e-ISSN: 2757-8836
ORIGINAL ARTICLE
J. Raw Mater. Process. Foods vol.1 (2020) 13-21

Recieved: 25/06/2020 Revised: 03/07/2020 Accepted article published: 05/07/2020 Published online: 06/07/2020

Characterization of aroma and aroma-active compounds of Turkish turmeric *(Curcuma longa)* extract

Songul Kesen

Department of Food Processing, Naci Topcuoglu Vocational High School, Gaziantep University, 27600 Gaziantep, Turkey

E-mail adress: songulkesen27@hotmail.com

ORCID No: 0000-0003-0587-1721

Abstract

This study was aimed to determine aroma and aroma–active compounds of Turkish turmeric extract by using gas chromatography–mass spectrometry. The volatile compounds of turmeric extract were isolated by the purge and trap extraction method. A total of 21 volatile compounds including volatile phenols, terpenoid alcohols, terpenes, esters, alcohols, aldehydes and terpenoid ketone were identified. The total amount of flavor compounds was found to be 49 561 µg/kg. It was assigned that phenols were the major compounds, followed by terpenoid alcohols. Among these compounds, guaiacol and cuminic alcohol were determined as the most abundant compounds with the amount of 11 479 µg/kg and 10 059 µg/kg, respectively. The results of aroma extract dilution analysis displayed 13 odour–active compounds. Flavor dilution factors of potent odorants ranged from 16 to 2048. Guaiacol (medicine, phenol) and α–curcumene (herbal) had the strongest aroma with the flavor dilution factor of 2048 and 1024.

Keywords: *turmeric; curcuma longa; volatile compounds; aroma–active compounds; purge and trap; aroma extract dilution analysis*

1. INTRODUCTION

Natural plants have been used for thousands of years in traditional treatment methods and drug production. Obtaining more information about these products is important in the improving of new drugs (Newman et al., 2002). Turmeric (*Curcuma longa*) is a common plant belonging to the family of Zingiberaceae grown especially in Africa and Asia regions, primarily in the Pakistan, India, China and Bangladesh. It is also called as saffron, saffron root, and yellow dye. It is perennial herbaceous plant species with yellow flowers and large–leaved. The main roots of the plant in the ground are pears or eggs shaped, and the side roots are finger–shaped. The upper face and the inside of the rhizomes is yellow and it has a bitter taste. The dried and ground root stocks of *Curcuma longa* are used as a colorant additive and spice for foods. Turmeric is used as a colorant for dyeing silk fabrics and fine leathers. To be used as a spice, the turmeric plant must be cleaned, boiled in water and then dried and crushed the root stems. Ground turmeric should be stored in darkness or containers protected from light because they are easily oxidized in light. Turmeric is used as a flavor in a variety of vegetable dishes and is also used in Indian curry sauce to better protect food and to enhance sensory properties such as flavor, aroma and appearance (Rackova et al., 2009; Carvalho et al., 2015). The rhizomes have also shown excellent anticancer, anti–inflammatory, antiulcer, and antioxidant effects (Amalraj et al. 2017; Danciu et al., 2018). The volatile oil of turmeric is broadly used in the field of cosmetics and health. It has antifungal, antimicrobial and antiartritic activities. Turmerone compounds are active components of turmeric oil and have been shown to have anti–inflammatory, anti–cancer, anti–angiogenic, neuro-pharmacological, and antiplatelet properties. Curcuminoids and volatile components are responsible for the efficiency of turmeric. These components are used as markers to evaluate the quality of turmeric and turmeric products (Lee, 2006; Chao et al., 2018).

