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DETERMINATION OF QUALITY ATTRIBUTES OF EUROPEAN PLUMS (*PRUNUS DOMESTICA* L.) CULTIVARS UNDER DIFFERENT DRYING CONDITIONS

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Abstract

This study was carried out with Stanley's and Sugar's pulm fruit in two separate convective and microwave dryers such as cabin-type and precision. It determined the drying performance and final quality attributes of Stanley' and 'Sugar' plum fruit. The study also measured the quality characteristics such as color, acidity (pH), soluble solids content (SSC) (Brix), titratable acidity (TA), total phenolics (TP), and total antioxidants (according to TEAC and FRAP tests). Fresh samples of the fruits were dried in cabin-type dryers and at a drying air temperature of 60, 65 and 70°C; and in the microwave dryer, dried for 30-50s at 540W and 30-50s at 720W at power outputs-hold times. The products were dried to wet-based moisture levels of 10-15%. For "Stanley" plums, the closest color, pH, SSC, TA, TP, TEAC, and FRAP values to the values of the fresh fruits (in other words, the most appropriate drying conditions) were respectively achieved in cabin 60°C, cabin 60°C, precision 65°C, microwave 540 W-50 s, cabin 60°C, cabin 60°C and cabin 60-65°C – precision 70°C treatments. For "Sugar" plums, the closest values to fresh fruit were respectively obtained from precision 70°C, cabin 60°C, precision 70°C, microwave 540 W-50 s, cabin 60°C, cabin 60-65°C, and precision 65°C treatments.

Key words: Drying, European plum, Quality, Chemical analysis.

Practical applications

This study dried the "Stanley" and "Sugar" plum. Three different dryers were used to collect data at different temperatures and power levels. In light of the results, a preservation of the quality parameter of these two plum varieties determined the better drying process. The findings can be a valuable resource and a framework for industrial applications for future studies.

Introduction

The European plum (*Prunus domestica* L.) is cultivated widely in different parts of the world. The United States, France, Italy and Turkey have been the world's leading producer of European plum products (Anon., 2015; Hedayatizadeh & Chaji, 2016). The European plum is very rich in many nutrients, besides sugar and carotenoids (Goyal *et al*., 2007; von Bennewitz *et al*., 2019; Mertoğlu *et al*., 2020). There are many health benefits of European plum, which energizes the human body and reduces stress and dysmnesia. It is also used to relieve cough, asthma, and several other disease agents (Polatcı, 2012). Turkey is ranked 8th in the world for European plum production, with an average annual production of 200,000 (Altay, 2019). Plums are also used as pulp and marmalade apart from fresh use. They are dried and used both for fruit tea and dry fruit. European plum has a quite high moisture content (80-88%). Therefore, they can easily be deformed during the harvest and post-harvest processes. The moisture content of the fruit is reduced to certain levels to prevent such deformations and spoils.

Drying is, among the oldest methods, applied to preserve fresh fruit for longer durations. In this method, the majority of the moisture of fresh food is removed; moisture activity is reduced to prevent microorganism activity (Pisalkar *et al*., 2011; Bahadur *et al*., 2019; Guclu & Okatan, 2020). There are several methods used to dry agricultural products. In natural drying, agricultural products are laid under the sun. Energy consumption is quite small, even zero in natural drying, thus, and is the most common method preferred by the producers. However, in natural drying, products are open for exposure to dust, soil, birds, and poisonous gases, and also the drying air temperature is not controlled. Therefore, artificial dryers have been developed to dry agricultural products (Doymaz *et al*., 2003; Özgen, 2014).

In this research, the "Stanley" and "Sugar" varieties of European plums were dried in cabin type, precision and microwave dryers at 60, 65 and 70°C, with drying temperatures at 540 and 720 W microwave power outputs and 30 and 50 second hold times. After drying, the conditions of the drying of both cultivars were most suitable and the final quality qualities were determined by drying pen under 10 different drying conditions. The drying conditions were determined.

