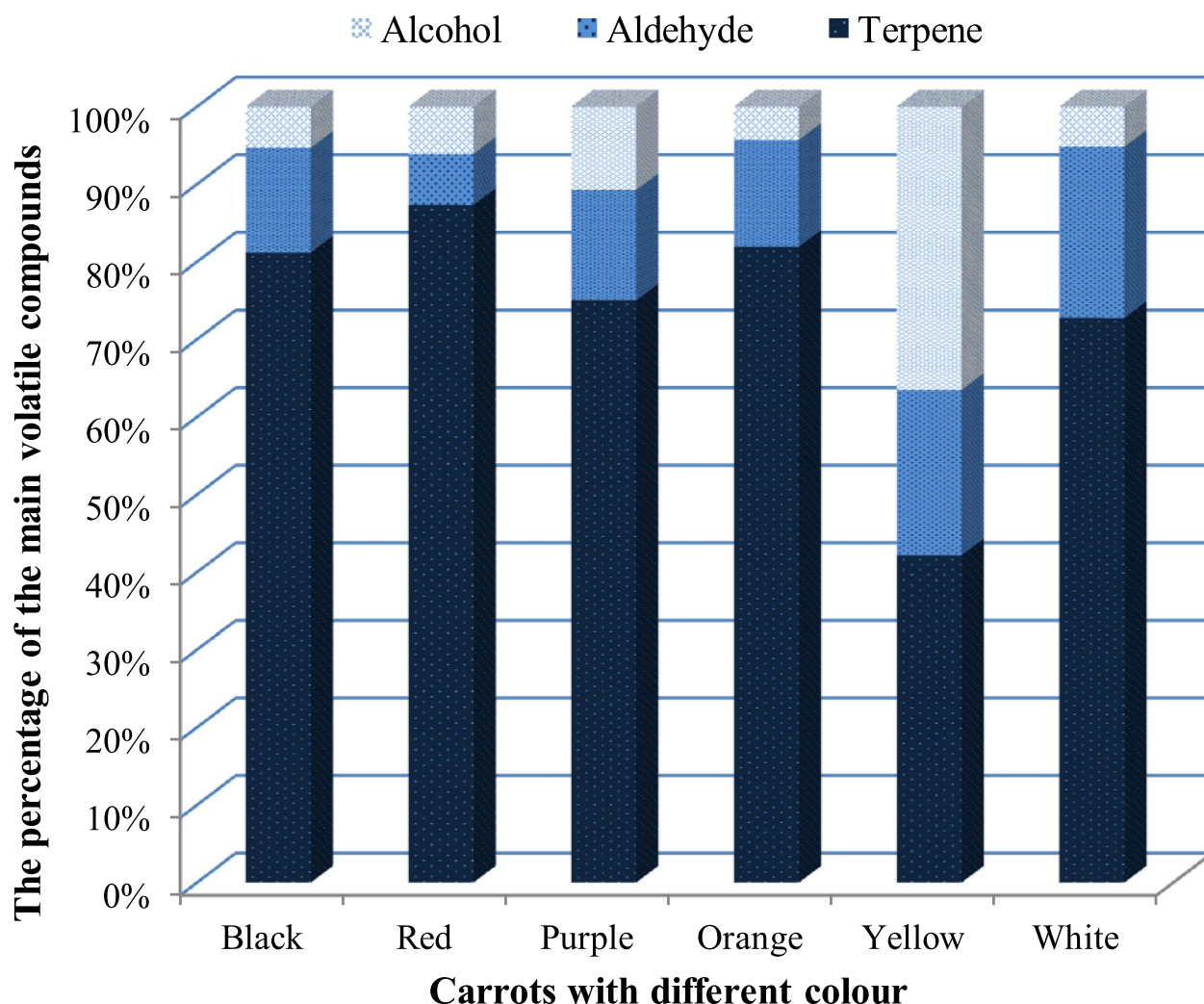




FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

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Identification of volatile organic compounds (VOCs) in different colour carrot (*Daucus carota* L.) cultivars using static headspace/gas chromatography/mass spectrometry