Aroma compounds are one of the main important constituents; quality forming and affecting consumer acceptance (Ayseli et al., 2014). Among chemical ingredients, these compounds determine the organoleptic properties of foods. Within the hundreds of aroma compounds, some of them determine the characteristic odor. These compounds are called aroma active compounds and can be detected with the aid of an olfactometric technique. The gas chromatography–olfactometry (GC–O) method serves to categorize aroma compounds as aroma–active and non–aroma–active compounds based on the sensitized smell concentrations (Garcia-Gonzalez et al., 2007; Kesen et al., 2013a). Some researchers examined the turmeric aroma profile. Guang–Ping et al. (2018) studied volatile components fraction of turmeric using supercritical fluid extraction method. They determined eight volatile terpene compounds and among them ar–curcumene (α-curcumene) and ar–turmerone (α-turmerone) were in the highest content based on the different fractions. Balaji and Chempakam (2018) found that the major compounds were turmerone, ar–turmerone, and curlone in turmeric aroma profile. According to literature, a study has not yet been reported to determine the aroma and aroma–active compounds of Turkish turmeric extract. Based on this information, the objective of this study was to: (i) isolate the aroma compounds of the turmeric extract with the PTE system and identify with GC–MS; (ii) assign aroma–active compounds of turmeric extract with AEDA method and GC–MS–O system, and (iii) specify the sensorial property of turmeric extract. Additionally, the odor activity values (OAV) of volatile compounds and the contribution of these compounds to overall aroma were calculated.

2. MATERIALS AND METHODS

2.1. Chemicals

The water was used purified by Millipore Q system (Millipore Corp., Saint–Quentin, France) in each analyze. Chemicals used in aroma extraction and concentration process (anhydrous sodium sulfate, dichloromethane and 2–octanol (internal standard)) were obtained from Merck (Darmstadt, Germany). Standards of aroma compounds used for identification were purchased from Sigma Aldrich (Sigma–Aldrich, Steinheim, Germany).

2.2. Turmeric (Curcuma longa) extract

Turmeric extract in a 100ml bottle was supplied from a medical herbalist in Bodrum/Turkey in August 2017. The extract was kept in dark glass bottle and conserved at 4 °C until analysis.

2.3. Extraction of aroma compounds

The aroma compounds of turmeric extract were obtained by using the purge and trap extraction system. In this way, the aroma compounds are screened on the special cartridge using carrier nitrogen gas controlled by the flow meter. The flow meter is connected to a separation system to divide the flow of the samples. Cartridge needle and nitrogen gas supply were connected to septum to hold volatile compounds. The Lichrolut ENresin (200 mg, Merck), which was most suitable for retaining the aroma compounds previously, was used as the adsorbent (Rodriguez-Bencomo et al., 2015). A 10 ml of turmeric extract was placed in a 20 ml flask and the oxygen removed by nitrogen gas. The samples were pretreated at 60 °C for 10 min Subsequently, extraction was continued for 90 min with 500 ml of nitrogen flow per min. The cartridge was then carefully removed and the volatiles collected eluted with 15 ml of dichloromethane. The volatile compounds and the dichloromethane mixture were treated with sodium sulfate (anhydrous) and the resulting extract concentrated using Kuderna Danish concentrator (Sigma Aldrich, St. Louis, USA) to 5 ml. At last, it was concentrated to 200 μl with nitrogen gas. The aromatic extract was kept in a 2 ml vial at –18 °C until analysis. This analysis was repeated three times and the concentration of the volatiles was determined by comparison with the internal standard which was 2–octanol with the concentration of 43.27 mg/L (Selli and Kelebek, 2011).

2.4. GC/FID and GC/MS Analysis

The GC (Agilent 6890) and a mass selective detector (Agilent 5973–MSD) was used to analyze aroma compounds. A flame ionization detector (FID) was used to measure of ions number hitting the collector and generated signal. The mobile phase known as carrier gas was helium with a flow rate of 1.5 ml/min. The DB–Wax column (30 m length x 0.25 mm i.d. x 0.5 μm thickness, CA, USA) contained in an oven was used to separate volatile compounds. The program conditions were adjusted as follows: oven start temperature was 50 °C for 1 min, then temperature was increased to 200 °C by enhancing 5 °C/min and after to 260 °C by increasing 8 °C/min and kept at this temperature for 5 min. After this stage, sample eluting from the column was split 1:1:1 for the FID, MSD, and sniffing mode via a Dean's switch. Finally, qualitatively chromatographic data was obtained as a graph against retention time. The identification of aroma compounds were carried out by using retention index, chemical standards and mass spectral database (NIST 98, Wiley 6). Internal standard method was used to calculated quantitatively concentration of each volatile compound.

2.5. Calculation of Odor Activity Values

The odor activity values (OAVs) were calculated by dividing the concentrations of volatile compounds with their odor thresholds (Luna et al., 2006). Only the compounds with an OAV greater than 1 were accepted to contribute individually to the turmeric aroma.