Materials and Methods

Products to be dried: In current experiments, the 'Stanley' and 'Sugar' pruning fruit were provided by the producing farm of the province of Tokat and brought in to the drying laboratories of the Biosystems Engineering Department of Tokat Gaziosmanpasa University. For drying processes, undamaged and proper plums were selected and then were sliced into half. These samples were kept at 4 ± 0.5ºC until the end of the experiments.

Moisture content: In each of the replicates, 50 ± 2g samples were used for fruit moisture content. For 4 replicates, measurements were performed. Samples were put in the oven at 70ºC and weighed at some intervals until the weight was changed to 0.01 g between two consecutive measurements (Yağcıoğlu, 1999; Wang *et al*., 2018).

Drying process: Plums were dried in cabin-type and precision dryers at 60, 65 and 70°C drying air temperatures and in microwave dryers at 540 and 720 W with 30 and 50 s holding times and 1 min rest times. Average 65 ± 2 g plums were used in the cabin and precision dryers, and 55 ± 2 g plums were used in the microwave dryer. Products were weighed at a precision balance (± 0.01 g) (Simşek Labortechnik Marks AND GF-3000 Turkey Model) at some intervals and dried up to a wet-base moisture level of 10-15%.

Dryers: Şimşek Laborteknik-brand (Turkey) ST-055 and ST-120-type dryers were cabin-type dryers used in this study. The ST-120 type dryer was larger than the other dryers, and it is possible to adjust the drying air temperature up to 250°C. Dry air temperature can be set to 150ºC for drying in the ST–055-type cabin dryer. The precision dryer is composed of three drying canals and sections. The air inside the interlocked cylinders was heated and sent to the drying section. Drying air temperature is controlled with the aid of a Pt-100 temperature sensor installed over the dryer. Vestel-brand and MD-GD23 model of microwave dryer was used. The dryer has a maximum output power of 900 W and dimensions of 305 x 508 x 385 mm (H x W x D). The products in the microwave oven were dried over the rotary glass-plate.

Color analysis: Color measurements on fresh and dry products were performed with a Minolta-brand CR400 model color meter. Measurements for fresh and dry products were made 15 times separately. The values of the L, a, b hunter lab chroma-meter were measured. These values are defined below; "L" indicates the brightness of the product and is expressed on a 0 - 100 scale. The "a" indicates red-green, "b" indicates yellow – blue colors and respectively takes +, - signs (McGuire, 1992). The measured L, a, and b values alone do not mean anything for the consumers. Thus, by calculating these values, chroma, redness index, hue angle, total color difference, and browning index values were calculated.

Chroma: It expresses the color tone of the product with lower values indicating pale colors and higher values indicating bright colors. According to Kavdir *et al*., (2007), chroma value was calculated by using the following equation;

$$C = (a^2 + b^2)^{1/2} \tag{1}$$

Reddening index: It is calculated as the ratio of a/b and expresses the reddening process of the product under present drying conditions (Babalik & Pazir, 1997).

Hue angle: Each angle corresponds to a color in a 360° color space (Fig. 1).

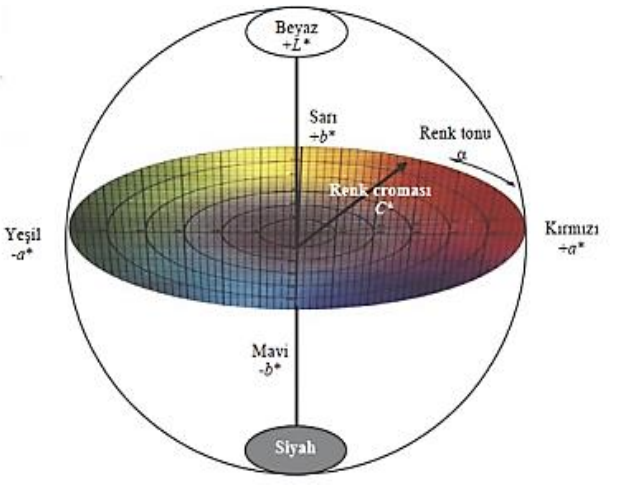

Fig. 1. Color gradient for hue angle (Çakır, 2015).

