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Effect of Drying Methods with the Application of Vacuum Microwaves on the Bioactive Compounds, Color, and Antioxidant Activity of Strawberry Fruits

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The objective of this study was to evaluate the application of vacuum-microwave drying (240, 360, and 480 W) in the production process of dehydrated strawberry and to compare and contrast the quality of these dehydrated strawberries in terms of their polyphenol compounds, concentration of some heat liable components, and color to that of freeze-dried, convective, and vaccuum-dried strawberry. Thus, the effect of vacuum-microwave drying and other drying methods on the antioxidant activity of berries was evaluated. Whole fresh and dried fruits were assessed for phenolics (anthocyanins, flavanols, hydroxycinnamic acids, and flavonols), ascorbic acid, and antioxidant activity (all parameters were calculated on a dry matter basis). Analysis of data shows that ellagic acid and flavanol changes were affected by drying techniques and cultivar. Drying destroyed anthocyanins, flavanols, and ascorbic acid, and there was a significant decrease in antioxidant activity. The most striking result was that conventional and vacuum drying decreased antioxidant activity in both cultivars, whereas contradictory results were found for vacuum-microwave processed strawberry. This study has demonstrated that vacuum-microwave drying, especially at 240 W, can produce high-quality products, with the additional advantage of reduced processing times, compared to other processes such as freeze-drying.

KEYWORDS: Strawberry; drying methods; phenolic compounds; ascorbic acid; DPPH; FRAP; ABTS

INTRODUCTION

Strawberries (*Fragaria* × *ananassa* Duch), both fresh and processed, are consumed in large quantities and can thus be a valuable source of compounds, such as phenolics. Antioxidative and antiproliferative activities of phenolics are known to have beneficial effect on health (*1*−*3*). Phenolic compounds detected in strawberries are anthocyanins, responsible for the red color of strawberry flesh, flavanols, and derivatives of hydroxycinnamic acid and ellagic acid (*4*). The harvesting season of strawberries in Poland and other European countries is usually very short; therefore, fresh strawberries are consumed in small quantities and large amounts are processed into frozen and dried fruits, jams, juices, nectars, purees, and juice concentrates (*5*−*8*). An improved stability of beneficial compounds, leading to an enhanced nutritional value, will obviously assist in marketing and distributing such products.

The following dehydration techniques are commonly employed to preserve fruits and vegetables: solar drying, heated air-drying, microwave drying, osmotic dehydration, foam-mat, spray-drying, freeze-drying, and spouted bed drying. The most popular method of fruit dehydration is convective drying. However, the method takes a very long time even at high temperature of the air applied as the drying agent. This usually results in a decrease of the quality of the dried product (*9*, *10*). Vacuum-microwave (VM) drying of fruits is becoming more and more popular thanks to its advantages. In this method microwaves penetrate the interior of the material subjected to drying, causing water to boil at low temperature. This creates a large vapor pressure differential between the center and the surface of the material, allowing rapid transport of moisture out of the product and preventing structural collapse (*11*). Yongsawatdigul and Gunasekaran (*12*) noticed that cranberries dried by the VM method had better color and texture than the same fruits dried by traditional convective method. VM drying of berries resulted in lower reduction of vitamin C and anthocyanins than traditional convective drying. No difference in antioxidant content in comparison to sublimation was found (*13*).

Strawberries contain higher levels of phenolic compounds than most other fruits which have shown beneficial effects on human health. Reports are available in the literature on ascorbic acid, phenol composition, and antioxidant activity of fresh

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strawberry fruits, but there is a lack of publications on the influence of different drying methods on the phenolic compounds and antioxidant activity. Therefore, the objective of this study was to evaluate the application of vacuum-microwave drying in the production process of dehydrated strawberry and to compare and contrast the quality of these dehydrated strawberries in terms of their polyphenol compounds, concentration of some heat liable components, and color to that of freeze-dried, convective, and vaccuum-dried strawberries. Thus, the effect of vacuum-microwave drying and other drying methods on the antioxidant activity of berries was evaluated.

MATERIALS AND METHODS

Chemicals. Chlorogenic acid, *p*-coumaric acid, ellagic acid, (+)-catechin, (−)-epicatechin, and procyanidin B_2 were purchased from Extrasynthese (Lyon Nord, France). Cyanidin 3-*O*-rutinoside, quercetin, and kaempferol 3-*O*-glycoside were supplied by Merck (Darmstadt, Germany). 1,1-Diphenyl-2-picrylhydrazyl radical (DPPH), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,2′-azinobis(3-ethylbenzthiazoline-6-sulfonic acid (ABTS), potassium persulfate, acetic acid, 2,4,6-tripyridyl-1,3,5-triazine (TPTZ), $FeCl_3$, and methanol were purchased from Sigma-Aldrich (Steinheim, Germany).

Materials. Samples of two strawberry (*Fragaria* × *ananassa* Duch) cultivars (Kent and Elsanta) were harvested (in Mościsko near Wrocław, Poland) at processing maturity, and the fresh fruits were processed in laboratory scale at Wrocław University in June 2007.