2.6. Olfactometric analysis

The one part of volatile compounds divided into three parts (at the rate of 1:1:1 for the flame ionization detector, mass selective detector, and sniffing port) from the GC effluent reach the sniffing port (Gerstel ODP–2, Linthicum, MD, USA). In the determination of aroma–active compounds, a neutralized capillary column (30 cm x 0.3 mm) heated at 240 °C and given humidified air at 40 °C was used.

2.7. Aroma extract dilution analysis (AEDA) The AEDA method was used to identify the characteristic aroma active compounds giving odor. At the beginning of the analysis, odorants were identified by smelling the extract concentrated to 200 μl. The AEDA method was used to identify the characteristic aroma active compounds giving odor. At the beginning of the analysis, odorants were identified by smelling the extract concentrated to 200 μl. Then, the aroma extract was diluted each time using dichloromethane in a rate of 1: 1, 1: 2, 1: 4, 1: 8, 1: 16, ..., 1: 1024, respectively, injected to GC, and sniffed again each time. Sniffing was continued until the odor was not felt. Each sensed odor was expressed as 2, 4, 8, ..., 1024, known as flavor dilution (FD) factor coincident to the dilution rates, respectively. As a result of the olfactometric analysis, the higher the FD value of a compound was expressed as the more dominant aroma–active compound in the aroma profile. Each diluted extract was smelled by three practised panelists in olfactometric sniffing port (Schieberle and Grosch, 1987).

2.8. Sensorial intensity and descriptive analysis

2.8.1. Panel

The panel was composed of nine panelists (five women and four men aged 26 to 43 years) from the Cukurova University (in Biotechnology Laboratory of Food Engineering Department). Panelists received training on how to perform sensory evaluation and odor separation, and they were asked to score on profile papers depending on this training.

2.8.2. Preparation of the samples for representative tests

In this study, representative tests were carried out to determine how similar the extract provided from the PT method to the analysis material. For this purpose, descriptive, similarity and intensity tests were applied. A cardboard smelling strip (Granger–Veyron, Lyas, France) was used to represent these quality parameters. In previous studies, cardboard strips have already produced reasonable results for the testability of olive oil (Kesen et al., 2015), dill and salt spice extracts (Jennings, 1981). In representative tests, 10 ml of the turmeric extract sample as reference (control) were taken and presented to the panelists after being specially coded in 25 ml brown glass bottles. On the other hand, the extract supplied by PT method was absorbed into special sniffing strip and left to stand for 1 min to evaporate solvent (dichloromethane). Sniffing strip was then introduced into the 25 ml brown glass bottle as reference material. Then, the comparison of the odors of aromatic extract with reference substance for the similarity test and intensity test was requested from the panelists. Also, samples were offered to characterize odour properties for descriptive analysis (Kesen et al., 2014). The room in which sensory analyzes are performed was odorless and noiseless, which does not affect the panelist's attention and the concentration of the sensory organs. A uniform illumination was provided to minimize optical influences and errors. Room temperature was 22°C .

2.8.3. Similarity and intensity test

These tests were exerted to find the similarity and intensity of the odour between the turmeric extract and its aromatic extract. The panelists were asked to sniff and score the reference sample and its aroma extract. A 10 cm scale was used for scoring. If the smell of the aroma extract is very different from the reference, it is indicated to the left and if it is very similar, it is indicated to the right. The score given by the panelists was determined by reading the centimeter from the left side of the marked place on the scale and average was taken (Kesen et al., 2015).

2.8.4. Descriptive test

Within the scope of this analysis, nine descriptive features including, sweet, roasted nut, medicine (phenol), herbal, garlic, sharp, mint, floral and vanilla were identified by trained panelists. The panelists were asked to characterize and score odor characteristics of the above mentioned descriptive features on a 10 cm scale by presenting the reference sample and aromatic extract. If there was no odor it was told to mark to the left, a strong odor to the right. The scores given by each panelist were determined on the scale and the mean value was calculated in centimeter.

2.9. Statistical analysis

The sensory scores of main sample and its aromatic extract were compared statistically using the analysis of independent samples of variance test (t–test) (SPSS statistics software version 22.0, Chicago, USA). All results obtained from analysis were given as mean of nine replication.

