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Quality Properties and Headspace Volatiles of Hot Air-Dried Strawberries

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Abstract: Strawberry is one of the most important soft fruit in food industry. With its flavor and antioxidant content, it is widely used mainly in confectionery and beverage industry. Strawberries are perishable and this limits their usage in foods. For that reason, drying is one of the solutions to make them durable. The aim of this study is to analyze certain quality parameters and headspace volatiles of hot air-dried 'Florida Fortuna' and 'Osmanlı' strawberries (Fragaria ×ananassa) at 50, 60 and 70°C. The results showed that drying the strawberry samples at high drying temperature caused a decrease in acidity and bulk density and a deterioration in ascorbic acid content. However, total phenolic contents and total color difference values of both of strawberry samples increased with drying process. A total of 24 headspace volatiles were detected in dried strawberries. The most abundant volatiles were dimethyl sulfide, acetic acid and acetone. The highest number of compound groups were aldehydes, acids, esters and sugar degradation products, respectively. The highest retention of fresh strawberry volatiles and minimum formation of sugar degradation products were obtained by drying at low temperature.

Key words: Strawberry, hot air-drying, quality, headspace volatiles.

INTRODUCTION

Strawberry is one of the most important soft fruit among berries that is produced over 9 million tonnes in the world in 2016. Turkey is the fifth country with 22% of total world production (FAO 2016). Strawberry is cultivated in the Mediterranean, Anatolia, Black Sea, Aegean and Marmara Regions of Turkey. Twenty-four percent of production is in the Aegean region. 'Florida Fortuna', 'DPI Rubygem', 'Osmanlı' and 'Sabrina' are the most common species cultivated in the Aegean Region (Serçe & Özgen 2015).

Berry fruits contain high amounts of flavonoids, anthocyanins, phenolic acids, vitamins and minerals. Because of their antioxidative effects, consumption of strawberries reduces the risk of cancer, neurodegenerative and cardiovascular diseases (Ayala-Zavala et al. 2004). Also, in recent studies it was reported that strawberries can be effective on the type 2 diabetes (Cheplick et al. 2010, Da Silva Pinto et al. 2008, Giampieri et al. 2012).

Strawberries are perishable fruits because of their high water activity. Although it is usually consumed as fresh, it can also be processed and used as juice, nectar, puree, jam, and jellies. Dried strawberries are the ingredients of some bakery products and yogurt. Drying is an old and the most common technique to decrease moisture content of foods. There are several drying methods such as freeze drying, hot-air drying, spray drying and drum drying for produce fruits chips and powder.

Freeze drying is considered as the best method for preserving of final products quality. However, it is costly and needs long process time (Caparino et al. 2012). Drum drying is inappropriate for aromatic foods because of the high temperature used in the process (Nindo & Tang 2007). Spray drying is a rapid technique for drying process but it can cause losses of several nutrients such as vitamins and minerals (Dziezak 1988). Although hot air-drying process is a commonly used method in food industry, it can cause undesirable changes in dried products (Nadian et al. 2015).

Currently, there are a large number of studies on effects of drying processes in fruits. However, there is no published data available on the changes of headspace volatile compounds of dried 'Florida Fortuna' and 'Osmanlı' strawberries at different time-temperature conditions. The aim of this study was to detect changes of certain quality parameters and volatile components in strawberries during convective drying at 50, 60 and 70 °C.

MATERIALS AND METHODS

Materials

Strawberries (the crop of 2018 which is harvested between March and June) (*Fragaria x ananassa Duch. Fortuna* and *Fragaria vesca*) were obtained from a local provider in Aydın (Turkey). The samples were kept at -18°C until the analysis.

Drying process

One hundred and fifty grams of sample were sliced to 3 mm thickness. Then, the slices were subjected to drying under constant air flow at three different temperatures (1 m/s air flow at 50°C for 27 h, 60°C for 21 h and 70°C for 15 h). Drying procedures were performed using Excalibur 4926OT dehydrator (California, USA). Drying was completed when samples had constant moisture content ($10\pm1\%$). Moisture contents of samples were identified by the infrared moisture equipment named MOC-63U Shimadzu (AOAC 1990). The dried samples were kept in an air-tight glass container and stored at +4°C until the analysis.

Water activity (a_w), bulk density, water holding capacity (WHC) and color

Water activity (a_w) of strawberry samples were measured using Testo 645 water activity system (Testo NV/SA, Lenzkirch, Germany). For determination of bulk density, dried samples were measured with a glass measuring cylinder and calculated using Equation 1 (Goula and Adamopoulos 2005) as follows:

$$\rho_{bulk} = \frac{m}{V}(\mathrm{g/ml}) \tag{1}$$

in which m is the weight of the sample and the v is the measured volume of the sample.

WHC was measured as suggested by Anderson (1982). Ten milliliters of water was added to 0.5 g dried samples (M_1) in a centrifuge tube (M_2). The mixture was hold in a water bath at 60 °C for 30 min and then transferred to an ice-water bath for 30 min to be cooled down. After centrifugation at 5000 rpm for 20 min, the supernatant was removed and the total weight of the tube was weighted (M_3). WHC was calculated using Equation 2.

$$WHC = \frac{M3 - M2\ (g)}{M1\ (g)} \tag{2}$$

Color values (L^*, a^* and b^*) were obtained by a color meter (ColorFlex EZ colorimeter, HunterLab, Virginia, USA). Hue angle ($h°$) and color difference (E) were calculated using Equation 3 and Equation 4.

$$E = [(L^* - L_0^*)^2 + (a* - a_0^*)^2 + (b^* - b_0^*)^2]^{1/2} \tag{3}$$

$$h^\circ = tan^{-1}(\frac{b*}{a*}) \tag{4}$$

Total Titratable Acidity and pH

Total titratable acidity was performed using a potentiometric titration (AOAC 2000) and pH was measured using Inolab 7110 pHmeter (WTW, Weilheim, Germany).

Total phenolic content (TPC) and ascorbic acid

TPC of samples was determined by Folin–Ciocalteu method (Singleton & Rossi 1965). The ascorbic acid content was measured as described by Hışıl (1993). The absorbances were read using a Thermo Scientific 60S UV-Visible spectrophotometer (Wisconsin, USA).