Drying Experiments. Fresh strawberries of Kent and Elsanta varieties of moisture contents of 8.1 and 10.4 kg $kg^{-1}$of dry weight (dw), respectively, were tested. Just before drying, strawberries were cut into halves. The required solar or forced drying time was shorter when whole strawberries were cut into halves, fourths, or disks (*14*). Four methods of dehydration were used: convection (convective dryer designed and made in the Agricultural Engineering Institute of Wrocław), vacuum-microwave drying (VM-200, Plazmatronika, Wrocław, Poland), freeze-drying (OE-950, Hungary), and vacuum-drying (SPT-200, ZEAMiL Horyzont, Kraków, Poland). Convective drying (CD) conditions were temperature of 70 °C and air velocity of 1 m s^{-1}. During the vaccum-microwave (VM) drying three powers of microwaves were applied: 240, 360, and 480 W. The pressure in the drying chamber varied between 4 and 6 kPa. During freeze-drying (FD) the pressure was reduced to 65 Pa. The temperature in the drying chamber was −60 °C, and the heating plate reached 30 °C. Vacuum drying (VD) was performed at 50 °C and 100 Pa. Drying kinetics for convective and VM dehydration were determined according to sample weight loss measured during drying. All determinations were performed in duplicates. Drying continued until the moisture content reached 0.05 kg kg^{-1} of dw (kg of water·kg^{-1} of dw). Moisture content was determined by drying the strawberry samples for 24 h in a vacuum dryer at 50 °C and 100 Pa.

HPLC Analysis of Polyphenols. About 2 g of each drying strawberry was ground in a laboratory mill to powder and weighed into a test tube for polyphenolic property analysis. A total of 10 mL of 80% aqueous methanol with 1% ascorbic acid was added, and the suspension was stirred slightly. Tubes were sonicated twice for 15 min and left at 4 °C. After 24 h, the extract was centrifuged for 5 min (15000 rpm), and supernatants were collected at 4 °C until use within 24 h.

The analysis of anthocyanins, flavan-3-ols, phenolic acids, and flavonol glycosides was carried out with an L-7455 liquid chromatograph with a diode array detector and an L-7100 quaternary pump equipped with a D-7000 HSM multisolvent delivery system (Merck-Hitachi, Tokyo, Japan). Separation was performed in a Synergi Fusion RP-80A column (250 mm × 4.6 mm, 4 μm); Phenomenex, Torrance, CA). The oven temperature was set at 30 °C. The mobile phase was composed of solvent A (45 mL of formic acid and 955 mL of water) and solvent B (acetonitrile). The program began with a linear gradient from 0 to 25% B in 36 min, followed by washing and reconditioning of the column. The flow rate was 1 mL min^{-1}, and the runs were monitored at wavelengths of 280 nm (flavan-3-ols), 320 nm (hydroxycinnamates), 360 nm (flavonol glycosides and ellagic acid), and 510 nm (anthocyanins). Photodiode array spectra were measured over the wavelength range of 200−600 nm in steps of 2 nm. Retention times and spectra were compared with those of pure standards within that range.

The amounts of the different phenolics in the samples were determined by HPLC. Calibration curves were constructed with (+)-catechin, *p*-coumaric acid, ellagic acid, quercetin, kaempferol, and cyanidin 3-*O*-rutinoside as standards. Quercetin 3-*O*-glycoside and kaempferol 3-*O*-glycoside were used for the quantification of all quercetin and kaempferol derivatives, respectively.

HPLC Analysis of Ascorbic Acid. Strawberry powders (0.5 g) were diluted with 0.1 M phosphoric acid and centrifuged at 14000 rpm during 10 min. The analysis of L-ascorbic acid was carried out on a Waters liquid chromatograph with a tunable absorbance detector (Waters 486) and quaternary pump with Waters 600 controller apparatus (Waters Associates, Milford, MA). A 20 μL sample was injected into a Chromolith Performance RP-18 column (100-4.6 mm) (Merck). The elution was carried out using 0.1M phosphoric acid, and the flow rate was 1 mL/min. The absorbance was monitored at 254 nm. The L-ascorbic acid was identified by comparison with standard. The calibration curve was prepared by plotting different concentrations of standard versus area measurements in HPLC.

Extraction of Polyphenol Compounds for Antioxidant Activity Analysis. About 5 g of each drying strawberry powder was weighed into a test tube for antioxidant property analysis. A total of 25 mL of 80% aqueous methanol with 1% HCl was added, and the suspension was stirred slightly. Tubes were sonicated for 15 min twice and left at 4 °C for 24 h. Afterward, the extract was centrifuged for 10 min (15000 rpm), and supernatants were collected at 4 °C to be used within 24 h.

Antioxidant Activity. *DPPH Radical Scavenging Spectrophotometric Assay.* The DPPH radical scavenging activity of dried strawberry was determined according to the method of Yen et al. (*15*). The DPPH solution (1 mL) was added to 1 mL of centrifuged supernatant with 3 mL of ethanol. The mixture was shaken vigorously and allowed to stand at room temperature in the dark for 10 min. The decrease in absorbance was measured at 517 nm using a Shimadzu UV-2401 PC spectrophotometer. Ethanol was used as blank. All determinations were performed in triplicate. The results of the assay were expressed relative to micromolar Trolox per 100 g of dry weight in terms of Trolox equivalent antioxidant capacity (TEAC).