3. RESULTS AND DISCUSSION

3.1. Results of aroma analysis

The aroma compounds stated in turmeric extract and their linear retention index values on DB–Wax column were given in Table 1. The average values (µg/kg) and standard deviations of the three replication were presented in the table. As shown in Table 1, various numbers and varieties of volatile compounds were detected in the turmeric extract.

A total of 21 aroma compounds containing different groups such as phenols (2), terpenoid alcohols (2), terpenes (5), esters (2), alcohols (7), aldehydes (2), and ketone (1) were identified. The total amount of aroma compounds was 49561 µg/kg. Among all aroma compounds detected in turmeric extract, the most dominant group were phenols (15010 µg/kg) followed by terpenoid alcohols (10408 µg/kg) accounting for 30.3 % and 21.0 % of total aroma compounds, respectively. As for other aroma compounds, terpenes were 20.8 %, while esters and alcohols were 12.6 %.

As a phenol compound, guaiacol was detected in the highest amount (11479 μg/kg) of all compounds and followed by cuminic alcohol (10059 μg/kg) as a terpenoid alcohol. Phenols were the most important compounds of turmeric extract.

Table 1. Aroma-active compounds of turmeric extract

No	LRI*	Compounds	Average ± std dev**	Identitiy***
		Phenols		
1	1861	Guaiacol	11479 ± 152	LRI, MS, Std
2	2039	Phenol	3531 ± 65	LRI, MS, Std
		Total	**15010**	
		Terpenoid alcohols		
3	1592	4-Terpineol	349 ± 7	LRI, MS, Std
4	2079	Cuminic alcohol	10059 ± 160	LRI, MS, Std
		Total	**10408**	
		Terpenes		
5	1206	1,8-Cineole	635 ± 12	LRI, MS, Std
6	1699	Verbenone	2520 ± 25	LRI, MS, Std
7	1718	Zingiberene	2608 ± 48	LRI, MS, Std
8	1724	β-Cadinene	232 ± 6	LRI, MS, Std
9	1786	α-Curcumene	4302 ± 89	LRI, MS, Std
		Total	**10297**	
		Esters		
10	1183	Isoamyl isobutyrate	6071 ± 119	LRI, MS, Tent
11	1673	Ethyl benzoate	188 ± 5	LRI, MS, Std
		Total	**6259**	
		Alcohols		
12	1200	3-Hexanol	472 ± 11	LRI, MS, Std
13	1394	5-Methyl-2-heptanol	459 ± 15	LRI, MS, Std
14	1449	2-Ethyl-1-hexanol	228 ± 3	LRI, MS, Std
15	1545	2,3-Butanediol	1085 ± 10	LRI, MS, Std
16	1578	1,3-Butanediol	1740 ± 27	LRI, MS, Std
17	1656	Furfuryl alcohol	169 ± 4	LRI, MS, Std
18	1867	Benzyl alcohol	2074 ± 21	LRI, MS, Std
		Total	**6228**	
		Aldehydes		
19	1502	Benzaldehyde	219 ± 8	LRI, MS, Std
20	2532	Vanillin	874 ± 20	LRI, MS, Std
		Total	**1093**	
		Terpenoid ketone		
21	1518	Camphor	267 ± 9	LRI, MS, Std
		Total	**267**	
		General Total	**49561**	

[a] *LRI: Linear retention index values on DB–WAX column.*
[b] *Average±std dev: Mean values of three replication as μg/kg ± standard deviation*
[c] *Identity: Identification methods; LRI (linear retention index), Std (chemical standard) and tent (tentatively identified by MS)*

