole or half drying.
### Table 1
Total dry matter and drying period values of plums

<table>
<thead>
<tr>
<th>Drying processes</th>
<th>Total dry matter</th>
<th>Drying period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Whole</td>
<td>Half</td>
</tr>
<tr>
<td>SD</td>
<td>81.82 ± 0.52a</td>
<td>81.62 ± 0.92a</td>
</tr>
<tr>
<td>MW 900 W</td>
<td>81.71 ± 0.50a</td>
<td>82.17 ± 0.31a</td>
</tr>
<tr>
<td>MW 720 W</td>
<td>81.07 ± 0.56a</td>
<td>81.72 ± 0.88a</td>
</tr>
<tr>
<td>MW 450 W</td>
<td>81.50 ± 0.57a</td>
<td>81.54 ± 0.44a</td>
</tr>
</tbody>
</table>

* Results are mean values ± standard deviation. The different letters indicate a difference at the significance level of p 0.05 among the results.

In studies on the drying of plums, it is reported that drying is terminated when the final moisture content of the product is 16–20% [23, 24, 25]. Therefore, the final moisture content of the product was selected as 18% in this study. However, when we look at the literature, there are studies with different moisture values. Li et al. 2021 [14] found the moisture values of prunes at 24.16%-24.62%, while Karaat 2019 [33] was 25%, Toğrul and Pehlivan, 2004 [19] determined 15–17%. Although the main reason for the differences between the studies is the targeted dry matter value, it is thought that the ripeness of the fruits, agricultural conditions and climatic changes affect the dry matter value [34].

Drying period was 17 days and 16 hours for whole plums dried in the sun and 4 days and 14 hours for half plums. The drying period of whole and half plum samples dried by microwave varied between 26 minutes 27 seconds and 48 minutes 20 seconds. During the microwave drying of whole plums, the drying period was 28 minutes 46 seconds for the MW 900 W drying process with the highest power, 29 minutes 40 seconds for the MW 720 W drying process and 48 minutes 20 seconds for the MW 450 W drying process. For half plums, the drying period for MW 900 W drying process with the highest power value was 26 minutes 27 seconds, 27 minutes 7 seconds for MW 720 W drying process and 43 minutes 40 seconds for MW 450 W drying process. When the results are analyzed, it is seen that microwave drying significantly reduces the drying period compared to sun drying. Sun and microwave-dried whole and half plum samples are shown in Fig. 1.

In all microwave drying applied to the samples within the scope of the study, the drying period decreased with the increase in microwave power. Similar results were found in the study obtained by Sarı et al. 2014 [35] in drying pineapple with the microwave. Half plums are dried in the sun-dried almost 4 times faster than whole plums. It is thought that the reason for this is that heat transfer is more difficult due to the shell structure of whole plums. Toğrul and Pehlivan 2004 achieved the targeted moisture content of 15–17% in 5 days by dipping plum samples with 1% NaOH for 10–15 seconds and sun drying. The effect of chemical immersion pretreatment on the reduction in drying period has also been reported in studies with different plum samples [9, 10, 33].
In the study conducted by Michalska et al. [16] microwave vacuum drying period was found to be 32–120 minutes and convection pre-drying-microwave final drying period was found to be 394–664 minutes. Compared to our study, it is thought that the drying period is longer because not only microwave drying but also microwave-assisted heated air is used and microwave temperature powers are lower. In studies where apple slices were dried with microwave, drying periods were reported as 20, 44, 58 and 138 minutes [36, 37]. Stanley variety plum samples, to which physical, chemical and microwave methods were applied as pretreatment, were dried under the sun by Karaat 2019 [33]. In the study conducted that the effect of pretreatment on drying period and plum colour, drying periods were found between 95–401 hours. Like the study, the drying period of the samples pretreated with NaOH (1%, 60°C, 1 min) was found to be 182 hours. It is thought that the difference in drying periods is because the sun drying process was carried out on different dates in the same year in both studies and the difference in the desired moisture values.

Total dry matter, total phenolic content, total flavonoids, total monomeric anthocyanins, antioxidant capacity and HMF analyses of Prunus domestica subsp. Insititia, damson plum whole and half samples dried under the sun and in microwaves with three different powers (450, 720 and 900 W) were performed and the results obtained are shown in Table 2.