$ABTS^{\bullet+}$ Radical Scavenging Spectrophotometric Assay. The free radical scavenging activity was determined by ABTS radical cation decolorization assay according to the method of Re et al. (*16*). ABTS was dissolved in water to a 7 mM concentration. ABTS radical cation ($ABTS^{\bullet+}$) was produced by reacting ABTS stock solution with 2.45 mM potassium persulfate (final concentration). Next the mixture was left to stand in the dark at room temperature for 12−16 h before use. The radical was stable in this form for more than 2 days when stored in the dark at room temperature. For the study of infusion samples the $ABTS^{\bullet+}$ solution was diluted with redistilled water to an absorbance of 0.700 (±0.02) at 734 nm. After the addition of 30 μL of supernatant to 3.0 mL of diluted $ABTS^{\bullet+}$ solution [A_{734nm} = 0.700 (±0.02)], the absorbance was read exactly 6 min after initial mixing. All determinations were performed in triplicate. The results of the assay were expressed relative to micromolar Trolox per 100 g of dry weight in terms of TEAC.

Ferric Reducing/Antioxidant Power (FRAP) Assay. The total antioxidant potential of a sample was determined using a FRAP assay by Benzie et al. (*17*) as a measure of antioxidant power. The assay was based on the reducing power of a compound (antioxidant). A potential antioxidant will reduce the ferric ion (Fe^{3+}) to the ferrous ion (Fe^{2+}); the latter forms a blue complex (Fe^{2+}/TPTZ), which increases the absorption at 593 nm. Briefly, the FRAP reagent was prepared by mixing acetate buffer (300 μM, pH 3.6), a solution of 10 μM TPTZ in 40 μM HCl, and 20 μM $FeCl_3$ at 10:1:1 (v/v/v). The FRAP reagent (300 μL) and sample solutions (10 μL) were added to each well and mixed thoroughly. The absorbance was taken at 593 nm after 10 min. A standard curve was prepared using different concentrations of Trolox. All solutions were used on the day of preparation. All determinations

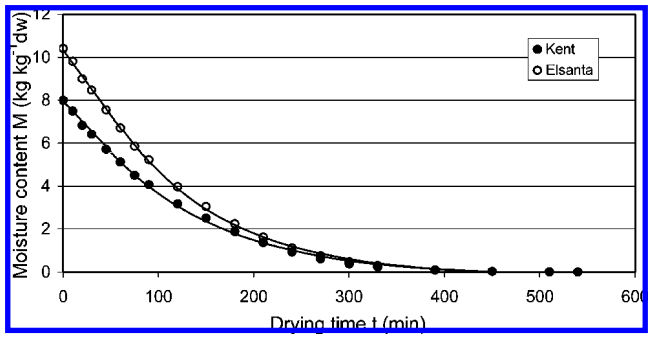

Figure 1. Drying kinetics of strawberries dehydrated by convective method.

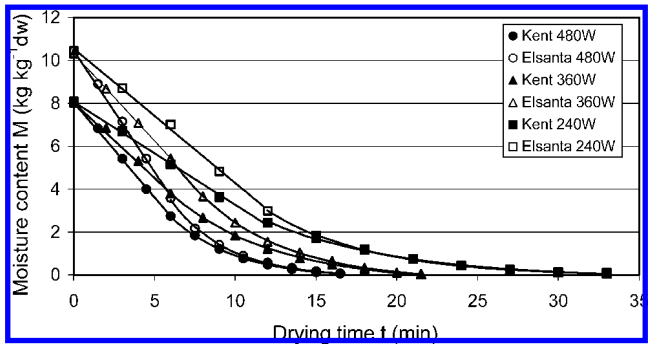

Figure 2. Drying kinetics of strawberries dehydrated by vacuum-microwave method at microwave power 480, 360, and 240 W.

were performed in triplicates. The results were corrected for dilution and expressed in micromolar Trolox per 100 g of dry weight.

Color Measurement. The color of strawberry powders was measured with Color Quest XE (HunterLab). Strawberry powders were placed in a glass cuvette (1 cm path), and the color was recorded using CIE $L^*a^*b^*$ 10°/D_{65} color spaces. L^* indicates lightness, and its value ranges from 0 (an ideal black object) to 100 (an ideal white object). In the CIE $L^*a^*b^*$ system a^* and b^* are the chromaticity coordinates. Positive a^* value indicates the red direction, negative a^* value is the green direction; positive b^* value is the yellow direction, and negative b^* value is the blue direction. Two derived color parameters hue angle (h°) and chroma value (C) were calculated using the following equations:

$$h^\circ = \arctan(b^*/a^*)$$

$$C = \sqrt{a^{*2}+b^{*2}}$$

Statistical Analysis. Statistical analysis was conducted using Statistica version 6.0 (StatSoft Poland). Significant differences ($P \leq 0.05$) between average responses were evaluated by using one-way ANOVA with Duncan's test.

RESULT AND DISCUSSION

Comparison of Drying Methods. During strawberry dehydration by the convective (**Figure 1**) and VM (**Figure 2**) methods, two drying periods were observed. The drying periods are typical for drying kinetics of biological materials (*18, 19*). The decrease in moisture content during the first period was described by a linear function (eq 1). During the second period water loss was described by the exponential function (eq 2).

$$M = A - Bt \quad (1)$$

$$M = C + D \times e^{-t/E} \quad (2)$$

In **Table 1** are given parameters $A-E$, which describe the drying process of both methods. The fruits of both studied strawberry varieties differed in initial moisture content. However, the times of drying for Kent and Elsanta were similar. As expected, the VM method was carried out more rapidly than the convective method. It was stated that the time of drying by convective method at 70 °C was 550 min. In the VM method with the power of microwaves increased from 240 to 480 W, the time of drying was shortened from 33 to 16.5 min. Piotrowski et al. (*20*) confirmed that the increase of microwave doses in microwave/air-drying influenced the shortening of process time both for osmotically dehydrated strawberries and for raw, not dehydrated, material. Krulis et al. (*21*) stated that the increase in microwave power resulted in higher values for energy efficiency and volume expansion of strawberries that were predried by convective method before VM drying.