Headspace volatile compounds

Five grams of fresh and dried sample was placed in 20 mL headspace vials separately and closed with silicone rubber septa. Samples were held at 80 °C and equilibrated for 20 min in the Agilent 7697A. Headspace Sampler (Agilent Technologies Inc., Santa Clara, CA, USA). At the end of the equilibrium, headspace volatiles were automatically transferred to gas chromatography. The temperature at sample needle and transmission lines were set as 85 °C and duration for injection for 1 min. The injection was performed at with an inlet temperature of 280 °C in split mode with a ratio of 1:50. The carrier gas was helium at 1 mL/min flow rate. Volatile analysis was performed on Agilent 7820A/5975C GC-MS instrument (Agilent Technologies Inc., Santa Clara, CA, USA) using a HP-5 column (30m ×0.32 mm i.d. × 0.25 µm) (Agilent Technologies Inc., USA). The initial oven temperature was set up at 60°C, then with 3 °C/min increase to 210 °C; followed by 20 °C/min increase to the final temperature at 240 °C with a holding time for 8.5 min. The mass detector temperatures were set as and 290 °C and the spectrum was scanned in total ion chromatogram (TIC) mode at 70eV. All analyses were performed in duplicates and compounds were tentatively identified. Two methods were used to identify volatile compounds. First, mass spectra of compounds were compared with reference mass spectra from the Wiley spectral library and second, retention indices of compounds were compared with the National Institute of Standards and Technology (NIST) database. Retention indices of volatiles were obtained by injecting hexane (C6) and n-alkane (C7-C20) standards (Sigma Aldrich, Missouri, USA) and calculating according to van Den Dool & Kratz (1963). Volatile compound concentrations were expressed as are percentages of individual peaks.

Statistical analysis

Statistical analyses were performed by using the software SPSS 20 (SPSS 20.0 for Windows Version; SPSS Inc., Chicago, IL) with the Duncan test to determine the differences between groups ($p \leq 0.05$). Principal component analysis (PCA) was performed using XLSTAT 2019 (Version 1, Addinsoft, NY, USA).

RESULTS AND DISCUSSION

Effect on physico-chemical properties

The results of quality parameters of fresh and dried strawberries were given in Table I. Initial moisture content of fresh ‘Florida Fortuna’ and ‘Osmanlı’ strawberries were found as 89.92±0.19% and 89.45±0.6%, respectively. There was no significant difference in the humidity of strawberry varieties that were dried at different temperatures (p>0.05).

Table I. Physical and chemical analyses of fresh and dried strawberry samples.

Samples*	Moisture content (%)	Titrable acidity (%)	pH	Water activity	Bulk density (g/ml)	WHC (g/g)
ForR	89.92 ± 0.19^{a}	0.13 ± 0.03^{a}	4.68 ± 0.06^{a}	0.96 ± 0.03^{a}		
For50	10.79 ± 0.36^{bA}	0.10 ± 0.018^{aA}	4.2 ± 0.04^{bcA}	0.37 ± 0.05^{bA}	10.75 ± 0.35^{aA}	0.76 ± 0.02^{aA}
For60	10.06 ± 0.15^{bB}	0.09 ± 0.004^{aA}	4.25 ± 0.005^{cA}	0.35 ± 0.01^{bA}	10.75 ± 0.35^{aA}	0.77 ± 0.08^{aA}
For70	9.29 ± 0.18^{bB}	0.06 ± 0.02^{bB}	4.49 ± 0.02^{dB}	0.34 ± 0.05^{bA}	10 ± 0.00^{aA}	0.83 ± 0.16^{aB}
OsmR	89.45 ± 0.6^{a}	1.07 ± 0.05^{a}	4.42 ± 0.01^{d}	0.97 ± 0.02^{a}		
Osm50	11.06 ± 0.29^{b1}	1.03 ± 0.09^{c1}	4.14 ± 0.02^{b1}	0.38 ± 0.01^{b1}	12.75 ± 0.35^{b1}	0.44 ± 0.01^{b1}
Osm60	9.21 ± 0.09^{b2}	1.02 ± 0.09^{c1}	4.21 ± 0.02^{bc2}	0.35 ± 0.05^{b2}	12.75 ± 0.35^{b1}	0.50 ± 0.03^{b2}
Osm70	9.23 ± 0.07^{b2}	0.96 ± 0.18^{c2}	4.22 ± 0.02^{bc2}	0.34 ± 0.02^{b2}	12.25 ± 0.35^{b1}	$0{,}52\pm0.01^{b2}$

Different lowercase letters (^{a} to ^{d}) shows significant difference within columns (p<0.05) Different uppercase letters (^{A} to ^{B}) and numbers (^{1} and ^{2}) shows significant difference within the strawberry variety (p<0.05).
*Sample codes for Florida Fortuna strawberries dried at 50°C, 60°C, 70°C and for fresh sample are For50, For60, For70 and ForR, respectively. Sample codes for Osmanlı strawberries dried at 50°C, 60°C, 70°C and for fresh sample are Osm50, Osm60, Osm70 and OsmR, respectively.

Drying treatments affected pH and acidity contents of strawberry samples. The pH value of dried strawberries at different temperatures ranged from 4.14 to 4.49. There was no significant difference (p>0.05) between pH values of ‘Florida Fortuna’ strawberries which were dried at 50 and 60 °C while the difference was found significant for ‘Osmanlı’ samples (p<0.05). The acidity of dried strawberries increased with increasing temperature. Similar results were found by Vega-Gálvez et al. (2009) in dried red peppers.

Water activity is useful in terms of estimation about storage conditions of foods (Šumić et al. 2013). It is also an important parameter for microbial stability and should be less than 0.6. The water activity of fresh strawberries was found to be about 0.96. At the end of the drying processes at all temperature degrees, the water activity value of samples was found below 0.4. According to this result, by drying process, the intended water activity level was achieved for microbiological safety. Bulk density is also related with water content of food and may be affected from drying techniques (Van Arsdel & Copley 1964). Bulk densities were found to be higher in the dried ‘Osmanlı’ strawberry samples than ‘Florida Fortuna’ samples. Drying temperature differences did not affect bulk density and water holding capacity (WHC) of dried strawberries. This might be to be due to the similarity of the final moisture. The maximum WHC was found as 0.83 ± 0.16 (g/g) in 'Fortuna' strawberry samples dried at 70°C.