Zehra Güler^{1*}, Fatih Karaca² and Halit Yetisir³

Abstract: Volatile organic compounds (VOCs) as well as sugar and acid contents affect carrot flavour. This study compared VOCs in 11 carrot cultivars. Gas chromatography/mass spectrometry using static headspace technique was applied to analyse the VOCs. The number of VOCs per sample ranged from 17 to 31. The primarily VOCs identified in raw carrots with the exception of “Yellow Stone” were terpenes, ranging from 65 to 95%. The monoterpenes with values ranging from 31 to 89% were higher than those (from 2 to 15%) of sesquiterpenes. Monoterpene α -terpinolene (with ranging from 23 to 63%) and (-)- α -pinene (26%), and alcohol ethanol (35%) was the main VOC in extracts from the nine carrot cultivars, “Purple” and “Yellow Stone”, respectively. As a result, among 16 identified monoterpenes, 7 monoterpenes (-)- α -pinene, (-)- β -pinene, β -myrcene, d-limonene, γ -terpinene, α -terpinolene and p-cymene constituted more than 60% of total VOCs identified in carrots including “Atomic Red”, “Nantes”, “Cosmic Purple”, “Red Samurai”, “Eregli Black”, “White Satin”, “Parmex” and “Baby Carrot”. Thus, these cultivars may advise to carrot breeders due to the beneficial effects of terpenes, especially monoterpenes on health.

Subjects: Environment & Agriculture; Food Chemistry; Food Science & Technology

Keywords: carrot; volatile compounds; static headspace; terpenes

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PUBLIC INTEREST STATEMENT

Carrot production in the world and in Turkey in the last decade has been increased by 48 and 41%, respectively. Increased consumption of carrot is mainly due to its sweetness and pleasant flavour and health benefits. The characteristic aroma and flavour of carrot are mainly due to its volatile compounds. Different coloured carrot cultivars (creamy-white, yellow, purple or violet root) have recently been bred by breeders. The present study describes the volatile organic compound (VOC) profiles in carrots with different colour grown in Turkey. This research is the first report on carrot cultivars grown under identical conditions in Turkey. The study showed that VOCs were markedly varied from cultivar to cultivar, in terms of their number and their percentage composition. VOCs were mostly made up of terpenes. Dark coloured carrots had higher levels of terpenes than light coloured carrots.

1. Introduction

Turkey is the 10th largest carrot (*Daucus carota* subsp. *sativus*) and turnip producer country with 569,855 tons in 25,901 ha area in the world (FAO, 2013). Studies have showed that carrots have anticancer, especially colon cancer, antiviral, antimicrobial, antifungal and antioxidant effects on human metabolism due to its falcarinol, terpenes, β -carotene, vitamins and fibre contents (Brandt et al., 2004; Paduch, Kandefer-Szerszeń, Trytek, & Fiedurek, 2007; Van Duyn & Pivonka, 2000). The optimal dietary manipulation could be a good alternative in preventing, mainly carcinoma diseases. Plants are cultivated by humans not only for their nutritional value and medicinal properties, but also for their unique aromas. Sweetness (sugar content), volatile compounds and color are important quality parameters for consumer acceptability of carrots (Gajewski, Szymczak, & Radzanowska, 2010). The distribution of volatile compounds in carrots is influenced by cultivar (genotype), growing conditions and genotype $\times$ environment interaction (Da Silva et al., 2007; Kebede et al., 2014; Kreutzmann, Thybo, Edelenbos, & Christensen, 2008). The flavour compounds are important for both eating quality of carrot and juice-processing industries, which demand attractive sensory cultivars. Recently, carrot cultivars with different colours (creamy-white, yellow, purple or violet root) have been bred by breeders. However, they show a large diversity in quality (Alasalvar, Grigor, Zhang, Quantick, & Shahidi, 2001; Kreutzmann et al., 2008).