Derivation of the functions describing the strawberry drying process let us determine the drying rate. The drying rates for convective and VM dehydration processes are shown in **Figures 3** and **4**. In the first period of dehydration, the drying rate was constant, whereas in the second period the drying rate was decreasing. At the beginning of dehydration the drying rate was higher for Elsanta than for Kent, despite the drying method. The drying rate was also much higher for the VM method compared to the convective method particularly when higher microwave power was applied. While drying, the differences in the drying rate were decreasing.

Improving the Nutritional Quality by Different Drying Methods. *Estimation of the Phenolic Compounds of Fresh Fruits and Changes after Drying.* The total phenolic content of berries was estimated by the HPLC method and is presented in **Tables 2** and **3**. The total phenolic contents of Kent and Elsanta strawberries were 1901.9 and 2405.9 mg/100 g of dw, respectively. Changes connected with strawberry drying were closely related not only to the applied drying technique but also to cultivar. Much lower residual values were observed for convectively dried products (64.5%) and vaccuum-dried strawberries (70.2%) in both varieties.

In the samples that were freeze-dried and VM-dried (especially VM-240W) the highest concentration of phenolic compounds was found (**Tables 2** and **3**). The lower amounts of phenolics in other dried fruits may be attributed to oxidative and thermal degradation of the phenolic compounds with increased heat intensity and length of heat treatment. The following compounds were identified in dried sample of strawberries: *p*-coumaric and ellagic acid derivatives, quercetin and kaempferol derivatives, anthocyanins, (+)-catechin, procyanidin B_3, and polymer proanthocyanidins. Proanthocyanidins and ellagic acid derivatives are the major polyphenol compounds of all strawberries. A significant ($P < 0.05$) decrease in the content of phenolic compounds occurred for both strawberry varieties as a result of drying. The Elsanta cultivar (1857.1 mg/100 g of dw) contained higher amounts of proanthocyanidins than Kent (1373.6 mg/100 g of dw). After drying, the content of proanthocyanidins was similar to that of a fresh sample only for FD and VM-240W methods. For the other methods much lower contents of proanthocyanidins than in fresh material of both varieties were observed. In comparison to the initial content in dried strawberries obtained by CD method, 68.0 and 67.4% of proanthocyanidins were found for Kent and Elsanta, respectively. The procyanidin content in dried strawberry slices is very important because they play the main role as radical scavenging compounds (*22*). As a result of the drying processes, especially FD and VM, the levels of (+)-catechin increased, especially for the Elsanta cultivar. This was due to the depolymerized effect of proanthocyanidins in strawberry and their conversion into elementary units. The same effect was observed by Zhu et al.

Table 1. Parameters *A*−*E* of the Equations That Describe the Dehydration Process Using Convective and Vacuum-Microwave (VM) Methods[a]

		equation parameters						
		first period			second period			
cultivar	type of drying method	*A*	*B*	R^2	*C*	*D*	*E*	R^2
Kent	convective method	7.953	0.0467	0.9986	−0.24	8.715	123.7	0.9988
	VM 240 W	8.065	0.4791	0.9983	−0.169	11.03	8.41	0.9993
	360 W	8.041	0.7035	0.9994	−0.330	10.81	6.235	0.9998
	480 W	8.035	0.8827	0.9995	−0.162	12.71	4.038	0.9999
Elsanta	convective method	10.33	0.0606	0.9978	−0.225	11.95	112.6	0.9984
	VM 240 W	10.55	0.6262	0.9980	−0.053	19.72	6.432	0.9998
	360 W	10.32	0.814	0.9994	−0.296	17.33	5.425	0.9997
	480 W	10.45	1.128	0.9993	−0.109	20.10	3.495	0.9997

[a] R^2, coefficient of determination; *A*, *B*, parameters of eq 1; *C*, *D*, *E*, parameters of eq 2.

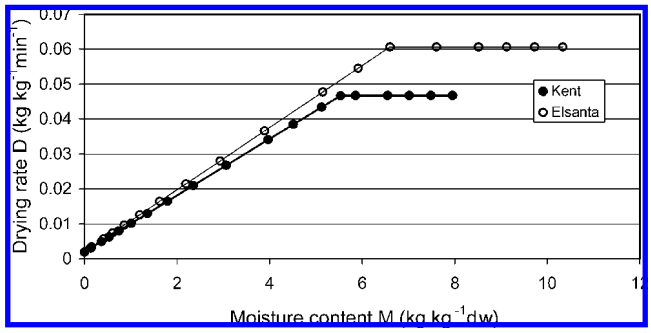

Figure 3. Drying rate during dehydration of strawberries using convective method.