In previous studies, most of the phenolic compounds have been reported to have many important benefits including antiallergenic, antiviral, antimicrobial effect, antioxidant properties, and also protective effects on hormone–dependent breast tumors or cardio–protective activities (Jennings, 1981; Obied et al., 2005; Cesari et al., 2019). Two phenol compounds (guaiacol and phenol) were found in the samples. Guaiacol found as the most important phenol compound is defined as colorless to yellowish oily liquid with a smoky odor and caustic burning taste (Pubchem, 2019).Terpenoid alcohols were the second major class of aroma compounds. Two terpenoid alcohols (10408 µg/kg) including 4–terpineol and cuminic alcohol were quantified in turmeric extract. Cuminic alcohol was the largest among these compounds (10059 µg/kg). Tahri et al. (2016) investigated aroma profile of cumin seed and powder samples. They detected that cuminic alcohol was the one of the principal volatile compounds. Terpenes were the third biggest group of aroma compounds. Terpenes are one of the most common groups of natural products. While they have many different functions in plants and animals, they are also important as aroma components in foods. A total of five terpene compounds including 1,8–cineole, verbenone, zingiberene, β–cadinene, and α–curcumene were detected in the extract. The total amount of these compounds was 10297 µg/kg. Within the terpenes, α–curcumene was the most plenty terpene compound with 4302 µg/kg followed by zingiberene (2608 µg/kg). Curcumene was also detected by Prakash et al. (2015) as one of the most abundant components of turmeric (Curcuma longa) rhizomes. Data from clinical trials, cell culture and animal research indicate that curcumin may have potential as a therapeutic factor in diseases such as chronic anterior uveitis, pancreatitis, arthritis and inflammatory bowel disease (Li et al., 2011).

The other detected chemical groups of volatiles were as follows; esters (6259 µg/kg-), alcohols (6228 µg/kg), aldehydes (1093 µg/kg) and ketone (267 µg/kg). The esters are responsible for both the mature flavour characteristic and fruity scents (Zannou et al., 2020). The amount of volatile esters increases depending on the activity of the alcohol acetyl transferase (AAT) enzyme (Selli and Kelebek, 2011).

3.2. Results of GC–MS–O analysis

In order to identify aroma–active compounds, PT aromatic extract which was determined to be suitable for use in aroma extraction with representative tests was analyzed by GC–MS–O. A total of 13 aroma-active compounds were characterized, including esters (2), alcohol (1), terpenes (4), phenol (1), terpenoid alcohol (1), aldehyde (1), and unknown compounds (3) with the flavor dilution (FD) factors ranged from 16 to 2048 while the odour activity values (OAV) within a range of 3.14 and 3826 (Table 2). Six compounds with an OAV higher than 1 were detected at concentrations greater than the corresponding odor threshold values and it is possible these components contribute to the overall aroma of turmeric extract. On the other hand, unknown compounds with the FD values of 16 and 32 were perceived by GC–MS–O, but these compounds were not identified by GC– MS. concentrations greater than the corresponding odor threshold values and it is possible these components contribute to the overall aroma of turmeric extract. On the other hand, unknown compounds with the FD values of 16 and 32 were perceived by GC–MS–O, but these compounds were not identified by GC–MS. Guaiacol was the one of aroma–active phenol compound identified in turmeric extract and had the strongest aroma with the FD of 2048, providing a medicine and phenol odour. This compound was found to be the highest amount among the total aroma compounds with a concentration rate of 23.2 %. In previous studies, guaiacol was found as the dominant aroma–active compound giving bitter, phenolic and smoke odour notes (Sadecka and Polovka, 2008). This compound was followed by α–curcumene with 1024 FD factor giving herbal characteristic odour. Characteristic odours perceived as dominant (FD: 256–2048) in turmeric extract were medicine, phenol, herbal, sharp, sweet and mint which were correlative with the results of sensory analyses. Meanwhile, woody, herbal, and vanilla odour descriptors had relatively lower FD factors (64–128). The terpenes detected in highest number were expressed by four important key odorants; α–curcumene (FD: 1024), zingiberene (FD: 512), 1,8–cineole (FD: 256) and β–cadinene (FD: 64)..