Chromatographic methods enable the identification and quantification of individual volatile component. Static headspace (SHS), dynamic headspace and solid-phase microextraction (SPME) analysis techniques have gained in popularity for analysing volatile compounds in various foods such as dairy products (Güler, 2007; Güler & Gürsoy-Balcı, 2011) and fruits such as cucumber (Güler, Karaca, & Yetisir, 2013), melon (Güler, Karaca, & Yetisir, 2014), and carrots (Kjeldsen, Christensen, & Edelenbos, 2001; Kreutzmann et al., 2008). Of these techniques, SHS may be more attractive as a technique for routine quality control due to its operational simplicity and reproducibility (Alasalvar, Grigor, & Quantick, 1999). In addition, SHS is report to more closely reflect the true flavour profile, but compounds are present at low levels, and some may not be detected (Teranishi & Kint, 1993). Although there were many studies on volatile compounds in various carrots (Alasalvar et al., 2001; Kjeldsen et al., 2001; Kjeldsen, Christensen, & Edelenbos, 2003; Kreutzmann et al., 2008), no study has been carried out on volatile compounds of a large cultivar variation including fresh carrots with black, red, purple, orange, yellow and white colours grown under the same conditions in open field. Thus, the objectives of present study were: (1) to identify volatile organic compounds (VOCs) in eleven carrot cultivars grown under the same conditions; (2) to determine whether the VOCs responsible for carrot flavour can be related to carrot colour.

2. Material and methods

2.1. Plant material

Eleven carrot (*D. carota* L.) cultivars including “Eregli Black”, “Purple”, “Red Samurai”, “Yellow Stone”, “Rainbow”, “Baby Carrot”, “Atomic Red”, “Cosmic Purple”, “White Satin”, “Parmex” and “Nantes” were used in this study. The soil was a sandy loam soil and 0.5 ton da^{-1} composted manure and 40 kg da^{-1} NH_4NO_3 were added to soil before seed sowing. Since soil potassium (K) and phosphor (P) contents were at sufficient level, these mineral elements were not added. No pesticide were used for pest and disease control in carrots.

Carrot seeds were sown with 15 $\times$ 4 cm spacing in 11 November 2009. Experimental design was randomized block and each cultivar replicated three times with 100 plants. Baby carrot and Parmex were harvested in 1 April 2010, Yellow Stone and White Satin were harvested 3 April 2010 and other carrot cultivars were harvested in 05 April 2010. Carrots being physical undamaged and representing characteristic size and colour for each cultivar were sampled for volatile compound analysis.

2.2. VOC determination

Samples for determination of VOCs were prepared in triplicate from five carrots at each replication. Roots were washed and brushed under running water; top and tail were cut using a sharp knife. Then

each carrot was cut into 1 cm³ pieces and placed in a chilled mortar and ground with a pestle. Ten grams of the homogenized sample was immediately transferred in 20-mL headspace vial (Agilent, USA), containing 3 g of NaCl, to inhibit enzyme reactions. The vials were sealed using crimp-top caps with TFE/silicone headspace septa (Agilent, USA). According to procedure described by Güler et al. (2013), extraction and identification of the volatile compounds were carried out by means of SHS—Agilent model 6890 gas chromatography (GC) and 5973 N mass spectrometry (MS) (Agilent, Palo Alto, CA, USA) equipped with a HP-INNOWAX capillary column (60 m × 0.25 mm id × 0.25 µm film thickness). Helium was used as carrier gas at a flow rate of 1 mL min⁻¹. The injector temperature was 200°C, set for splitless injection. The oven temperature program was initially held at 45°C for 1 min and then programmed from 45°C by a ramp of 1.5°C min⁻¹ up to 80°C and then at 10°C min⁻¹ to reach a final temperature of 200°C, which was held for 15 min. The mass selective (MS) detector was operating in the scan mode within a mass range 33–330 m z⁻¹ at 1 scan s⁻¹, with electron energy of 70 eV. The interface line to MS was set at 250°C. The total analysis time was 42.3 min. Volatile compounds were identified by a computer matching of their mass spectral data supplemented with a Wiley7n.1 and Nist 02.L. GC-MS libraries and then the identities of most were confirmed by GC retention time and MS ion spectra of authentic standards. The retention indices were also determined for all constituents by using homologous series of *n*-alkanes C₅–C₂₅. Results from the volatile analyses were expressed as the percentage of each compounds integrated area relative to the total integration of compounds identified.