The changes in total phenolic, total flavonoid and total monomeric anthocyanin content

The effect of different drying methods on the total phenolic content of dried whole plums was found to be significant \[F (305.707) = 0.0001, p < 0.05\] and calculated as 20.27-115.54 mg/kg GAE dw for all plums. For all plums, the minimum total phenolic content was recorded in sun-dried products, while the maximum was recorded in MW 900 W microwave-dried products. Furthermore, the effect of semi-dried plums on total phenolic content was found to be significant \[F (174.723) = 0.0001, p < 0.05\]. As the power level increased for all plums dried in microwave, the total phenolic content also increased. The reason for this is thought to be the short drying period at high power levels. Likewise, total phenolic content increased as the microwave power increased in half plums. For sun drying, whole or half drying was insignificant for total phenolic content \((p > 0.05)\). Whole or half drying was significant for MW 450 W microwave type in terms of total phenolic content \((p < 0.05)\). Total phenolic content was calculated as 29.32-117.66 mg/kg GAE dw for half plums. For half plums, the minimum total phenolic content was recorded in sun-dried products and the maximum total phenolic content was recorded in MW 720 W microwave-dried products. However, the higher total phenolic content of plums dried at MW 720 W than plums dried at MW 900 W was associated with a lower drying temperature. Similar results were observed in the study conducted by Rodriguez et al. in 2015 [27] to analyze the effect of combined methods of drying D’ente (Prunus doméstica L.) plum by cutting it into 8 pieces. The phenolic content, which was 305.15 ± 60.99 mg/100 g GAE dw in fresh fruit juice, was found to be 114.93-688.54 mg/100 g GAE dw after osmotic dehydration and hot air drying. Depending on the drying temperature, when an air temperature of 60°C was used, the total phenol content was lower than the fresh fruit value; however, when the plums were dried at 70 or 80°C, the total phenol content was higher than the value obtained in fresh plums in most of the conditions tested. Higher total phenolic content was generally found in plums dried at 70°C [27]. The same result was obtained by Piga et al. 2003 [38]. In a study investigating the
effect of fresh plum processing on the total phenolic content of the resulting dried plums and expressed as CE/100 g dw, increased in air-dried plums, whereas it decreased in plums osmotically dehydrated in 70% sucrose and then air-dried at 60°C [39].

The effect of different drying methods on the total flavonoid content of dried whole plums was found to be significant [F (181.754) = 0.0..0.01, p < 0.05]. Total flavonoid content was calculated as 1.72–7.34 mg CE/kg dw for all plums. For all plums, the minimum total flavonoid content was recorded in sun-dried products, while the maximum total flavonoid content was recorded in products dried with MW 900 W microwave. Furthermore, the effect of dried half plums on total flavonoid content was found to be significant [F(48.151) = 0.0..0.01, p < 0.05]. Total flavonoid content was calculated as 2.63–7.32 mg CE/kg dw for half plums. The minimum total flavonoid content for half plums was recorded in sun-dried products, while the maximum total flavonoid content was obtained in products dried with MW 900 W microwave. Sun drying was insignificant for total flavonoid content in whole or half plums (p > 0.05), whereas microwave type with MW 720 W and MW 450 W power was significant for total flavonoid content in whole or half plums (p < 0.05).
Table 2
Results of chemical analysis results of the dried plums.

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Samples</th>
<th>Drying processes</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>SD</td>
</tr>
<tr>
<td>Total phenolic content (mg/kg GAE dw)</td>
<td>Raw material</td>
<td>66.92 ± 0.54</td>
</tr>
<tr>
<td></td>
<td>Whole</td>
<td>20.27 ± 2.16d</td>
</tr>
<tr>
<td></td>
<td>Half</td>
<td>29.32 ± 4.19d</td>
</tr>
<tr>
<td>Total flavonoid (mg/kg CE dw)</td>
<td>Raw material</td>
<td>4.59 ± 0.29</td>
</tr>
<tr>
<td></td>
<td>Whole</td>
<td>1.72 ± 0.34b</td>
</tr>
<tr>
<td></td>
<td>Half</td>
<td>2.63 ± 0.21c</td>
</tr>
<tr>
<td>Total anthocyanin (mg/kg dw)</td>
<td>Raw material</td>
<td>44.67 ± 8.86</td>
</tr>
<tr>
<td></td>
<td>Whole</td>
<td>3.62 ± 0.32b</td>
</tr>
<tr>
<td></td>
<td>Half</td>
<td>17.95 ± 2.36b</td>
</tr>
<tr>
<td>Antioxidant capacity (µM Trolox/g dw)</td>
<td>Raw material</td>
<td>9.76 ± 0.28</td>
</tr>
<tr>
<td></td>
<td>Whole</td>
<td>16.54 ± 3.19b</td>
</tr>
<tr>
<td></td>
<td>Half</td>
<td>19.36 ± 2.60c</td>
</tr>
<tr>
<td>HMF (mg/kg)</td>
<td>Raw material</td>
<td>nd**</td>
</tr>
<tr>
<td></td>
<td>Whole</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>Half</td>
<td>nd</td>
</tr>
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</table>