Table 2. Aroma compounds of turmeric extract

No	LRI[a]	Aroma active compounds	Odor[b]	Ot[c] (mg/kg)	OAV[d]	FD Factor[e]
1	1183	Isoamyl isobutyrate	Sweet	0.087 [1]	69.8	512
2	1206	1,8-Cineole	Mint	0.023 [2]	27.6	256
3	1234	Unknown 1	Citrusy			32
4	1296	Unknown 2	Buttery			16
5	1673	Ethyl benzoate	Floral	0.06 [3]	3.14	32
6	1718	Zingiberene	Sharp	nd	-	512
7	1724	β-Cadinene	Woody	nd	-	64
8	1786	α-Curcumene	Herbal	nd	-	1024
9	1861	Guaiacol	Medicine, phenol	0.003 [4]	3826	2048
10	1867	Benzyl alcohol	Floral	0.62 [5]	3.35	32
11	1917	Unknown 3	Mint			32
12	2079	Cuminic alcohol	Herbal	nd	-	64
13	2532	Vanillin	Vanilla	0.058 [6]	15.1	128

[a]Linear retention index on DB–WAX capillary column.
[b]Odour description sensed in olfactometry.
[c]Odour threshold values in water obtained from the stated references (1: Schnabel et al., 1988; 2: Mookdasanit et al., 2003; 3: Buttery et al., 1988; 4: Rothe and Schrodter, 1996; 5: Pyysalo et al., 1977; 6; Buttery et al., 1999).
[d]The Odour activity values obtained from dividing concentration of the compounds (mg/kg) by their odour threshold.
[e]FD factor is the maximum dilution of the extract determined by AEDA

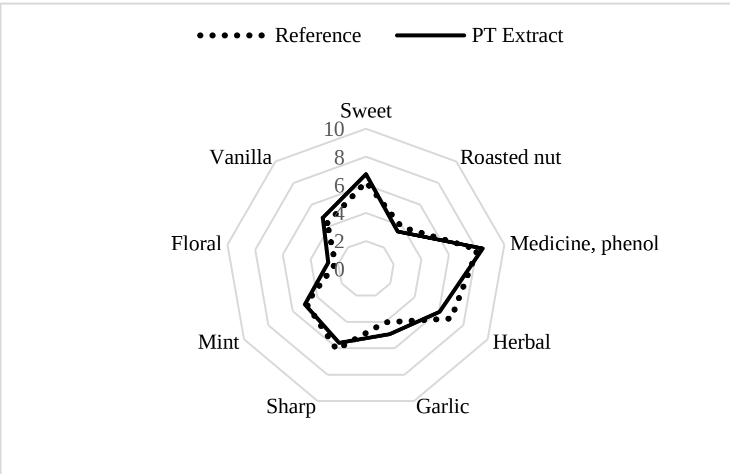

Fig. 1. Sensory descriptors of turmeric extract and its PT aromatic extract

Isoamyl isobutyrate was evaluated with sweet odour note with the same FD values of zingiberene (FD: 512).The other aroma–active compound with FD factor of 128 were vanillin (vanilla). The other compounds which were less effective in the characteristic odor formation and had lower FD values (32). These compounds were ethyl benzoate and benzyl alcohol with floral odour note.

Table 3. Descriptive results of turmeric extract and its PT aromatic extract

Panelists	Reference	PT Extract
Sweet	6.21	6.76
Roasted nut	3.93	3.50
Medicine, phenol	8.06	8.44
Herbal	7.01	6.06
Garlic	4.03	4.93
Sharp	6.09	5.59
Mint	4.90	5.01
Floral	2.21	2.71
Vanilla	4.28	4.78

[a]Letters for the same row indicate significant differences among reference and extract ($p < 0.05$).

Within the all key aromas of Curcuma longa extract, three unknown compounds were presented with a noteworthy flavor dilution factors characterizing odour. Unknown 1 (LRI=1234) and unknown 3 (LRI=1917) were potent aroma compounds provided a citrusy and mint odours with a FD factor of 32while unknown 2 (LRI=1296, FD=16) provided buttery aroma

3.3.2. Similarity and intensity values of aromatic extract

In the framework of this analysis, the average of the similarity and intensity scores determined by the panelists were calculated. According to the results marked on a 10 cm scale, the mean of the similarity score of the PT aromatic extract on smelling strip was found to be 7.9 cm. Additionally, the mean intensity score of the same extract was found to be 8.8 cm. Compared to the current literature (Kesen et al., 2013b; Kesen et al., 2014; Kesen et al., 2018), intensity and similarity scores of the aromatic extract were found to be appropriate for olfactometric analysis. According to the similarity and intensity scores, it was clearly observed that the aromatic extract were in close similarity with the the reference material.