2.3. Statistical analysis

Data were analysed using SAS procedures (SAS, 2005). The means and standard deviations were calculated using PROC TABULATE. PROC PRINCOMP was used to conduct principle component (PC). The output of this analysis is eigenvalues, eigenvectors and standardized principal component scores. The accessions plotted using PROC P3G with PC scores. Differences in means were examined using Tukey's studentized range test (*t*-test).

3. Result and discussion

VOCs identified in carrots were classified into three main chemical classes: monoterpenes, sesquiterpenes and aldehydes (Table 1). Only a few volatiles were detected in other chemical classes: ketones, polypropanoids and alcohols. The number of volatiles per sample ranged from 17–31. All carrot cultivars contained 12 VOCs in common: monoterpenes (–)-β-pinene, β-myrcene, d-limonene, γ-terpinene, α-terpinolene, p-cymene, sesquiterpenes (–)-β-caryophyllene, *trans*-γ-bisabolene; aldehydes acetaldehyde, hexanal and octanal; alcohol ethanol. These 12 VOCs may be characteristic for carrot flavour. Our data are in agreement with previous reports that the terpenes are considered to be the most important volatiles identified in raw carrots (Alasalvar et al., 1999; Kjeldsen et al., 2001, 2003; Kreutzmann et al., 2008). In the present study, the percentages of terpenes showed a wide variation from cultivar to cultivar (Table 1). Terpenes with the highest value made up 94% of the total of VOCs in “Atomic Red”, and they were the lowest in “Yellow Stone” (40%). The monoterpenes were predominant VOCs in carrots over sesquiterpenes (Figure 1). Among 16 identified monoterpenes, 7 monoterpenes presented in relatively high proportions in all samples: (–)-α-pinene (0.71–25.68%), (–)-β-pinene (0.57–5.06%), β-myrcene (0.48–14.55%), d-limonene (1.41–4.78%), γ-terpinene (1.16–21.18%), α-terpinolene (17.67–62.90%) and p-cymene (1.20–11.55%). Monoterpene sabinene was not detected in “Eregli Black”. As reported by Kreutzmann et al. (2008), the levels of sabinene in “Yellow Stone” and “White Satin” carrots were significantly higher than those in red and purple carrots. Monoterpene α-terpinolene was the most abundant VOCs in the nine carrot cultivars including “Eregli Black”, “Cosmic Purple”, “Red Samurai”, “Atomic Red”, “Parmex”, “Nantes”, “Baby carrot”, “Rainbow” and “White Satin”. These results were similar to the report by Kjeldsen et al. (2001). “Purple” and “Yellow Stone” cultivars had α-pinene and ethanol as the most abundant VOC, respectively. The second highest VOC for five cultivars (“Red Samurai”, “Atomic Red”, “Parmex”, “Nantes”, “Baby Carrot”) was γ-terpinene, ranging from 9 to 22%. p-Cymene (11%) for “Eregli Black”, α-terpinolene (21–18%) for “Purple” and “Yellow Stone”, β-myrcene (16%) for “Cosmic Purple” and acetaldehyde (20–18%) for “Rainbow” and “White Satin” were found as the second highest VOC. So these VOCs may be specific for each cultivar mentioned. When compared with the other carrots, “Eregli Black”, “Cosmic Purple”,

Table 1. The percentages of volatile organic compounds (VOCs) in 11 carrot cultivars