In color analysis, L^* values of all the dried strawberry samples were higher than the fresh samples, except in 'Florida Fortuna' sample dried at 70°C (Table II). This might be due to the drying process causing the browning of strawberries. The redness (a^*) values of strawberries decreased with increase in drying temperature for both of strawberry varieties. Karabulut et al. (2007) reported similar results in dried apricots. The b^* values of fresh 'Florida Fortuna' strawberry samples were higher than the fresh 'Osmanlı' samples. The yellowness of the dried samples was also affected by the drying process. Similar results have been reported for dried hawthorn fruit (Crataegus spp.) (Aral & Beşe 2016). The hue angle value of dried strawberries at different temperatures ranged from 45.11 to 56.98. The hue angle values of all samples decreased continuously with increasing drying temperatures. Total color change (E), that is a combination of parameters lightness, redness and yellowness values, is a colorimetric parameter used to characterize the changes of colors in foods during processing. As shown in Table II, strawberry which dried with hot-air at 70 °C had the highest color change. The E value of strawberries increased with increasing drying temperatures. Similar results were reported by Nadian et al. (2015), who conducted a study to analyzed effects of hot-air drying on color changes of apple slices.

Table II. Color values of fresh and dried strawberry samples.

Samples$^{\diamond}$	L^*	a^*	b^*	**Hue°**	ΔE^{+}
ForR	30.93 ± 0.79^{a}	34.24 ± 0.64^{a}	17.9 ± 0.46^{a}	62.40 ± 0.11^{a}	
For50	32.91 ± 0.17^{abA}	25.06 ± 0.28^{bA}	16.29 ± 0.31^{bA}	56.98 ± 0.46^{bA}	9.53 ± 0.27^{bA}
For60	35.65 ± 0.28^{bA}	24.79 ± 0.59^{bA}	18.03 ± 0.11^{cB}	53.98 ± 0.02^{bcB}	10.57 ± 0.14^{bB}
For70	28.95 ± 0.31^{aB}	18.17 ± 0.16^{cB}	15.22 ± 0.17^{dA}	50.07 ± 0.13^{cB}	16.41 ± 0.08^{cC}
OsmR	38.32 ± 0.64^{c}	34.75 ± 0.13^{ab}	14.74 ± 0.45^{d}	67.01 ± 0.38^{d}	
Osm50	36.73 ± 0.33^{bc1}	22.71 ± 0.69^{bd1}	18.99 ± 0.51^{c1}	50.09 ± 0.05^{c1}	12.87 ± 0.33^{b1}
Osm60	37.46 ± 0.59^{bc1}	20.98 ± 0.70^{d2}	20.81 ± 0.52^{e2}	45.23 ± 0.16^{e2}	15.07 ± 0.07^{c2}
Osm70	35.04 ± 0.11^{b2}	18.88 ± 0.71^{c2}	18.81 ± 0.53^{c1}	45.11 ± 0.59^{e2}	16.71 ± 0.16^{c3}

Different lowercase letters (^{a} to ^{e}) shows significant difference within columns (p<0.05) Different uppercase letters (^{A} to ^{C}) and numbers (^{1} and ^{3}) shows significant difference within the strawberry variety (p<0.05).
$^{\diamond}$ Sample codes are as explained in Table I.
$^{+}$Color difference.

Phenolic compounds which help to prevent various cancer with its antioxidant activity provide color and flavor to fruits and vegetables (Murugesan & Orsat 2011). Figure 1 shows the amount of total phenolic and vitamin C contents in fresh and dried strawberry samples. Total phenolic contents of fresh strawberry varieties of 'Florida Fortuna' and 'Osmanlı' was found 31.21 and 132.26 mg GAE/100 g db, respectively. In several studies to determine the total phenolic content of fresh strawberry samples, the phenolic content for different varieties was found to be 86 mg GAE/100 g db (Rekika et al. 2005), 144.86 mg GAE/100 g db (Wang & Lewers 2007), 228 mg GAE/100 g db (Yıldız et al. 2014). Differences in conditions such as light, water availability, temperature, soil type during fruit cultivation may cause this situation. The effects of temperature on total phenolic content were found significantly different among samples. The phenolic contents of dried samples were higher than fresh samples. Total phenolic contents of both strawberry varieties increased with increasing temperature from 50 to 70 °C. Similar findings were reported by Lutz et al. (2015) in a study conducted on dehydrated tomatoes and green apples. This may be related to bound phenolic compounds releasing or complex phenolic compounds hydrolyzation.

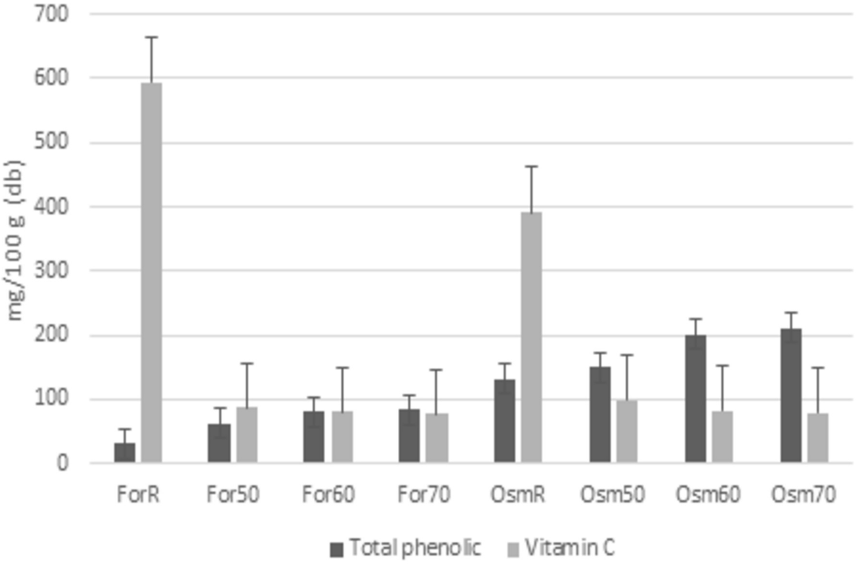

Figure 1. Total phenolic and vitamin C contents of strawberries.

The ascorbic acid content of fresh strawberry varieties of ‘Florida Fortuna’ and ‘Osmanlı’ was found 594.15 and 391.39 mg/100 db respectively. The differences among ascorbic acid contents of dried strawberries were found significantly different (p<0.05). At drying temperature of 50 °C, the ascorbic acid content of dried ‘Osmanlı’ strawberries was recorded as 98.61 mg /100g db. When drying temperature increased to 60 and 70°C, the ascorbic acid content was found to decrease to 82.29 and 77.9 mg /100g db, respectively. These findings were in accordance with the results reported by Chin et al. (2015) and Tekgül & Baysal (2018) on drying of kiwi slices and lemon peels, respectively. The lowest retention of ascorbic acid content was recorded in ‘Florida Fortuna’ strawberries dried at 70°C. The ascorbic acid degradation occurred during drying caused by high temperatures, therefore; the ascorbic acid content decreased with the increase of temperature as reported by Erentürk et al. (2005). This may be due to oxidation of ascorbic acid.