4. CONCLUSION

To summarize, this is the first study to determine aroma–active compounds of Turkish turmeric (Curcuma longa) extract. The most dominant aroma compounds were phenols and followed by terpenoid alcohols. Among all aroma compounds, guaiaco(phenol) was detected most abundant and followed by cuminic alcohol (terpenoid alcohol). According to the results of the olfactometric analysis, characteristic odours in turmeric extract were specified by medicine/phenol, herbal, sharp, sweet and mint which were correlative with the results of sensory analyses. Meanwhile, vanilla, woody and herbal odour descriptors had relatively lower FD factors. Guaiacol, is a phenol compound, had the strongest aroma with the FD of 2048, providing a medicine and phenol odour.

REFERENCES

Amalraj, A., Pius, A., Gopi, S., & Gopi, S. (2017). Biological activities of curcuminoids, other biomolecules from turmeric and their derivatives – A review. *Journal of Traditional and Complementary Medicine*, 7(2), 205-233.

Ayseli, M.T., Filik, G., & Selli, S. (2014). Evaluation of volatile compounds in chicken breast meat using simultaneous distillation and extraction with odour activity value. *Journal of Food and Nutrition Research*, 53, 137–142.

Balaji, S., & Chempakam, B. (2018). Anti–bacterial effect of essential oils extracted from selected spices of zingiberaceae. *Natural Products Journal*, 8, 70–76.

Buttery, R.G., Turnbaugh, J.G., & Ling, L.C. (1988). Contribution of volatiles to rice aroma. *Journal of Agricultural and Food Chemistry*, 36, 1006–1009.

Buttery, R.G., Orts, W.J., Takeoka, G.R., & Nam, Y. (1999). Volatile flavor components of rice cakes. *Journal of Agricultural and Food Chemistry*, 47, 4353–4356.

Carvalho, P.I.N., Osorio–Tobon, J.F., Rostagno, M.A., Petenate, A.J., & Meireles, M.A.M. (2015). Techno–economic evaluation of the extraction of turmeric (*Curcuma longa* L.) oil and ar–turmerone using supercritical carbon dioxide. *The Journal of Supercritical Fluids*, 105, 44–54.

Cesari, L., Canabady-Rochelle, L., & Mutelet, F. (2019). Separation of phenols from lignin pyrolysis oil using ionic liquid. *Separation and Purification Technology*, 209, 528–534.

Chao, I.C., Wang, C.M., Li, S.P., Lin, L.G., Ye, W.C., & Zhang, Q.W. (2018). Simultaneous quantification of three curcuminoids and three volatile components of *Curcuma* *longa* using pressurized liquid extraction and high–performance liquid chromatography. *Molecules*, 23, 1568.

Danciu, V., Hosu, A., & Cimpoiu, C. (2018). Thin–layer chromatography in spices analysis. *Journal of Liquid Chromatography and Related Technologies*, 41, 282–300

Kesen, S., Kelebek, H., Sen, K., Ulas, M., & Selli, S. (2013a). GC–MS–olfactometric characterization of the key aroma compounds in Turkish olive oils by application of the aroma extract dilution analysis. *Food Research International*, 54, 1987–1994.

Garcia–Gonzalez, D.L., Tena, N., & Aparicio, R. (2007). Characterization of olive paste volatiles to predict the sensory quality of virgin olive oil. *European Journal of Lipid Science and Technology,* 109, 663–672.

Guang-Ping, L.V., De-Jun, H., Yan-Qing, Z., Qing-Wen, Z., Jing, Z., & Shao-Ping, L. (2018). Preparation and application of standardized typical volatile components fraction from turmeric (*Curcuma longa* L.) by supercritical fluid extraction and step molecular distillation. *Molecules*, 23, 1831.

Jennings, A.C. (1981). The determination of dihydroxy phenolic compounds in extracts of plant tissues. *Analytical Biochemistry*, 118, 396–398.

Kesen, S., Kelebek, H., & Selli, S. (2013b). Characterization of the volatile, phenolic and antioxidant properties of monovarietal olive oil obtained from cv. Halhali. Journal of the American Oil Chemists' Society, 90, 1685–1696.

Kesen S., Kelebek, H., & Selli, S. (2014). Characterization of the Key Aroma Compounds in Turkish Olive Oils from Different Geographic Origins by Application of Aroma Extract Dilution Analysis (AEDA). *Journal of Agricultural and Food Chemistry*, 62, 391-401.