The angles corresponding to basic colors; 0 for red, 90 for yellow, 180 green, and 270 for blue (Fig. 1). Hue angle is calculated with the aid of the following equation; (McGuire, 1992).

$$h^{\circ} = \tan^{-1}(\frac{b}{a}) \tag{2}$$

Total color difference: This parameter is used to identify the change in color after drying as compared to the fresh color of the fruit (Muñoz-López *et al*., 2018). The total color difference is calculated with the aid of the following equation;

$$\Delta E = \sqrt{(L_t - L_k)^2 + (a_t - a_k)^2 + (b_t - b_k)^2} \tag{3}$$

where; L_t, a_t, and b_t indicate brightness, red-green and yellow-blue values, respectively; L_k, a_k, and b_k indicate color values of dry product.

Browning index values: BI values are indicating browning index value and x coefficients express post-drying browning values of the product. According to Plou *et al*., (1999), the browning index value is calculated with the aid of the following equations;

$$BI = \frac{[100(x - 0,31)]}{0,17} \tag{4}$$

$$x = \frac{a + (1,75xL)}{[(5,645xL) + (a - (3,012xb))]} \tag{5}$$

Chemical analyses: The pH, titratable acidity (TA), and soluble solids content (SSC) of fresh and dried Stanley, and sugar European plums were determined and the most appropriate drying conditions were determined as compared to fresh products. The methods specified in (Okatan & Çolak, 2019) were used in analyses.

Total phenolics of fresh and dried products were determined following the method of Singleton & Rossi (1965) and Polat *et al*., (2020). Fruit extract, Folin-Ciocalteu's, and distilled water were mixed in a ratio of 1:1:20, kept for a while, and supplemented with 7% sodium carbonate. At the end of two-hour incubation, the solution had a bluish color. Readings were performed in a spectrophotometer (Model T60U, PG Instruments) at 750 nm wavelength and results were expressed in gallic acid equivalent µg GAE/g.

The TEAC method was used to determine the total antioxidant capacity of the products (Saracoglu, 2018). For TEAC analysis, 7 mM ABTS (2, 2-Azino-bis 3-ethylbenzothiazoline 6-sulfonic acid) was mixed with 2.45 mM potassium bisulphate and kept at dark for 12-16 hours. Then this solution was purified with sodium acetate buffer (pH 4.5) as to have an absorbance value of 0.700 ± 0.01 in a spectrophotometer (Model T60U, PG Instruments) at 734 nm wavelength. About 20 µL fruit extract was mixed with 2.98 mL buffer and absorbance was read after 10 min in a spectrophotometer at 734 nm wavelength. Results were calculated with Trolox (10–100 µmol/L) standard curves and expressed in µmol Trolox equivalent/g fresh fruit (µgTE/g) (Gündüz and Saracoglu, 2012; Öztürk *et al*., 2013; Mertoglu *et al*., 2019).

Results and Discussion

Drying data: The average wet moisture of the European plums was measured 82, and 85% for Stanley and 84, and 92% for the sugar variety. Doymaz (2004) in a drying study, reported the average wet-based moisture content of plums as 84.30%.

In drying processes, plums were dried up to wet-based moisture contents of 10-15%. Yıldız *et al*., (2015) carried out a study to determine the drying characteristics of bananas and dried banana samples up to wet-based moisture contents of 10-15%. Average drying performance and dimensionless moisture ratios of the plum varieties are provided in Table 1.

Table 1. Average final moisture ratios and drying durations of the plums.

Drying method	Drying conditions		Cultivar	Average final moisture (%)	Drying durations
Cabin-type dryer	60°C		Stanley	12,86	32 hours
			Sugar	9,41	33 hours
	65°C		Stanley	15,68	30 hours
			Sugar	10,16	32 hours
	70°C		Stanley	14,71	24 hours
			Sugar	16,24	22 hours
Precision dryer	60°C		Stanley	15,00	24 hours
			Sugar	9,74	18 hours
	65°C		Stanley	14,41	18 hours
			Sugar	13,35	15 hours
	70°C		Stanley	11,61	12 hours
			Sugar	11,23	9 hours
Microwave dryer	540 W	50 sec	Stanley	17,48	12.5 min
			Sugar	11.62	13 min
		30 sec	Stanley	16,87	10.8 min
			Sugar	14.34	11.7 min
	720 W	50 sec	Stanley	10,13	10 min
			Sugar	13.15	10.5 min
		30 sec	Stanley	11,40	9.2 min
			Sugar	12.10	10 min