Headspace Volatiles of Fresh Strawberries

In fresh strawberries there were more compounds detected in ‘Osmanlı’ strawberries (15 volatiles) than in ‘Florida Fortuna’ strawberries (13 volatiles) (Table III). A total of 17 volatiles were detected in the headspace of both strawberries consisting of 3 aldehydes (hexanal, (E)-2-hexenal and nonanal), 5 esters (ethyl acetate, methyl butyrate, methyl hexanoate, ethyl hexanoate and hexyl acetate), 2 acids (2-methyl butanoic acid and hexanoic acid), 2 Maillard reaction and sugar degradation product (furfural and 2,5-dimethyl-4-methoxy-3(2*H*)-furanone), 2 ketones (acetone and 2,3-butanedione), 2 alkanes (2,2,4,4-tetramethyl butane and heptane), 1 aromatic hydrocarbon (toluene) and 1 terpene (limonene). According to previous studies, fresh strawberry volatiles consist of esters, ketones, furans, terpenes, aldehydes and sulfur compounds (Yan et al. 2018). In fresh strawberries, esters are the most important compounds which are responsible for fruity flavor. They were previously detected among the main volatiles of several fresh strawberry varieties (Severo et al. 2017, Görgüç et al. 2019, Parra-Palma et al. 2019). When amino acids, sugars and lipids in fruits degraded to alcohols and acids, alcohol acyltransferase enzyme catalyzes esterification and esters are formed (Forney et al. 2000). In this study, ester group compounds found in the highest numbers. In another study, 2,5-Dimethyl-4-methoxy-3(*2H*)-furanone, ethyl acetate, methyl butyrate and (*E*)-2-hexenal were detected among the major odor active compound in two subtropical strawberry varieties by Du et al. (2011). In this study, 2-methyl butanoic acid, nonanal and furfural were only detected in 'Florida Fortuna' strawberries; while hexanoic acid, 2,2,4,4-tetramethyl butane, toluene, hexyl acetate and 2,5-dimethyl-4-methoxy-3(*2H*)-furanone were only detected in 'Osmanlı' strawberries. Both varieties had similar predominant volatiles in varying abundance. Ketones were the most abundant in both raw strawberries followed by esters and aldehydes. Acetone previously was detected as one of main headspace volatiles in fresh Honeoye and Korona strawberries (Nielsen & Leufvén 2008). Even though volatile profile of two strawberry varieties similar to each other, difference in abundance of main compounds may result in flavor difference between two samples. In 'Florida Fortuna' sample, acetone (*nail polish odor*) was the most abundant compounds followed by diacetyl (*butter odor*) and ethyl acetate (*pineapple odor*). In 'Osmanlı' sample, diacetyl was the most abundant compound followed by ethyl hexanoate (*apple peel, fruit odor*) and acetone.

Table III. Headspace volatiles of dried 'Florida Fortuna' and 'Osmanlı' strawberries at different drying temperatures.