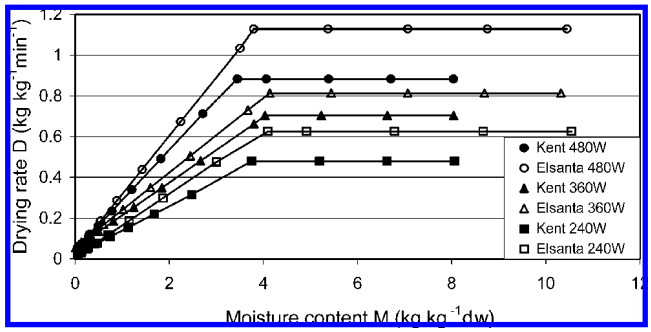

Figure 4. Drying rate during dehydration of strawberries using convective and vacuum-microwave (VM) method.

(*23*) for (−)-epicatechin in chocolate and by Somers et al. (*24*) in stored wines. This is in line with results reported by Piga et al. and Del Caro et al. (*25*, *26*). It is possibly due to the liberation of phenolic compounds from the matrix during the process. Chism et al. (*27*) has mentioned that fruits and vegetables normally have higher contents of phenolic compounds in their outer parts than in the vacuoles.

Probably, food processes might accelerate the release of more bound phenolic compounds that are released due to the breakdown of cellular constituents. Although disruption of cell walls may also trigger the release of oxidative and hydrolytic enzymes that would destroy the antioxidant activity in fruits, the high temperature of the hot-air drying process would deactivate these enzymes and prevent the loss of phenolic compounds and, therefore, lead to the increase of antioxidant activity. Strawberry fruits consist of seeds, called achenes, which are richer in phenolics than the flesh (*28*). During fruit drying, cell structures of hard achenes are disrupted and increased phenolic extraction takes place, which would explain some higher content of this compound in dried fruits than in fresh material.

Estimation of Anthocyanins and Color after Processing. The color of the strawberry dried products is an important quality factor. Strawberries have relatively high anthocyanin content (*3*, *4*). The total anthocyanin contents of the investigated strawberry fruits were 294.4 and 372.6 mg/100 g of dw for Kent and Elsanta, respectively (**Table 3**). Pelargonidin 3-*O*-glucoside was the predominant anthocyanin in the investigated sample, and it constituted 90% of total anthocyanins (pel-3- M-gl- > pel-3-rut ≥ cya-3-glu). This result is consistent with the findings of other authors (*7*). The Elsanta cultivar had more ($P < 0.05$) anthocyanins before and after the drying process than the Kent cultivar. Pelargonidin 3-*O*-glucoside was less stable during drying than other anthocyanins. The anthocyanin content of VM berries was significantly different from that of the FD sample and was higher than that of CD and VD dried fruits. Fruits dehydrated by CD had the lowest ($P < 0.05$) anthocyanin content (that is, 36 and 27% of fresh fruits for Elsanta and Kent, respectively). It is clear that strawberries dried with higher power (VM-480W) had lower content of anthocyanins and other polyphenols than those dried with lower power (VM-360W and -240W). The results suggest a direct relationship between the length and intensity of heat treatment and the degree of anthocyanin loss. This is consistent with results reported by Kwok et al. (*29*). Therefore, although anthocyanin is lost due to the exposure to high temperatures, the pigment that is retained is concentrated in a reduced volume. As well, the conditions of drying (high temperature and the presence of oxygen) may promote the activity of polyphenol oxidase, resulting in browning that characterizes many dehydrated food materials (*30*).

The lightness (*L**), redness (*a**), and yellowness (*b**) values of dried strawberry are presented in **Table 4**. Results show that dried Elsanta and Kent cultivars had similar color values. The color of the dried samples showed a moderate degradation with drying as indicated by the slight reduction of *L** values and slightly increased yellowness (*b**) for strawberry samples. Among the dehydrated samples, those freeze-dried had the lowest *L** values, indicating that most light was reflected, whereas the air-dried and VD samples had the higher *L** values. Lowering of the *L** value gave darker dried strawberry products. For *a** values, FD and VM were not significantly different, but they were more red than CD and VD dried samples ($P < 0.05$). The freeze-dried strawberries of both cultivars exhibited higher *a** values. The VM dried fruits were significantly different from other samples, but they had significantly less *a** and *b** value than the VM-280W samples for the Elsanta cultivar.

The intensity of the red color observed during freeze-drying for Kent and Elsanta, during VM-240W and -360W for Kent, and during VM-240W for Elsanta increased 2−3 times in comparison with the fresh fruit. The color reinforcement

Table 2. Effects of Drying Method and Strawberry Cultivar on Phenolic Compounds (mg/100 g of dw)[a]