Compounds	Chemical group ^c	RI	Carrots*										LSD	
			E. Black	A. Red	R. Samuraj	Parmex	Nantes	B. Carrot	C. Purple	Purple	Y. Stone	Rainbow	W. Satin	
(-)- α -Pinene ^a	MT	969	0.71	6.62	6.51	4.58	2.91	3.55	4.50	25.68	1.42	6.93	4.57	4.38**
Camphene ^a	MT	1,010	Nd	0.19	0.21	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0.09**
(-)- β -Pinene ^b	MT	1,051	2.01	5.06	3.76	0.83	0.57	2.78	0.21	2.04	1.74	1.87	4.19	0.24**
(+)-Sabinen(Thujene) ^a	MT	1,060	Nd	0.60	0.38	3.23	0.82	3.39	1.62	0.45	3.23	2.10	2.02	0.11**
β -Myrcene ^a	MT	1,097	1.99	1.20	2.74	0.54	0.48	0.65	14.55	1.14	1.14	2.03	1.88	0.96**
α -Phellandrene ^b	MT	1,105	Nd	0.54	Nd	Nd	0.29	Nd	0.24	Nd	Nd	Nd	Nd	0.29**
γ -Terpinolene ^b	MT	1,118	Nd	0.15	0.14	Nd	Nd	Nd	1.10	0.85	Nd	Nd	Nd	
Di-Limonene ^a	MT	1,132	4.45	3.40	3.05	2.22	2.02	1.80	3.41	1.48	1.41	2.49	4.48	1.24**
β -Phellandrene ^a	MT	1,058	Nd	0.34	0.24	Nd	Nd	Nd	0.22	Nd	Nd	2.95	Nd	
Trans- α -ocimene ^b	MT	1,159	Nd	1.64	0.73	1.69	Nd	1.17	Nd	0.13	Nd	Nd	Nd	0.27**
γ -Terpinene ^b	MT	1,142	4.26	13.11	11.16	16.07	10.37	21.88	9.12	3.04	1.16	9.13	4.15	3.25**
α -Terpinolene ^a	MT	1,206	47.36	47.71	40.40	29.11	62.90	23.13	40.62	21.10	17.67	23.41	39.11	8.88**
p-Cymene ^a	MT	1,195	10.67	6.99	7.41	11.55	3.82	7.81	4.46	1.20	3.00	4.04	6.94	1.34**
Carvone ^b	MT	1,330	Nd	0.17	0.13	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0.04**
Isobornylacetate ^b	MT	1,598	0.36	0.81	0.38	Nd	0.84	0.10	0.62	Nd	Nd	0.43	0.13	0.36**
p-Cymenene ^b	MT	1,383	1.92	0.63	0.47	Nd	0.47	Nd	0.52	Nd	Nd	Nd	0.14	0.35**
δ -Cadinene ^b	ST	1,459	Nd	0.21	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	
(-)- β -Caryophyllene ^b	ST	1,638	0.75	0.74	0.82	3.49	1.50	8.85	0.16	4.72	5.22	7.72	3.85	2.72**
Trans- β -farnesene ^b	ST	1,731	0.19	0.35	0.13	Nd	Nd	0.12	2.26	0.34	Nd	Nd	0.26	0.45**
α -Humulene ^b	ST	>1,924	0.75	0.30	Nd	Nd	0.40	0.65	Nd	Nd	0.30	0.60	Nd	
α -Zingiberene ^b	ST	1,806	Nd	0.35	0.12	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0.06**
Trans- γ -bisabolene ^b	ST	1,924	3.21	2.14	0.98	1.82	2.40	2.25	2.66	2.69	3.60	6.54	0.80	1.27**
Cis- α -bisabolene ^b	ST	>1,924	1.07	1.34	Nd	0.18	0.94	0.29	0.36	Nd	0.08	0.16	0.18	
Acetaldehyde ^a		<900	7.83	3.37	7.74	15.78	6.26	12.23	8.01	17.81	13.91	19.54	17.67	5.92**
Hexanal ^a	FAD	1,021	1.71	0.20	0.45	1.74	0.18	1.22	0.73	0.49	3.73	1.47	2.32	0.72**
Heptanal ^a	FAD	1,120	1.56	0.26	0.36	0.71	0.14	0.36	0.64	Nd	0.41	Nd	0.63	0.61**
Octanal ^a	FAD	1,210	2.15	0.39	0.39	1.22	0.34	0.90	0.33	0.71	2.14	0.92	1.41	0.49**
6-Methyl-5-Hepten-2-one ^a	IT	1,259	1.36	0.95	0.65	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0.45**
Ethanol ^a		<900	5.20	2.23	9.94	4.48	1.83	6.49	4.85	16.85	34.57	8.14	5.17	2.53**
2-Methyl coumarin ^b	PP	1,383	0.25	0.19	0.15	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0.13**
o-Allyltoluen (Myristicin) ^b	PP	>1,924	1.00	0.25	0.09	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0.12**