	RI*				Peak Area Percentage$^{\#}$							
No	Measure^{+}	Lit†	Compound	Odor Properties$^{\diamond}$	For50	For60	For70	ForR	Osm50	Osm60	Osm70	OsmR
1	>600	512	Acetone	Nail polish	14.9 ± 2.8^{abA}	7.64 ± 2.6^{aB}	6.61 ± 0.28^{aB}	29.4 ± 1.8^{cC}	17.2 ± 1.6^{b1}	7.21 ± 1.7^{a1}	8.30 ± 5.4^{a1}	13.4 ± 16.7^{ab1}
2	>600	517	Dimethyl sulfide	Cabbage, sulfur, gasoline	22.3 ± 0.19^{aA}	21.0 ± 3.3^{aA}	20.5 ± 3.1^{aA}	nd	13.2 ± 2.5^{b1}	15.6 ± 3.7^{b1}	16.3 ± 6.9^{b1}	nd
3	600	595	Acetic acid	Vinegar, sour	15.1 ± 0.88^{aA}	12.2 ± 0.47^{b}	10.2 ± 0.88^{cC}	nd	9.86 ± 0.17^{c1}	8.91 ± 1.3^{d2}	7.10 ± 0.73^{e3}	nd
4	605	591	2,3-Butanedione (diacetyl)	Butter	2.61 ± 0.57^{aA}	0.99 ± 0.26^{bB}	1.47 ± 0.96^{bB}	17.5 ± 1.1^{cC}	3.16 ± 0.03^{a1}	1.44 ± 0.04^{b2}	2.72 ± 1.0^{a1}	25.6 ± 0.49^{d3}
5	628	621	Ethyl acetate	Pineapple	3.28 ± 2.3^{abA}	0.85 ± 0.13^{aB}	3.97 ± 2.0^{bA}	14.8 ± 0.35^{cC}	1.96 ± 0.16^{a1}	2.18 ± 0.40^{a1}	2.14 ± 0.82^{a1}	8.18 ± 0.27^{d2}
6	641	648	3-Methylbutanal	Cocoa, almond	1.28 ± 0.08^{aA}	1.44 ± 0.37^{aA}	1.64 ± 0.41^{aA}	nd	1.47 ± 0.40^{a1}	1.62 ± 0.64^{a1}	1.27 ± 0.70^{a1}	nd
7	650	657	2-Methylbutanal	Malt	1.30 ± 0.04^{aA}	1.38 ± 0.05^{aA}	1.32 ± 0.16^{aA}	nd	0.76 ± 0.29^{b1}	0.98 ± 0.29^{ab1}	1.13 ± 1.0^{ab1}	nd
8	689	-$^{\bullet}$	2,2,3,3-Tetramethyl butane	(No odor)	nd	nd	nd	nd	0.93 ± 0.04^{a}	0.78 ± 0.04^{a}	1.03 ± 0.54^{a}	1.06 ± 0.64^{a}
9	700	-	Heptane	Alkane	1.60 ± 0.92^{aA}	0.40 ± 0.18^{bB}	0.25 ± 0.06^{bB}	3.62 ± 1.7^{cC}	0.59 ± 0.04^{b1}	0.17 ± 0.03^{b2}	0.52 ± 0.04^{b1}	0.99 ± 0.08^{ab3}
10	714	712	Acetoin	Butter, cream	5.16 ± 0.32^{aA}	1.95 ± 2.2^{bB}	4.74 ± 0.13^{aA}	nd	7.24 ± 0.47^{c1}	9.02 ± 1.0^{d2}	6.61 ± 1.5^{c1}	nd
11	725	724	Methyl butyrate	Ether, fruit, sweet	1.09 ± 0.04^{aA}	0.61 ± 0.11^{bB}	0.49 ± 0.00^{bB}	4.49 ± 1.5^{cC}	0.30 ± 0.01^{b1}	0.36 ± 0.04^{ab1}	0.30 ± 0.04^{b1}	1.00 ± 0.40^{b2}
12	744	757	Isobutanoic acid	Acidic, cheesy	0.46 ± 0.08^{aA}	0.67 ± 0.09^{aB}	0.45 ± 0.11^{aA}	nd	1.63 ± 0.50^{b1}	1.43 ± 0.01^{b1}	1.01 ± 0.55^{c2}	nd
13	763	762	Toluene	Oil paint	nd	nd	nd	nd	8.62 ± 0.15^{a}	7.58 ± 1.4^{b}	5.16 ± 1.8^{c}	2.50 ± 0.29^{d}
14	802	802	Hexanal	Grass, tallow, fat	4.72 ± 0.23^{aA}	2.35 ± 0.26^{bB}	1.52 ± 0.08^{cC}	12.1 ± 0.37^{dD}	1.77 ± 0.27^{c1}	1.13 ± 0.46^{e2}	0.88 ± 0.04^{e2}	6.14 ± 0.27^{f3}
15	839	838	Furfural	Bread, almond, sweet	7.70 ± 0.99^{aA}	32.4 ± 0.81^{bB}	38.8 ± 2.4^{cC}	2.20 ± 0.98^{dD}	5.97 ± 0.04^{e1}	20.4 ± 1.6^{f2}	36.3 ± 7.8^{c3}	nd
16	843	846	2-Methylbutanoic acid	Acidic, cheesy	2.30 ± 1.21^{aA}	2.06 ± 0.94^{aA}	1.82 ± 0.37^{aA}	1.75 ± 1.3^{aA}	1.52 ± 0.47^{a1}	1.44 ± 0.06^{a1}	1.33 ± 1.07^{a1}	nd
17	858	856	*(E)*-2-Hexenal	Green, leaf	1.78 ± 1.1^{aA}	0.46 ± 0.23^{bB}	0.35 ± 0.05^{bB}	2.88 ± 0.23^{cC}	0.35 ± 0.09^{b1}	0.16 ± 0.01^{b2}	0.22 ± 0.01^{b2}	1.33 ± 0.14^{a3}
18	876	875	*m*-Xylene	Plastic	1.27 ± 0.04^{a}	0.66 ± 0.13^{b}	0.67 ± 0.28^{b}	nd	nd	nd	nd	nd
19	928	927	Methyl hexanoate	Fruit, fresh, sweet	1.03 ± 0.32^{aA}	0.39 ± 0.04^{bB}	0.44 ± 0.18^{bB}	2.06 ± 0.35^{dC}	0.97 ± 0.08^{a1}	0.89 ± 015^{c1}	0.58 ± 0.19^{bc1}	2.12 ± 0.58^{d2}
20	954	-	2,5-Dimethyl-3(2*H*)-furanone	Caramellic	2.09 ± 0.72^{aA}	1.21 ± 0.11^{bB}	1.33 ± 0.16^{bcB}	nd	1.16 ± 0.04^{b1}	1.64 ± 0.30^{c2}	0.65 ± 0.23^{d3}	nd
21	977	974	Hexanoic acid	Sweat	1.16 ± 0.11^{aA}	0.54 ± 0.48^{bB}	0.41 ± 0.30^{bB}	nd	nd	nd	nd	2.07 ± 1.1^{c}
22	982	-	2,3-Dihydro-3,5-dihydroxy-6-methyl-4*H*-pyran-4-one	(No odor)	1.20 ± 0.58^{aA}	0.51 ± 0.31^{aB}	0.37 ± 0.14^{aB}	nd	9.12 ± 1.7^{b1}	8.27 ± 0.15^{b1}	2.88 ± 2.0^{c2}	nd
23	1000	1000	Ethyl hexanoate	Apple peel, fruit	1.37 ± 0.16^{abA}	1.04 ± 0.31^{aB}	0.57 ± 0.19^{aC}	2.58 ± 0.06^{bD}	5.14 ± 0.57^{c1}	4.23 ± 0.56^{c1}	1.58 ± 0.3^{ab2}	14.6 ± 2.8^{d3}
24	1012	1013	Hexyl acetate	Fruity, herbal	nd	nd	nd	nd	nd	nd	nd	4.22 ± 1.8^{a}
25	1033	1031	Limonene	Lemon, orange	0.41 ± 0.04^{abA}	0.63 ± 0.19^{bA}	0.32 ± 0.04^{abB}	2.39 ± 0.23^{cC}	nd	nd	nd	5.44 ± 1.1^{d}
26	1065	1051	2,5-Dimethyl-4-methoxy-3(2*H*)-furanone (mesifurane)	Caramel, sweet, mildew	4.71 ± 0.32^{aA}	3.30 ± 0.32^{bB}	1.98 ± 0.04^{cC}	nd	7.12 ± 0.32^{d1}	4.66 ± 2.0^{a2}	2.01 ± 0.67^{c3}	1.99 ± 0.45^{c3}
27	1106	1106	Nonanal	Fat, citrus, green	1.27 ± 0.29^{a}	0.27 ± 0.05^{b}	0.36 ± 0.06^{b}	4.14 ± 0.08^{c}	nd	nd	nd	nd

*RI: Retention Indices. $^{+}$ Retention indices were calculated by injecting n-alkane (C7-20) solution in HP5 column. † Retention indices obtained from NIST database (www.nist.gov). $^{\diamond}$ Odor properties are based on www.flavornet.org and www.thegoodscentscompany.com database. $^{\#}$ Sample codes are as explained in Table I. nd: Compound is under detection limit of GC-MS. $^{\bullet}$ Not found.