As it is shown in Table 1 the drying air temperature influenced the drying performance and, with increasing temperatures, decreasing drying durations were observed. Kaya *et al*., (2015) conducted persimmon drying experiments and reported increased drying ratios but reduced drying durations with an increase in drying air temperatures. Taşova (2016) carried out a study with a temperature-controlled microwave dryer and reported decreasing drying durations with increasing temperatures.

In the cabin-type dryer, drying durations at 60, 65, and 70°C drying air temperatures were respectively identified as 32, 30, and 24 hours for Stanley plums and as 33, 32, and 22 h for Sugar plums. In the precision dryer, drying durations at 60, 65, and 70°C drying air temperatures were respectively measured as 24, 18, and 12 hours for Stanley cultivar and as 18, 15, and 9 hours for Sugar cultivar. Precision dryer yielded shorter drying durations than the cabin-type dryer.

In microwave dryer, drying durations at 540W-30 s and 540W-50 s microwave power outputs were respectively measured as 12.5 and 10.8 minutes for Stanley plums and as 13 and 11.7 minutes for sugar plums. Drying durations at 720W-30 s and 720W-50 s microwave power outputs were respectively measured as 10 and 9.2 minutes for Stanley plums and as 10.5 and 10 minutes for sugar plums. Holding times influenced drying durations of plum cultivars in a microwave dryer. Holding times reduced drying durations and the longest duration (13 minutes) was observed at 540W-30 s treatment and the shortest (10 minutes) in 720 W-50 s treatment. It was observed based on drying durations that sugar plums had longer drying durations than Stanley plums in all drying treatments. Doymaz, (2004) dried plums with/without pre-chemical solution treatments at 65°C drying air temperature and 1.2 m/s airflow rate of a laboratory-type dryer and reported drying duration as 36 hours for pre-treated ones and as 51 hours for the ones without pre-chemical treatment. Ioannou *et al*., (2011) dried plum samples at 50, 70, 75, and 85°C drying air temperatures and reported, drying durations as between 3.5-24 hours. Matteo *et al*., (2003) dried plums with/without pre-chemical treatments and reported drying durations as between 25–40 hours.

Color values: Measured and calculated color values of fresh and dried plums are provided in Table 2.

The drying conditions for the best chroma values of Stanley and sugar plums were identified respectively as cabin-60°C and precision-70°C drying air temperatures (Table 2). Taşova (2016) carried out drying experiments with cabin-type dryers and obtained the closest chroma value to the fresh fruit at 60°C drying air temperature. Polatcı & Taşova (2017) carried out a hawthorn drying study with temperature-controlled microwave dryer at 50, 60, and 70°C drying air temperatures and reported the best chroma values as compared to the fresh fruit for 50°C drying air temperature. The least color change as compared to the fresh fruit was obtained from 540W-30 s treatment. Sumnu *et al*., (2005) carried out a carrot drying study with convective, microwave, and halogen-lamp microwave dryers and reported the least color change for microwave dryers. Alibaş, (2015) also reported the least color change in mango fruit for microwave dryer at 4 different power outputs and 50°C drying air temperature. As compared to the fresh fruit, the least browning was respectively observed in precision-65°C and precision-60°C drying air temperatures.

Chemical analyses: The pH, SSC, and TA values of the plum varieties are provided in Table 3.

There was a statistically significant difference between fresh samples and applications of both types used in the analysis. According to the fresh sample, the drying process increased the TSS and TA values while decreasing the pH value. Similar results were obtained in previous studies (Akgün *et al*., 2018; Miletić *et al*., 2019). Among the applications, the highest TSS value was obtained in the 60°C applications of the Precision Dryer. The drying process of plum fruits increased the TA values, while the highest values were determined in the drying processes with Microwave Dryer.