cultivar	drying method	*p*-coumaroyl glycoside	ellagic acid glycoside	quercetin 3-*O*-glycoside	kaempferol 3-*O*-glycoside	(+)-catechin	procyanidin B_3	procyanidin polymers	DP	total polyphenols
Kent	fresh	9.7 ± 1.3c	13.6 ± 0.8c	12.2 ± 1.2c	4.3 ± 1.0c	47.4 ± 0.4c	146.7 ± 3.4a	1373.6 ± 21cd	4.86	1901.9
	FD	10.0 ± 1.1c	9.0 ± 1.2g	14.4 ± 1.4c	4.9 ± 0.9c	47.8 ± 1.7c	108.2 ± 2.7b	1306.1 ± 11d	6.54	1802.7
	VD	7.1 ± 1.9e	7.7 ± 1.0h	10.0 ± 2.1e	3.7 ± 0.7d	24.9 ± 2.5e	78.1 ± 1.9d	1127.6 ± 13f	4.84	1331.7
	VM-240W	7.4 ± 0.9e	7.7 ± 2.1h	12.8 ± 1.7c	4.1 ± 0.4c	39.9 ± 1.9d	97.2 ± 3.2c	1305.1 ± 9d	6.13	1702.0
	VM-360W	7.5 ± 1.0e	12.7 ± 1.2d	13.9 ± 1.9c	4.2 ± 0.7c	48.2 ± 2.6bc	104.5 ± 3.7b	1229.9 ± 14e	6.42	1649.5
	VM-480 W	8.5 ± 2.1d	11.2 ± 1.1e	22.4 ± 2.5a	4.3 ± 0.2c	49.2 ± 2.8b	108.9 ± 3.8b	1241.1 ± 25e	6.72	1657.4
	CD	7.3 ± 1.7e	10.4 ± 2.1f	10.5 ± 1.0e	4.6 ± 0.7c	21.8 ± 2.1e	153.7 ± 1.0a	933.0 ± 14g	4.07	1220.5
Elsanta	fresh	32.1 ± 3.1a	17.8 ± 1.7a	16.1 ± 2.1b	4.8 ± 0.4c	42.3 ± 1.9d	63.2 ± 0.9e	1857.1 ± 16a	5.90	2405.9
	FD	30.7 ± 1.9ab	12.2 ± 1.4d	13.4 ± 1.9c	6.5 ± 0.9b	49.0 ± 2.3bc	61.5 ± 2.5e	1863.1 ± 22a	6.22	2411.5
	VD	26.0 ± 2.3b	17.0 ± 0.6b	10.6 ± 1.4e	7.6 ± 1.1a	20.6 ± 1.1e	28.8 ± 1.1h	1468.8 ± 16c	5.11	1667.6
	VM-240W	34.9 ± 1.9a	7.8 ± 2.0h	11.6 ± 1.3d	6.7 ± 0.9b	46.2 ± 1.6c	61.2 ± 1.9e	1828.2 ± 25a	6.18	2302.4
	VM-360W	31.3 ± 2.5a	12.9 ± 1.4d	11.7 ± 0.9d	6.9 ± 1.0b	50.2 ± 3.1b	56.7 ± 2.5f	1795.8 ± 18b	5.10	2277.8
	VM-480W	27.7 ± 3.1b	17.9 ± 1.8a	11.7 ± 1.6d	7.1 ± 0.4a	54.3 ± 1.8a	52.3 ± 2.7f	1763.5 ± 14b	5.85	2253.2
	CD	26.9 ± 1.1b	12.1 ± 1.2d	16.5 ± 1.9b	7.9 ± 1.3a	55.1 ± 3.5a	46.2 ± 1.2g	1241.1 ± 13e	5.90	1541.5

[a] FD, freeze-drying; VD, vacuum drying; VM, vacuum-microwave drying; CD, convection drying; DP, degree of polymerization; mean values with different letters within each block differ significantly ($P < 0.05$). Total of polyphenols, sum of the determined phenolic compounds from **Tables 2** and **3**.

Table 3. Effects of Drying Method and Strawberry Cultivars on Anthocyanins (mg/100 g of dw)[a]

cultivar	drying method	cyanidin 3-*O*-glucoside	pelargonidin 3-*O*-glucoside	pelargonidin 3-*O*-rutinoside	pelargonidin 3-*O*-malonyl-glucoside	total anthocyanins
Kent	fresh	8.3 ± 1.2b	215.4 ± 2.7c	11.0 ± 2.4a	59.7 ± 1.2d	294.4
	FD	9.9 ± 1.6a	218.9 ± 3.Xc	8.5 ± 1.5b	64.8 ± 0.4d	302.1
	VD	2.6 ± 0.8f	53.9 ± 1.8f	2.6 ± 3.5f	13.5 ± 0.1h	72.6
	VM-240W	7.7 ± 1.0c	166.2 ± 2.9d	7.2 ± 1.7c	46.8 ± 2.5e	227.9
	VM-360W	6.6 ± 1.2d	165.2 ± 3.1d	7.3 ± 0.9c	49.6 ± 2.1e	228.7
	VM-480W	7.9 ± 0.8c	151.4 ± 2.6d	5.9 ± 1.0d	46.6 ± 1.7e	211.8
	CD	2.6 ± 0.9f	59.75 ± 3.5f	3.4 ± 0.7e	13.7 ± 0.9h	79.4
Elsanta	fresh	3.7 ± 0.6e	271.0 ± 3.2a	1.9 ± 0.9g	96.0 ± 2.6a	372.6
	FD	3.5 ± 0.2e	274.8 ± 1.9a	1.7 ± 0.5h	95.2 ± 2.8a	375.2
	VD	0.8 ± 0.7h	65.1 ± 1.6f	0.2 ± 0.0k	22.1 ± 3.1g	88.2
	VM-240W	2.9 ± 0.3e	228.5 ± 2.5b	1.1 ± 0.2i	73.3 ± 1.2c	305.8
	VM-360W	3.0 ± 0.7e	227.3 ± 3.8b	0.9 ± 0.1j	81.0 ± 4.1bc	312.2
	VM-480W	3.2 ± 0.2e	226.1 ± 4.1b	0.7 ± 0.1j	88.6 ± 2.4b	318.6
	CD	1.8 ± 0.9g	97.1 ± 1.6e	0.3 ± 0.0k	36.6 ± 1.0f	135.8

[a] FD, freeze-drying; VD, vacuum drying; VM, vacuum-microwave drying; CD, convection drying; DP, degree of polymerization; mean values with different letters within each block differ significantly ($P < 0.05$).