Different lowercase letters (^{a} to ^{f}) shows significant difference within peak area percentage rows (p<0.05) Different uppercase letters (^{A} to ^{D}) and numbers (^{1} and ^{3}) shows significant difference within the strawberry variety (p<0.05).

Headspace Volatiles of Dried Strawberries

After drying strawberries at 3 different temperatures, 10 additional volatile compounds were detected in their headspace which were not present in fresh strawberries (Table III). These compounds were 2 aldehydes (2-methylbutanal, 3-methylbutanal), 2 acids (acetic acid, isobutanoic acid), 2 Maillard reaction and sugar degradation products (2,5-dimethyl-3(2*H*)-furanone and 2,3-dihydro-3,5-dihydroxy-6-methyl-4*H*-pyran-4-one), 1 ketone (acetoin), 1 aromatic hydrocarbon (m-xylene) and 1 sulfur-containing compound (dimethyl sulfide). Even though, fresh 'Osmanlı' strawberries contained more volatiles than fresh 'Florida Fortuna' strawberries; dried 'Florida Fortuna' samples had more volatiles (24 compounds) than 'Osmanlı' samples (22 compounds). In 'Osmanlı' samples, drying process resulted in degradation of hexanoic acid, hexyl acetate and limonene to under detection limits. In 'Florida Fortuna' samples, all the compounds from the fresh samples were also detected in dried samples. From the detected compounds in dry samples, nonanal and m-xylene were not detected in any 'Osmanlı' strawberries; while 2,2,4,4-tetramethyl butane and toluene were not detected in any 'Florida Fortuna' strawberries. In both varieties, drying resulted in significant decreases in the levels of eight common compounds, which were diacetyl, ethyl acetate, heptane, methyl butyrate, hexanal, *(E)*-2-hexenal, methyl hexanoate and ethyl hexanoate. In addition to those compounds, acetone and nonanal were significantly decreased in 'Florida Fortuna' samples; while toluene was significantly decreased in 'Osmanlı' sample. Overall, dimethyl sulfide (*cabbage, sulfur, gasoline-like odor*), acetic acid (*vinegar, sour odor*), acetone (*nail polish odor*), furfural (*bread, almond, sweet odor*) and acetoin (*butter, cream odor*) were main volatiles in dried samples. At 50°C, dimethyl sulfide was the most abundant compound in 'Florida Fortuna' samples and acetone was the most abundant compound in 'Osmanlı' samples; since acetone, which was the most abundant compound in fresh sample, was significantly decreased in 'Florida Fortuna' samples upon drying. Furfural levels of both samples were significantly increased upon increasing drying temperatures. In samples treated at 60°C and 70°C, furfural was the most abundant compound. Abonyi et al. (2002) found that aldehydes were the most abundant compounds whereas esters had the highest number in spray dried strawberry puree.

As one of the main volatiles in dried strawberries, dimethyl sulfide, is known as an off-flavor compound formed during thermal processing of fruits and vegetables (Scherb et al. 2009). Acetic acid and esters are formed in strawberries during maturation period from aldehydes (Yamashita et al. 1977). Acetic acid is also formed from hemicellulose in thermally treated plant materials and it plays a role in further formation of furfural and other aldehydes (Tjeerdsma et al. 1998). While aldehydes such as hexanal, (*E*)-2-hexenal and nonanal naturally occur in fruits; other aldehydes such as 2- and 3-methylbutanals and furfural are product of Maillard reaction formed during drying process. Furfural is known as a main sugar degradation product by heat treatment (Bonn 1985). Since strawberries contains ∼4.89% sugar (USDA 2010), during drying several sugar degradation products are formed. In addition, exposure to high temperatures for a long time might adversely affect the volatile profile of strawberries due to degradation of present compounds and formation of new compounds. In this study, the longest treatment time was for the samples dried at 50°C. However; the results showed that drying at low temperature (50°C) resulted in the highest retention of acetone (which is the main compound in fresh strawberries) and minimum formation of furfural. Furthermore, retention of esters

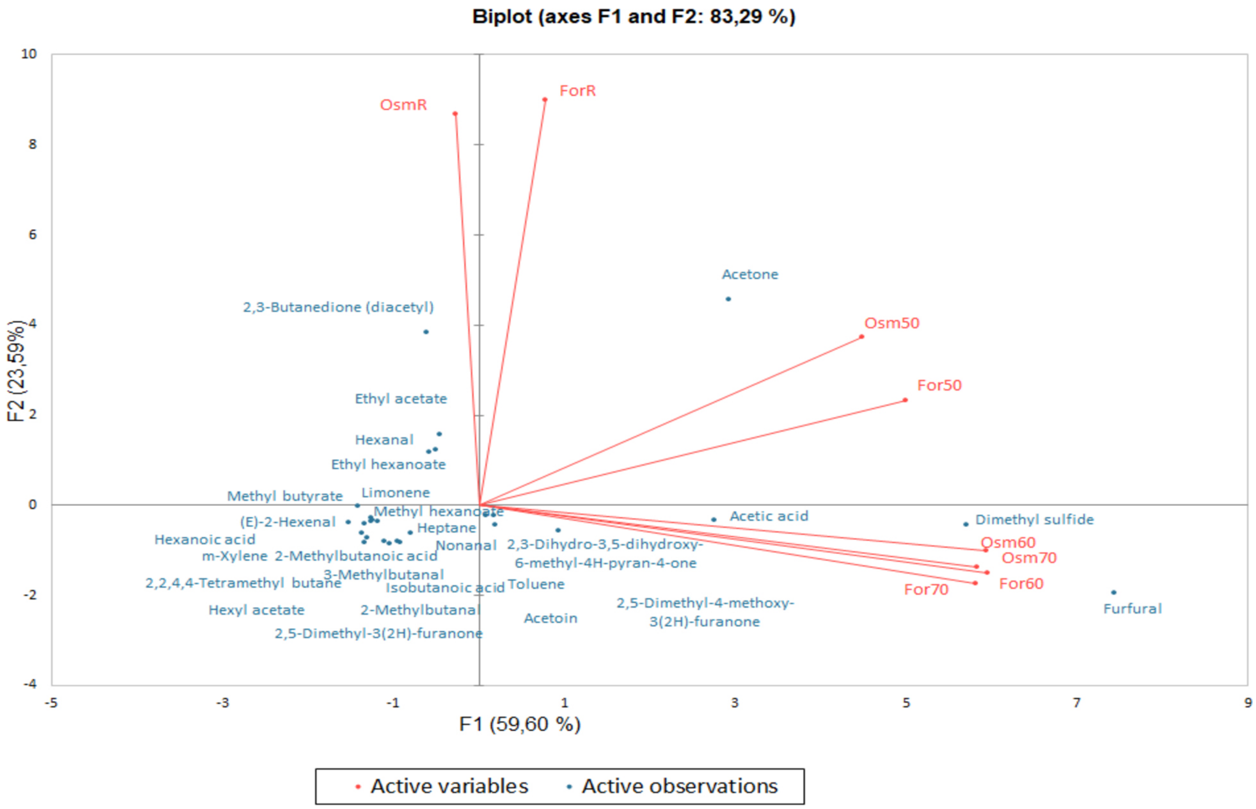

Figure 2. Principal component analysis of strawberries. F1 (59.60%) and F2 (23.59%) explained in total of 83.29% of the variance.