Total phenolics and total antioxidants of plum varieties are provided in Table 4.

Table 2. Final moisture contents and drying durations of plums.

Drying Conditions	Cultivar	L	a	b	C	Hue angle	ΔE	BI
Fresh	Stanley	53,99	-6,12	29,81	30,43	-78,40	-	-
	Sugar	56,80	-2,95	31,28	31,42	-84,62	-	-
60 °C Cabin	Stanley	55,64	5,87	29,78	30,36	78,85	38,04	81,40
	Sugar	37,29	9,72	23,74	25,66	67,74	26,41	114,23
65°C Cabin	Stanley	51,83	5,94	27,36	28,00	77,75	35,30	80,69
	Sugar	39,81	9,02	24,02	25,66	69,42	27,59	104,41
70°C Cabin	Stanley	54,22	5,25	30,60	31,05	80,27	37,28	86,42
	Sugar	44,63	9,16	26,48	28,02	70,92	30,86	100,71
60°C Precision	Stanley	52,49	2,21	23,68	23,78	84,67	37,28	61,21
	Sugar	48,14	7,69	26,73	27,81	73,95	32,83	89,47
65°C Precision	Stanley	59,44	2,67	26,65	26,78	84,27	41,88	60,96
	Sugar	53,75	6,34	27,62	28,33	77,08	36,60	78,31
70°C Precision	Stanley	59,45	2,70	31,54	31,65	85,10	41,91	75,70
	Sugar	49,43	7,74	28,06	29,11	74,58	33,85	91,73
720 W-50 sec	Stanley	35,71	5,47	14,79	15,77	69,71	24,28	63,64
	Sugar	35,73	5,83	17,08	18,05	71,15	23,92	75,27
720 W-30 sec	Stanley	32,34	7,17	19,99	21,24	70,27	22,24	107,29
	Sugar	34,24	7,46	22,19	23,41	71,41	24,00	113,65
540 W-50 sec	Stanley	30,15	9.41	17,87	20,20	62,12	20,93	108,23
	Sugar	37,23	9,94	24,51	26,45	67,92	26,76	119,61
540 W-30 sec	Stanley	25,12	9,35	9,12	13,06	44,26	16,89	71,17
	Sugar	26,95	10,75	10,43	14,98	44,13	18,23	76,75

Table 3. Average pH, SSC, and TA values of plums.

Drying conditions		Stanley			Sugar		
		TSS	pH	TA	TSS	pH	TA
Fresh		13.83^{f}	3.99^{a}	1.07^{h}	14.33^{i}	3.66^{a}	1.24^{h}
Cabin	60°C	58.00^{e}	3.79^{b}	4.92^{d}	45.00^{h}	3.37^{bc}	6.74^{f}
	65°C	64.00^{d}	3.72^{cd}	6.07^{b}	64.00^{fg}	3.34^{c}	9.68^{c}
	70°C	67.00^{cd}	3.59^{ef}	4.95^{d}	69,67^{cd}	3.25^{d}	10.76^{b}
Precision	60°C	90.67^{a}	3.80^{b}	4.25^{e}	86.33^{a}	3.41^{b}	6.27^{g}
	65°C	67.00^{cd}	3.77^{bc}	4.43^{e}	67.67^{de}	3.38^{bc}	7.06^{e}
	70°C	77.00^{b}	3.61^{e}	3.16^{f}	70.33^{c}	3.39^{bc}	6.11^{g}
Mic. 720 W	50 sec	69.67^{cd}	3.55^{efg}	7.58^{a}	81.00^{b}	3.27^{d}	13.39^{a}
	30 sec	66.33^{cd}	3.54^{efg}	7.51^{a}	66.33^{ef}	3.28^{d}	11.02^{b}
Mic. 540 W	50 sec	71.00^{c}	3.69^{d}	2.76^{g}	81.01^{b}	3.27^{d}	13.38^{a}
	30 sec	81.67^{b}	3.51^{g}	5.40^{c}	62.67^{g}	3.29^{d}	9.32^{d}

Table 4. Total phenolics and total antioxidants (TEAC and FRAP) of plum varieties.