Table 4. Effects of Drying Method and Strawberry Cultivars on Color, Hue Angle, and Chroma Value[a]

cultivar	drying method	*L**	*a**	*b**	*h*°	*C*
Kent	raw	88.86 ± 0.02b	0.60 ± 0.03e	0.22 ± 0.03e	0.35	0.94
	FD	88.14 ± 0.05b	3.12 ± 0.01a	1.10 ± 0.11b	0.39	3.73
	VD	89.16 ± 0.03a	0.84 ± 0.08d	0.29 ± 0.03e	0.49	0.79
	VM-240W	88.64 ± 0.10b	1.07 ± 0.02c	0.45 ± 0.12d	0.33	1.32
	VM-360W	88.09 ± 0.23b	1.63 ± 0.10b	0.60 ± 0.03c	0.39	0.84
	VM-480W	88.34 ± 0.04b	0.94 ± 0.04d	0.35 ± 0.02e	0.44	0.70
	CD	87.66 ± 0.27c	0.20 ± 0.02f	0.14 ± 0.06f	0.54	0.52
Elsanta	raw	89.01 ± 0.11a	0.88 ± 0.01d	0.32 ± 0.01	0.35	0.64
	FD	87.79 ± 0.09c	3.44 ± 0.12a	1.43 ± 0.09a	0.34	3.31
	VD	88.99 ± 0.28a	0.70 ± 0.01e	0.37 ± 0.01e	0.33	0.89
	VM-240W	88.36 ± 0.17b	1.25 ± 0.02c	0.43 ± 0.01d	0.40	1.16
	VM-360W	88.85 ± 0.03b	0.78 ± 0.01e	0.32 ± 0.03e	0.35	1.74
	VM-480W	88.92 ± 0.05b	0.63 ± 0.03e	0.30 ± 0.05e	0.36	1.00
	CD	87.01 ± 0.11c	0.45 ± 0.01e	0.27 ± 0.01e	0.61	0.24

[a] *h*°, hue angle; *C*, chroma value; FD, freeze-drying; VD, vacuum drying; VM, vacuum-microwave drying; CD, convection drying; mean values with different letters within each block differ significantly ($P < 0.05$).

observed during freeze-drying and VM drying may be interpreted from different points of view. It has been previously attributed to a prefreezing step (*31*) and pigment concentration due to water reduction (*32*). This phenomenon can also be explained by the effect of pH because anthocyanin color varies according to pH (*33*). According to Flink et al. (*34*), the concentration of H^+ increases during the freezing process, and it can be changed by up to 3 pH units. In acid aqueous solutions anthocyanins exist as a mixture of four structures in equilibrium: flavylium cation (red), quinoidal base (blue), carbinol pseudobase (colorless), and chalcone (colorless or light yellow). Therefore, a increases in H^+ concentration during drying can change the anthocyanin equilibrium in the production of flavylium cation, which may increase the intensity of red color.

The sole analysis of parameters *L**, *a**, and *b** is not enough to interpret changes in color during processing. According to Abers and Wrolstad (*35*), the hue angle has the most significant correlation with visual scores, and the chroma value (*C*) gives

Table 5. Effects of Drying Method and Strawberry Cultivar on Antioxidant Activity and Ascorbic Acid Content[a]

cultivar	drying method	antioxidant activity (μM Trolox/100 g of dw) DPPH	ABTS	FRAP	ascorbic acid (mg/100 g of dw)
Kent	raw	21.0 ± 0.8b	3.1 ± 0.4b	17.2 ± 0.3b	340.2 ± 2.9f
	FD	18.8 ± 1.3fg	2.3 ± 0.9e	12.4 ± 0.2f	333.7 ± 3.3g
	VD	11.2 ± 0.4g	1.6 ± 0.2f	9.6 ± 0.5i	138.0 ± 1.9l
	VM-240W	14.2 ± 0.5f	2.3 ± 0.5d	13.1 ± 0.3e	298.5 ± 2.6h
	VM-360W	17.0 ± 1.1d	2.4 ± 0.0d	14.0 ± 0.6e	276.5 ± 3.4i
	VM-480W	17.0 ± 0.6d	2.5 ± 0.3d	13.8 ± 0.0e	264.7 ± 3.2j
	CD	13.0 ± 0.9h	2.1 ± 0.5g	10.4 ± 0.3h	94.9 ± 1.9m
Elsanta	raw	24.3 ± 0.4a	3.6 ± 0.0a	18.1 ± 0.9a	680.2 ± 3.2a
	FD	20.6 ± 0.9b	2.9 ± 0.2c	16.8 ± 0.7c	676.2 ± 1.9b
	VD	15.8 ± 0.5e	2.4 ± 0.1d	11.7 ± 0.2e	260.4 ± 1.5j
	VM-240W	18.9 ± 1.1c	2.9 ± 0.5c	14.4 ± 0.1d	593.1 ± 0.9c
	VM-360W	15.3 ± 0.2e	2.1 ± 0.6f	12.5 ± 0.8f	450.6 ± 2.6d
	VM-480W	20.5 ± 0.5b	3.0 ± 0.0b	16.2 ± 0.5c	437.2 ± 2.7e
	CD	15.2 ± 0.9e	2.7 ± 0.1f	13.6 ± 0.9 g	185.1 ± 3.5k

[a] FD, freeze-drying; VD, vacuum drying; VM, vacuum-microwave drying; CD, convection drying; mean values with different letters within each block differ significantly ($P < 0.05$).

a good indication of the amount of color. Hue angles ($h°$) of the convectively dried strawberry samples were significantly increase compared to fresh and other drying samples which, in combination with a comparatively low chroma value (C), describes the brown color of the processed fruits (**Table 4**). Besides thermal pigment degradation, Maillard reactions may also be responsible for the formation of brown compounds.