which are important volatiles with their fruity odors, were the highest in samples treated at 50°C. In conclusion, if conventional drying method is to be used, drying at low temperatures for long time might be preferred over drying at high temperatures for short time to obtain more fruity-flavored dried strawberries.

Principal component analysis of strawberries

Principal component analysis (PCA) of strawberries was performed according to the data from aroma profile (Figure 2). Biplots revealed that F1 and F2 explained 59.60% and 23.59% of the total variation. 2,3-Butanedione (diacetyl), ethyl acetate, hexanal, limonene which lie in the negative region of F1 and positive region of F2 were clustered together with Fresh ‘Osmanlı’ (OsmR) sample. Acetone which lie on the positive regions of F1 and F2, was correlated with cultivar fresh ‘Florida Fortuna’ (ForR) and samples treated at 50 °C (For50 and Osm50). This compound was present for ForR, Osm50 and For50 at percentage of 29.42, 17.17 and 14.87, respectively, was higher compared to the percentage in other cultivars. Samples that were treated at 60 °C and 70 °C (Osm60, Osm70, For60, For70) and their characteristic volatile compounds such as furfural, dimethyl sulfide, acetic acid, toluene, 2,3-Dihydro-3,5-dihydroxy-6-methyl-4*H*-pyran-4-one, 2,5-Dimethyl-4-methoxy-3(2*H*)-furanone (mesifurane) were clustered together. These results show that, strawberries that are dried at high temperatures shows similar volatile compound pattern.

Therefore, they can be used as substitutes for each other in food application when there is a scarcity of intended variety.

CONCLUSION

This study is the first in identifying volatile and quality changes simultaneously in hot-air dried strawberries treated at different temperatures. In terms of quality analysis, color values, physicochemical properties, total phenolic and ascorbic acid contents of hot air-dried strawberry samples were affected by drying temperature. Especially the total phenolic content increased by increasing temperature. Comparing the quality parameters for strawberry samples, bulk density, vitamin C, total phenolic content, lightness, yellowness and redness were found to decrease at high drying temperature (> 50 °C), whereas WHC increase. Even though there was a small increase in water holding capacities, they were not significantly affected by temperature difference. Drying at low temperature (50 °C) resulted in the highest retention of fresh strawberry volatiles and minimum formation of sugar degradation products. At high temperatures (60 °C and 70°C), volatile profile of dried strawberries showed similar pattern in 'Florida Fortuna' and 'Osmanlı' varieties. Main volatiles were dimethyl sulfide, acetic acid and acetone. The highest number of compound groups were aldehydes, followed by acids, esters and sugar degradation products. Further research is suggested to analyze the effect on volatile and quality changes on overall flavor of strawberries and consumer acceptance.

REFERENCES

ABONYI B, FENG H, TANG J, EDWARDS C, CHEW B, MATTINSON D & FELLMAN J. 2002. Quality retention in strawberry and carrot purees dried with Refractance WindowTM system. J Food Sci 67(3): 1051-1056.

ACA. 1990. Official methods of analysis. Association of the Official Analytical Chemists, 15th ed Association of official Analytical Chemists, Arlington, Virginia.

ANDERSON R. 1982. Water absorption and solubility and amylograph characteristics of roll-cooked small grain products. Cereal Chem 59(2): 265-269.

AOAC. Official Methods of Analysis 2000. Association of Official Analytical Chemists (17th Edn). Gaithersburg, Md, USA.

ARAL S & BEŞE AV. 2016. Convective drying of hawthorn fruit (Crataegus spp.): Effect of experimental parameters on drying kinetics, color, shrinkage, and rehydration capacity. Food Chem 210: 577-584.

AYALA-ZAVALA JF, WANG SY, WANG CY & GONZÁLEZ-AGUILAR GA. 2004. Effect of storage temperatures on antioxidant capacity and aroma compounds in strawberry fruit. LWT-Food Science and Technology 37(7): 687-695.

BONN G. 1985. High-performance liquid chromatographic elution behaviour of oligosaccharides, monosaccharides and sugar degradation products on series-connected ion-exchange resin columns using water as the mobile phase. J Chromatogr A 322: 411-424.

CAPARINO O, TANG J, NINDO C, SABLANI S, POWERS J & FELLMAN J. 2012. Effect of drying methods on the physical properties and microstructures of mango (Philippine 'Carabao'var.) powder. J Food Eng 111(1): 135-148.

CHEPLICK S, KWON YI, BHOWMIK P & SHETTY K. 2010. Phenolic-linked variation in strawberry cultivars for potential dietary management of hyperglycemia and related complications of hypertension. Bioresour Technol 101(1): 404-413.

CHIN S, SIEW E & SOON W. 2015. Drying characteristics and quality evaluation of kiwi slices under hot air natural convective drying method. Int Food Res J 22(6).

DA SILVA PINTO M, KWON YI, APOSTOLIDIS E, LAJOLO FM, GENOVESE MI & SHETTY K. 2008. Functionality of bioactive compounds in Brazilian strawberry (Fragaria× ananassa Duch.) cultivars: evaluation of hyperglycemia and hypertension potential using in vitro models. J Agric Food Chem 56(12): 4386-4392.

DU X, PLOTTO A, BALDWIN E & ROUSEFF R. 2011. Evaluation of volatiles from two subtropical strawberry cultivars using GC-olfactometry, GC-MS odor activity values, and sensory analysis. J Agric Food Chem 59(23): 12569-12577.

DZIEZAK JD. 1988. Microencapsulation and encapsulated ingredients. Food Technol (Chicago) 42(4): 136-153.