Drying Conditions		Stanley			Sugar		
		TP (µg GAE/dw)	TEAC (µmolTE/g dw)	FRAP (µmolTE/g dw)	TP (µg GAE/dw)	TEAC (µmolTE/g dw)	FRAP (µmolTE/g dw)
Fresh		439.59^{l}	2.26^{lm}	2.36^{gh}	497.95^{m}	1.60^{o}	1.15^{g}
Cabin	60°C	1756.91^{jk}	5.60^{jklm}	5.62^{fgh}	1248.32^{lm}	3.53^{mno}	4.20^{efg}
	65°C	2394.73^{ij}	6.25^{hijk}	6.61^{fgh}	2244.66^{jk}	4.68^{lmn}	4.76^{efg}
	70°C	3907.99^{fg}	13.54^{fg}	13.66^{de}	3941.34^{gh}	12.17^{g}	16.02^{d}
Precision	60°C	2886.64^{hi}	9.65^{gh}	9.00^{ef}	2740.74^{ij}	7.83^{hk}	7.11^{ef}
	65°C	2599.00^{hij}	6.85^{hij}	6.62^{fgh}	3511.96^{hi}	12.85^{fg}	14.38^{d}
	70°C	4683.37^{ef}	17.65^{e}	16.97^{d}	4987.69^{e}	16.11^{ef}	15.09^{d}
Mic. 720 W	50 sec	8914.65^{c}	30.82^{c}	29.82^{b}	14000.43^{a}	58.99^{a}	48.85^{a}
	30 sec	7167.95^{d}	24.41^{d}	24.83^{c}	12241.32^{b}	45.52^{c}	35.05^{b}
Mic. 540 W	50 sec	19753.41^{b}	75.13^{b}	78.34^{a}	10382.056^{c}	51.57^{b}	43.94^{a}
	30 sec	23138.43^{a}	88.28^{a}	76.32^{a}	7434.75^{d}	28.75^{d}	30.62^{bc}

Changes in certain phytochemical compounds (total phenolic content and antioxidant activity) resulting from the drying of plum fruits are included in Table 4. In all the applications used in the study, the number of phytochemicals was higher than the fresh samples. Dramatic increases in the number of phytochemicals were observed; especially in samples obtained using the Microwave Dryer. Prunes obtained as a result of using a Microwave Dryer in the plum drying process can be considered as a functional food due to the high amount of phytochemicals. Similar results were obtained in previous studies (Stacewicz-Sapuntzakis, 2013; Miletić *et al*., 2019).

Conclusion

European plums are quite rich in nutrients for human health. The shelf life of the fruit should be prolonged through various methods for off-season consumption of them. Drying is among the most common methods to preserve fruit. In this study, Stanley and Sugar European plum varieties were dried under 10 different drying conditions. Drying performance and final quality attributes were determined to identify the most appropriate drying conditions. Color, pH, soluble solids content, titratable acidity, total phenolics, and total antioxidant capacity (TEAC and FRAP) were determined as the quality criteria. Following conclusions were drawn based on present findings;

For both Stanley and Sugar plums, the shortest and the longest drying durations were respectively observed in microwave 720W-50 s and cabin 60°C treatments.

For Stanley and Sugar plums, the color values closest to fresh fruits were respectively obtained from cabin 60°C and precision 70°C treatments.

In Stanley plums, the closest pH, TSS, and TA values to the fresh fruit were respectively achieved in cabin 60°C, precision 65°C and microwave 540W-50 s treatments. In sugar plums, the closest values were respectively achieved in cabin 60°C, precision 70°C and microwave 540W-50 s treatments.

For both plum varieties, the closest total phenolics to the fresh fruits were obtained from cabin 60°C drying treatments.

In Stanley and sugar plums, the closest TEAC values to the fresh fruits were respectively obtained from cabin 60°C and cabin 60-65°C treatments and the closest FRAP values were respectively achieved in cabin 60-65°C-precision 70°C and precision 65°C treatments.

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