^aMass spectra (MS) and GC retention indices (RI) were consistent with those of reference compounds unless noted.^bTentatively identified. No standard available but the MS is consistent with published data (Wiley7n.1/ Nist 02.L).^cWT: monoterpene; ST: sesquiterpene; IT: irregular terpene; FAD: fatty acid derivative; PP: phenylpropanoid.

Note: E. Black: Eregli Black; C. Purple: Cosmic Purple; R. Samuraj: Red Samuraj; A. Red: Atomic Red; B. Carrot: Baby Carrot; Y. Stone: Yellow Stone; W. Satin: White Satin.

* $p < 0.05$.** $p < 0.001$.

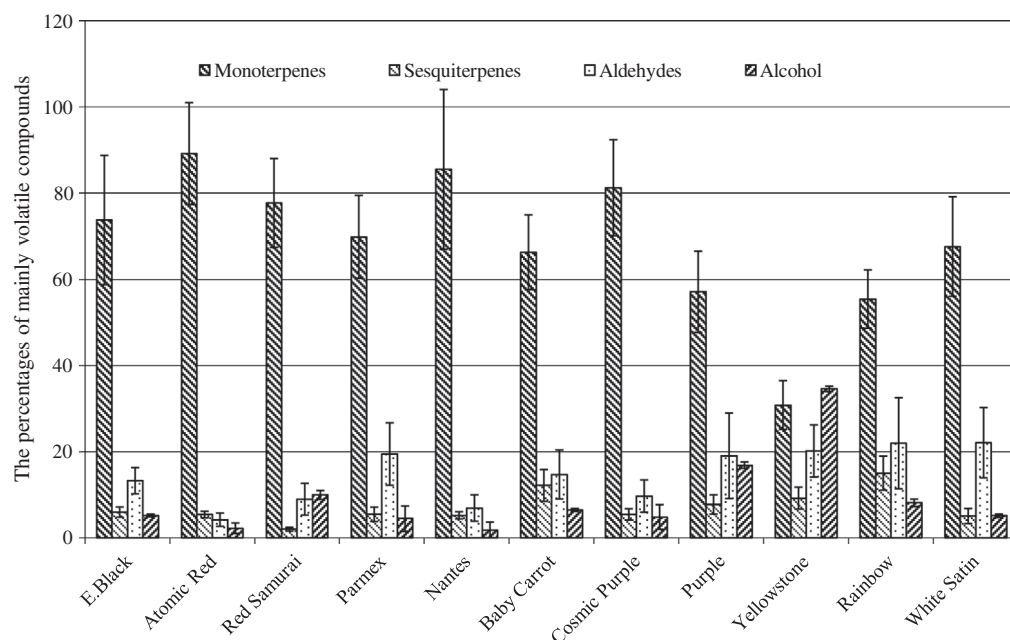
“Purple”, “Red Samurai”, “Atomic Red” and “White Satin” carrots may possess high antimicrobial and antifungal activities due to high levels of α -terpinolene and α -pinene which accounted for 44–66% of the total VOCs identified in carrots mentioned (Paduch et al., 2007). Interestingly, orange coloured carrots especially “Baby Carrot” and “Nantes” contained considerably higher γ -terpinene than the other carrots. γ -Terpinene has an inhibitory activity against *E. coli* (Cox, Mann, & Markham, 2001). Red coloured carrots (“Atomic Red” and “Red Samurai”) have the largest monoterpenes, which may affect consumers’ preference compared with carrots with orange, yellow and white colour. It was also noted that monoterpene carvone newly identified in “Red Samurai” and “Atomic Red” genotypes only.