ERENTURK S, GULABOGLU MS & GULTEKIN S. 2005. The effects of cutting and drying medium on the vitamin C content of rosehip during drying. J Food Eng 68(4): 513-518.

FAOSTAT F & PRODUCTION AC. 2016. Food and agriculture organization of the united nations, 2010. Roma, Italy.

FORNEY CF, KALT W & JORDAN MA. 2000. The composition of strawberry aroma is influenced by cultivar, maturity, and storage. HortScience 35(6): 1022-1026.

GIAMPIERI F, TULIPANI S, ALVAREZ-SUAREZ JM, QUILES JL, MEZZETTI B & BATTINO M. 2012. The strawberry: Composition, nutritional quality, and impact on human health. Nutrition 28(1): 9-19.

GÖRGÜÇ A, YILDIRIM A, TAKMA DK, ERTEN ES & YILMAZ FM. 2019. Aydın ilinde yetiştirilen ticari çilek çeşitlerinin fiziksel, kimyasal, biyoaktif ve aroma özellikleri. Harran Tarım ve Gıda Bilimleri Dergisi 23(2): 131-141.

GOULA AM & ADAMOPOULOS KG. 2005. Spray drying of tomato pulp in dehumidified air: II. The effect on powder properties. J Food Eng 66(1): 35-42.

HIŞIL Y. 1993. Enstrümantal Gıda Analizler Laboratuar Kılavuzu. Ege Üniversitesi, Mühendislik Fakültesi Çoğaltma Yayınları 55.

KARABULUT I, TOPCU A, DURAN A, TURAN S & OZTURK B. 2007. Effect of hot air drying and sun drying on color values and β-carotene content of apricot (Prunus armenica L.). LWT-Food Science and Technology 40(5): 753-758.

LUTZ M, HERNÁNDEZ J & HENRíQUEZ C. 2015. Phenolic content and antioxidant capacity in fresh and dry fruits and vegetables grown in Chile. CyTA-Journal of Food 13(4): 541-547.

NADIAN MH, RAFIEE S, AGHBASHLO M, HOSSEINPOUR S & MOHTASEBI SS. 2015. Continuous real-time monitoring and neural network modeling of apple slices color changes during hot air drying. Food Bioprod Process 94: 263-274.

NIELSEN T & LEUFVÉN A. 2008. The effect of modified atmosphere packaging on the quality of Honeoye and Korona strawberries. Food Chem 107(3): 1053-1063.

NINDO C & TANG J. 2007. Refractance window dehydration technology: a novel contact drying method. Drying Technol 25(1): 37-48.

PARRA-PALMA C, ÚBEDA C, GIL M, RAMOS P, CASTRO RI & MORALES-QUINTANA L. 2019. Comparative study of the volatile organic compounds of four strawberry cultivars and it relation to alcohol acyltransferase enzymatic activity. Sci Hortic 251: 65-72.

REKIKA D, KHANIZADEH S, DESCHÊNES M, LEVASSEUR A, CHARLES MT, TSAO R & YANG R. 2005. Antioxidant capacity and phenolic content of selected strawberry genotypes. HortScience 40(6): 1777-1781.

SCHERB J, KREISSL J, HAUPT S & SCHIEBERLE P. 2009. Quantitation of S-methylmethionine in raw vegetables and green malt by a stable isotope dilution assay using LC-MS/MS: comparison with dimethyl sulfide formation after heat treatment. J Agric Food Chem 57(19): 9091-9096.

SERÇE S & ÖZGEN M. 2015. Turkish soft fruit production. Chron Hortic 55(3): 16-20.

SEVERO J, DE OLIVEIRA IR, BOTT R, LE BOURVELLEC C, RENARD CM, PAGE D, CHAVES FC & ROMBALDI CV. 2017. Preharvest UV-C radiation impacts strawberry metabolite content and volatile organic compound production. LWT-Food Science and Technology 85: 390-393.

SINGLETON VL & ROSSI JA. 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am J Enol Vitic 16(3): 144-158.

ŠUMIĆ Z, TEPIĆ A, VIDOVIĆ S, JOKIĆ S & MALBAŠA R. 2013. Optimization of frozen sour cherries vacuum drying process. Food Chem 136(1): 55-63.

TEKGÜL Y & BAYSAL T. 2018. Comparative evaluation of quality properties and volatile profiles of lemon peels subjected to different drying techniques. J Food Process Eng 41(8): e12902.

TJEERDSMA B, BOONSTRA M, PIZZI A, TEKELY P & MILITZ H. 1998. Characterisation of thermally modified wood: molecular reasons for wood performance improvement. Holz als Roh-und Werkstoff 56(3): 149-153.

USDA & ARS. 2010. USDA national nutrient database for standard reference, release 23.

VAN ARSDEL WB & COPLEY MJ. 1964. Food dehydration. Volume 2. Products and Technology. Westport, Connecticut: AVI Publ. Co. Inc.

VAN DEN DOOL H & KRATZ PD. 1963. A generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography. J Chromatogr A 11: 463-471.

VEGA-GÁLVEZ A, DI SCALA K, RODRíGUEZ K, LEMUS-MONDACA R, MIRANDA M, LÓPEZ J & PEREZ-WON M. 2009. Effect of air-drying temperature on physico-chemical properties, antioxidant capacity, colour and total phenolic content of red pepper (Capsicum annuum, L. var. Hungarian). Food Chem 117(4): 647-653.

WANG SY & LEWERS KS. 2007. Antioxidant capacity and flavonoid content in wild strawberries. J Am Soc Hortic Sci 132(5): 629-637.

YAMASHITA I, IINO K, NEMOTO Y & YOSHIKAWA S. 1977. Studies on flavor development in strawberries. 4. Biosynthesis of volatile alcohol and esters from aldehyde during ripening. J Agric Food Chem 25(5): 1165-1168.

YAN JW, BAN ZJ, LU HY, LI D, POVERENOV E, LUO ZS & LI L. 2018. The aroma volatile repertoire in strawberry fruit: A review. J Sci Food Agric 98(12): 4395-4402.

YILDIZ H, ERCISLI S, HEGEDUS A, AKBULUT M, TOPDAS E & ALIMAN J. 2014. Bioactive content and antioxidant characteristics of wild (Fragaria vesca L.) and cultivated strawberry (Fragaria× ananassa Duch.) fruits from Turkey. J Appl Bot Food Qual 87.

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