* Results are mean values ± standard deviation. The different letters indicate a difference at the significance level of p 0.05 among the results. **nd: not detected
Total flavonoid content increased as the power level increased in microwave-dried whole and half plums. The reason for this was thought to be the short drying period at a high-power level. Similar results were obtained in the study conducted by Rodriguez et al. 2015 [27], and the amount of flavonoid substance, which was 56.43 ± 18.40 mg CE/100 g dw in fresh plum, was 22.64–192.70 mg CE/100 g dw after osmotic dehydration and subsequent hot air drying. At 60°C drying temperature, flavonoid contents were lower than fresh plums for most conditions. However, when plums were dried at 70 or 80°C, flavonoid contents were reported to be higher than those obtained from fresh plums for most of the conditions tested. Similar results were observed in the study by Piga et al. (2013) [38]. In the study conducted by Kim et al., (2003) [40] on 6 plum varieties (Beltsville Elite B70197, Cacak Best, French Damson, Long John, Stanley, Yugoslavian Elite T101), the total flavonoid content was found to be 118–237 mg CE/100 g on a fresh weight basis. The results are compatible with the present study.

The effect of different drying methods on the total monomeric anthocyanin value of dried whole plums was found to be significant \( F(185.705) = 0.0..0.01, p < 0.05 \)}. Total monomeric anthocyanin was calculated as 3.62–36.42 mg/kg for whole plums. For whole plums, the minimum total monomeric anthocyanin was in the products dried under the sun, while the maximum total monomeric anthocyanin was obtained in the products dried with MW 450 W microwave. It was also found that the effect of half plums on total monomeric anthocyanin was significant \( F(21.732) = 0.001, p < 0.05 \)}. Total monomeric anthocyanin was calculated as 17.95–36.95 mg/kg for half plums. The minimum total monomeric anthocyanin content for half plums was recorded in sun-dried products, while the maximum total monomeric anthocyanin content was obtained in MW 720 W microwave-dried products. Anthocyanin content was significant \( p < 0.05 \) in whole or half plums for sun-dried and MW 900 W; however, anthocyanin was not significant \( p > 0.05 \) in whole or half plums for MW 720 W microwave type. It was considered that the total anthocyanin values of whole plum samples dried under the sun were much lower compared to half plums due to the very long drying period. In a similar study, Michalska et al. (2016) [16] dried plums using 5 different methods (freeze drying, vacuum drying convection drying, microwave vacuum drying and convection pre-drying and microwave post-drying). It was reported that the lowest anthocyanin value was obtained in the convection drying method with 59.5 mg/kg dw and the highest value was in the freeze drying method with 892.27 mg/kg. Anthocyanins were destroyed by drying [39]. In this study, it was observed that the anthocyanin content of the samples dried by microwave was close to these values, while the samples dried under the sun were less than these values. It was thought that the low total anthocyanin values of the sun-dried plum samples were due to the long drying period.

Antioxidant capacity

The effect of different drying methods on the antioxidant capacity value of dried whole plums was found to be significant \( F(32.256) = 0.0..0.01, p < 0.05 \)}. The antioxidant capacity value was calculated as 16.54–43.05 µM Trolox/g for whole plums. The minimum antioxidant capacity value for all plums was recorded in sun-dried products, while the maximum antioxidant capacity was obtained in products dried at MW 720 W microwave power. In addition, the antioxidant capacity value had a significant effect on half-dried plums \( F(105.605) = 0.0..0.01, p < 0.05 \). The antioxidant capacity was found 19.36–60.07 µM Trolox/g
for half plums. The minimum antioxidant capacity for half plums was recorded in sun-dried products, while the maximum antioxidant capacity was obtained in products dried with MW 720 W microwave. In terms of antioxidant capacity, the effect of all drying types was insignificant for whole or half plums (p > 0.05). Antioxidant capacity increased with increasing microwave power level for whole and half plums; however, since the temperature was lower at MW 720 W power level than at MW 900 W power level, antioxidant capacity was found higher in products dried at MW 720 W microwave power. The lowest antioxidant capacity between both drying methods was found in the products dried under the sun. Michalska et al. (2016) [16] dried plums using 5 methods (freeze drying, vacuum drying convection drying, microwave vacuum drying and convection pre-drying and microwave post-drying). According to ABTS method, the minimum antioxidant capacity was found to be 7.39 mmol Trolox/100 g dw in convection drying, while the maximum value was found as 14.25 mmol Trolox/100 g dw in microwave-assisted vacuum drying.