Changes of Vitamin C after Processing. **Table 5** show the changes of the content of vitamin C after the drying process. A higher level of vitamin C ($P < 0.05$) was found in Elsanta strawberry than in Kent. In the base experiments, the content of residual ascorbic acid proved to be >98% of the initial value when sampling after the FD drying and from 60 to 87% of the initial value when sampling after VM drying. When applying the CD and VD processing conditions, significantly ($P < 0.05$) lower stabilities of ascorbic acid of approximately 28.3 and 40%, respectively, were observed. Inyang and McLaughlin (*36*, *37*) also showed that higher drying temperatures had a negative effect on ascorbic acid retention. Lin (*10*) reported that losses of vitamin C and carotene were higher during air-drying compared to those during vacuum- and freeze-drying. Caixeta et al. (*38*) observed a decrease in vitamin C content with the increase of drying temperature and heat transfer coefficient. Although at a higher temperature and with a higher heat transfer coefficient the drying time was shorter, the loss of vitamin C was higher. The oxidation of ascorbic acid in the presence of conventional and vacuum treatments is a possible explanation for these losses. The relatively long drying time (550 min in 70 °C) associated with air-drying contributes to the severe loss of vitamin C.

Changes in Antioxidant Activity after Processing. To estimate the antioxidant activity of the fresh and dehydrated strawberries, the DPPH, ABTS, and FRAP methods were used. Among the six treatments, the greatest antioxidant activity was observed for the FD and VM samples. Regardless of the processing method employed, Elsanta, which possesses more polyphenolic compounds and vitamin C, had greater antioxidant activity than the Kent cultivar.

Lower ($P < 0.05$) DPPH radical scavenging activity was obtained for dehydrated fruits compared with fresh sample (**Table 5**). FD-processed samples produced significantly ($P < 0.05$) higher DPPH scavenging activities, compared with VM dried, which accounted for 85 and 89% of the original activity found in fresh Elsanta and Kent, respectively. VD and CD processing resulted in berries retaining ($P < 0.05$) lower DPPH radical scavenging affinity.

Antioxidant activities of strawberry as measured by ABTS ranged from 3.07 μM Trolox/100 g of dw for the Kent cultivar to 3.58 μM Trolox/100 g of dw for the Elsanta cultivar. The VM (240, 360, and 480 W) gave the highest ABTS radical scavenging followed by FD of processed and fresh strawberries of both varieties (**Table 5**).

For the FRAP assay we observed more differences between fresh and dried samples, especially for the Kent cultivar. A higher FRAP value was obtained by the VM method than by FD and other drying methods. It was observed that strawberry fruits dehydrated by the VD method contained lower antioxidant activity and reducing power than strawberries dehydrated by traditional convection drying methods (CD). This behavior could be the result of two factors: (i) it is known that polyphenols in an intermediate stage of oxidation have greater antioxidant power than initially (*39*, *40*) even though this is temporary; and (ii) high-temperature stabilization procedures may lead to the formation of new compounds with higher antioxidant activity. This is essentially the case of the Maillard reaction, which creates various products that are the Maillard reaction products (MRPs), which have antioxidant power, often by a chain breaking type mechanism (*39*, *41*, *42*). Therefore, we can presume that the increased antioxidant activity for convention-alaly dried sample can be attributed to Maillard reaction products. This hypothesis appears to be confirmed by the obtained color results. CD samples had much lower L^* values than VD samples, indicating more browning. The apparent anomaly of the strawberry dried by convection method at 70 °C is yet to be explained. A similar effect was observed for prunes by Piga et al. (*25*). Moreover, these authors have shown that the increase of antioxidant capacity due to the MRPs did not compensate for the destruction of the phenolics.

Conclusion. This paper presents an overview of the loss of non-nutritive phytochemicals (polyphenol compounds and ascorbic acid) during drying of strawberries by different methods. Vaccum-microwave drying was shown to be effective in preserving the heat- and oxygen-sensitive phenolic components and ascorbic acid of strawberries. Vacuum-microwave dried strawberry with applied 240 W had higher levels of vitamin C, anthocyanins, and phenolic compounds, antioxidant activity, and color than other strawberries dried at other VM powers and with the rest of the drying methods. Among all dried strawberries, the freeze-dried had the greatest antioxidant effect. This study has demonstrated that vacuum-microwave drying, especially at 240 W, can produce high-quality products, with the additional advantage of reduced processing times, compared to other processes such as convective and vacuum-drying. Recently, dried fruits have been promoted as a convenient health-enhancing food, and their consumption steadily increases. They are becoming a valuable addition to breakfasts, desserts, and between-meal snacks.

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