With respect to sesquiterpenes, all seven identified sesquiterpenes were present only in “Atomic Red” carrot (Table 1). The relative value of sesquiterpene per carrot ranged from 2 to 15%. Cultivars “Purple” and “Red Samurai” contained the least sesquiterpenes in terms of their number and their percentage composition. The major sesquiterpenes identified in carrots were (-)- β -caryophyllene and *trans*- γ -bisabolene. “Rainbow” had the highest per cent value (15.5%) of sesquiterpenes. However, the relative proportion of sesquiterpenes per carrot was markedly lower than results reported by Kjeldsen et al. (2003). This may be due to the differences in cultivar and growing conditions since the experimental carrots were grown on open field. Sesquiterpene δ -cadinene newly identified in “Atomic Red” carrot only was found to be major constituent of fruit oil of Cinnamon (Paranagama et al., 2001).

As for aldehydes, acetaldehyde, hexanal and octanal were detected in all cultivars (Table 1). Hexanal, heptanal and octanal were detected at trace levels over acetaldehyde. As shown in Figure 1, light coloured carrots such as “Rainbow”, “White Satin”, “Yellow Stone”, “Parmex” and “Purple” had aldehydes, especially acetaldehyde, at high levels compared with dark coloured genotypes (“Eregli Black”, “Red Samurai”, “Atomic Red”). Cultivars “Purple” and “Rainbow” also did not contain heptanal. Aldehydes hexanal, heptanal and octanal are produced by plants as a result of oxidative degradation of C_{18} unsaturated fatty acid linoleic and linolenic acids in surface lipids (Reddy & Guerrero, 2004). However, acetaldehyde is formed from alanine amino acid via Strecker degradation.

Ethanol identified in all carrots was the most abundant VOCs in “Yellow Stone” accounting for approximately 34% of the total volatiles. This finding was similar to the report by Soria, Sanz, and Villamiel (2008) for fresh Nadril variety using SPME technique. Interestingly, cultivar “Yellow Stone”

Figure 1. The percentage composition of the main classes of volatiles organic compounds identified in each carrot cultivar.



also contained at the less number (17) of VOCs compared with the other cultivars. This may be due to suppress in recovery of minor volatile compounds of high ethanol level (Deibler & Delwiche, 2003). Seljasen, Hoftun, and Bengtsson (2001) reported that acetaldehyde and ethanol markedly increased in carrots during refrigerated storage. The present study showed that the existence of both aldehydes and ethanol in all fresh carrots and their levels are probably related to carrot variety rather than volatile extraction technique and storage conditions.

Concerning phenolpropanoids, 2-methyl coumarin and myristicin (o-allyltoluen) were detected only in “Eregli Black”, “Red Samurai” and “Atomic Red” at trace levels. Phenylpropanoids have antifungal activity, which defends plants against herbivores and pathogens (Galeotti, Barile, Curir, Dolci, & Lanzotti, 2008). Myristicin alone has been previously detected in carrots (Kjeldsen et al., 2001, 2003; Soria et al., 2008). Compound 2-methyl coumarin was newly identified in carrots. Coumarins, bioactive compounds, are characterized by bitter flavours. They can play a significant role for the health-promoting properties of carrots. Irregular terpene 6-methyl-5-hepten-2-one is formed from degradation of carotenoids (Lewinsohn et al., 2005). Like phenylpropanoids, 6-methyl-5-hepten-2-one was detected in carrots with dark colour such as “Eregli Black”, “Purple”, “Red Samurai” and “Atomic Red”.