Formation of HMF

The effect of different drying methods on the HMF content of dried whole plums was significant [F (59.327) = 0.0..0.01, p < 0.05)]. HMF content was calculated as 156.85-624.63 mg/kg for whole plums. The minimum amount of HMF for all plums was recorded in products dried at MW 720 W microwave power, while the maximum amount of HMF was obtained in products dried at MW 450 W microwave power. Also, the effect of semi-dried plums on HMF content was found to be significant [F(8.212) = 0.026, p < 0.05)]. The amount of HMF was 121.15-317.28 mg/kg for half plums. The minimum amount of HMF was obtained in products dried at MW 720 W microwave power, while the maximum amount of HMF was obtained in products dried at MW 450 W microwave power. Michalska et al. (2016) [16] dried plums using 5 methods (freeze-drying, vacuum drying convection drying, microwave vacuum drying and convection pre-drying and microwave post-drying). The minimum HMF value was 70.01 mg/kg dw in the freeze-drying method and the maximum HMF value was 70.01 mg/kg dw in the convection-drying method. In the study conducted by Murkovic et al. in 2006 [41], it was reported that plums contained a very high-level of 2200 mg/kg HMF. Donovan et al.1998 [42] found HMF values as 220 ppm for seedted prunes and 291 ppm for seedted prunes in their study conducted in 1998 and stated that HMF was not found in fresh plums.

The HMF values increased with temperature. In this case, while the lowest HMF value was expected to be obtained at MW 450 W power, it was thought that the HMF value increased because the drying period at MW 450 W power was almost twice compared to other microwave drying powers. Fruits such as prunes, grapes, figs and apricots have high amounts of reducing sugars and amino acids necessary for the formation of the Maillard reaction. HMF formed during the Maillard reaction is used as an indicator of browning reaction products and it was also observed that the HMF values of microwave-dried samples varied according to the literature results, while HMF was not detected in sun-dried samples. The reasons for the different HMF content of prunes considered the effects of different plum varieties (different in
terms of sugar and amino acid content) and different growing conditions as well as the effects of the treatments applied during drying and storage.

4. Conclusions

In this study, some quality characteristics of damson plum were dried under the sun and at different microwave powers. Microwave drying conditions are the drying conditions that we can recommend in damson plum drying trials. It is thought that the chemical properties of the plums dried at three power levels are better preserved and dried by drying at MW 720 W power, which shows a little difference in drying period, and the recommended MW 900 W power microwave applications. Total phenolic content, total flavonoids, anthocyanins and antioxidant capacity found to be higher for microwave drying at MW 720 W than for microwave drying at MW 900 W. In addition, drying period decreased with the increase in microwave power level. According to the data obtained, microwave drying method reduces the drying period, significantly reduces operating costs, eliminates the need for a large drying area, and thus there is no need for drying depending on climatic conditions. For this reason, it is thought that the study has the potential to contribute to both the fruit and vegetable drying sector and the national economy.

Declarations

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Author contributions

All authors contributed to the study concept and design. All authors have read and approved the final manuscript.

Dilay Yıldız: Formal analysis, Writing, Research.

Özlem Çağında: Methodology, Research, Writing-review, and Editing.

Declaration of competitive interest

The authors declare that they have no known competing financial interests or personal relationships to declare in relation to the content of this article.

Data availability

The datasets created and analyzed during the present study are not publicly available. However, they are available from the corresponding author upon reasonable request.

Ethical statements
This study does not require any ethics committee approval.

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References

26. AOAC. Methods No:934.06 Moisture in Dried Fruits (2005a)
33. F. E. Karaat, Akademik Ziraat Dergisi (2019) http://dx.doi.org/10.29278/azd.541157
Figures

Sun and microwave-dried whole and half-plum samples