PCA was applied to whole data obtained from VOCs analyses. This multivariate statistical technique allows clustering and grouping of observations with similar properties group. According to statistical results, the carrots were divided into three groups (Table 2). Principal component one (PC1) distinguished the VOCs of “Red Samurai” and “Atomic Red” from “Purple”, “Yellow Stone” and “Rainbow”. Although both “Red Samurai” and “Atomic Red” had volatile compounds camphene, carvone, isobornylacetate, p-cymenene, 2-methyl coumarin and myristicin, “Purple”, “Yellow Stone” and “Rainbow” did not contain them. PC2 contained “Eregli Black” only. As “Eregli Black” had no sabinen, and had the lowest level of α -pinene and the highest levels of limonene and myristicin. It was completely different from the other carrot. PC3 distinguished “Baby Carrot” and “Parmex” from “Cosmic Purple” and “Nantes”. “Cosmic Purple” and “Nantes” had the similar proportions of α -phellandrene, isobornylacetate and p-cymenene, and did not contain *trans*- α -ocimene, whereas “Baby Carrot” and “Parmex” had no compounds mentioned and had *trans*- α -ocimene. According to PCA, VOCs camphene, carvone, isobornylacetate, p-cymenene, 2-methyl coumarin, myristicin, sabinen, α -pinene, limonene α -phellandrene and *trans*- α -ocimene can play a key role for distinguishing of carrot cultivars.

Table 2. Result of PCA on the volatile compounds of carrot cultivars showing the scores on the significant PC

Carrots	Principal component		
	1	2	3
Eregli Black	0.92	5.89	-0.53
Purple	-2.12	-1.64	-1.42
Red Samurai	3.32	-0.17	0.91
Yellow Stone	-4.49	1.17	0.00
Rainbow	-2.41	-1.64	-0.43
Baby Carrot	-1.76	-1.42	2.46
Atomic Red	5.67	-0.76	1.76
Cosmic Purple	1.64	-0.66	-2.82
White Satin	-1.20	0.98	0.02
Parmex	-1.53	-0.14	2.21
Nantes	1.96	-1.63	-2.15
Variance (%)	56.8	22.40	10.30

Notes: The percentage variance accounted for by each PC. Carrots in each principal component, in proportion to the magnitude of their variation value (bold numeric), are independent from the carrots in the other principal component. Carrots in the same principal component are related to each other, according to positive and negative variation.

Overall, although the investigated carrot cultivars were grown under identical soil and climate conditions, there were wide variations in numbers and proportions of VOCs among the investigated cultivars. This finding indicates that genetic factors are responsible, which is in agreement with the previous reports (Howard et al., 1995).

4. Conclusion

The results showed that the distribution of VOCs significantly varied from cultivar to cultivar. This situation may lead to the diversity of flavours among carrot cultivars. Except for cultivars “Purple” and “Yellow Stone”, the most important specific component for carrot aroma was α -terpinolene which especially in orange coloured cultivar “Nantes” with value of about 63% was predominant VOC. Actually, in terms of the percentage composition of VOCs, cultivar “Nantes” was similar to “Atomic Red” carrot. Both cultivars contained terpenes at the highest levels and aldehydes at the lowest levels. Dominance for a low content of carrot volatile terpenoids has been observed in cultivar “Yellow Stone”. Carvone, 2-methyl coumarin and δ -cadinene were newly identified in carrot cultivars. VOCs are important for carrot flavour, which are plentiful in dark coloured cultivars such as “Atomic Red”, “Red Samurai”, “Cosmic Purple” and “Nantes”. This could be attributed to the aroma compounds of carrots are formed mostly at red and orange stages, so it is important to regulate these two stages in order to improve the desirable quality of carrots. Further studies may be desired to determine the correlations between individual aroma compound and flavour attributes in carrot cultivars.

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Competing interests

The authors declare no competing interest.

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Cover image

Source: Authors.

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