Kesen, S., Amanpour, A., Sarhir, S.T., Sevindik, O., Guclu, G., Kelebek, H., & Selli, S. (2018). Characterization of aroma–active compounds in seed extract of black cumin (*Nigella sativa* L.) by aroma extract dilution analysis. *Foods*, 7, 98.

Lee, H.S. (2006). Antiplatelet property of *Curcuma longa* L. rhizome-derived ar-turmerone. *Bioresource Technology*, 97, 1372-1376.

Li, S., Yuan, W., Deng, G., Wang, P., Yang, P., & Aggarwal, B.B. (2011). Chemical Composition and Product Quality Control of Turmeric (*Curcuma longa* L.). *Pharmaceutical Crops*, 2, 28–54.

Luna, G., Morales, M.T., & Aparicio, R. (2006). Characterisation of 30 varietal virgin olive oils by their volatile compositions. *Food Chemistry*, 98, 243–252.

Mookdasanit, J., Tamura, H., Yoshizawa, T., Tkunaga, T., & Nakanishi, K. (2003). Trace volatile components in essential oil of Citrus sudachi by means of modified solvent extraction method. *Food Science and Technology Research*, 9, 54–61.

Newman, D.J., Cragg, G.M., & Snader, K.M. (2003). Natural products as sources of new drugs over the period 1981–2002. *Journal of Natural Products*, 66, 1022-1037.

Obied, H.K., Allen, M.S., Bedgood, D.R., Prenzler, P.D., Robards, K., & Stockmann, R. (2005). Bioactivity and analysis of biophenols recovered from olive mill waste. *Journal of Agricultural and Food Chemistry*, 53, 823–837.

Prakash, R., Agarwal, S., Srivastava, A., & Nigam, V. (2015). GC–MS Analysis of essential oil of turmeric rhizome and its activity against sporothrix schenckii fungus. *Oriental Journal of Chemistry*, 31, 2213–2214.

Pubchem, Open Chemistry Database [online] https://pubchem.ncbi.nlm.nih.gov/compound/guaiacol (accessed on 10 Nisan 2020).

Pyysalo, T., Suihko, M., & Honkanen, E. (1977). Odour thresholds of the major volatiles identified in cloudberry (*Rubus chamaemorus* L.) and arctic bramble (*Rubus arcticus* L.). *LWT Lebensmittel-Wissenschaft und – Technologie*, 10, 36–39.

Rackova, L., Kostalova, D., Bezakova, L., Fialova, S., Bauerova, K., Toth, J., Stefek, M., Vanko, M., Holkova, I., & Oblozinsky, M. (2009). Comparative study of two natural antioxidants, curcumin and *Curcuma longa* extract. *Journal of Food and Nutrition Research*, 48, 148–152.

Reiners, J., & Grosch, W. (1998). Odorants of virgin olive oils with different flavor profiles. *Journal of Agricultural and Food Chemistry*, 46, 2754–2763.

Rodriguez-Bencomo, J.J., Kelebek H., Sonmezdag A.S., Rodriguez-Alcala L., Fontecha J., Selli S. (2015).Characterization of the Aroma-Active, Phenolic, and Lipid Profiles of the Pistachio (*Pistacia vera* L.) Nut as Affected by the Single and Double Roasting Process, *Journal of Agricultural and Food Chemistry*, 63, 7830-7839.

Rothe, M., & Schrodter, R. (1996) Flavour contribution of ethanol, a neglected aroma compound in Flavour Science: Recent Developments (pp 348–349). *The Royal Society of Chemistry*, UK.

Sadecka, J., & Polovka, M. (2008). Multi–experimental study of γ–radiation impact on oregano (*Origanum vulgare* L.). *Journal of Food and Nutrition Research*, 47, 85–91.

Schieberle, P., & Grosch, W. (1987). Evaluation of the flavour of wheat and rye crust by aroma extract dilution analysis. *Zeitschrift für Lebensmittel-Untersuchung und Forschung*, 185, 111–113.

Schnabel, K.O., Beltz, H.D., & Ranson, C.V. (1988). Untersuchungen zur Struktur–Aktivitäts–Beziehung bei Geruchsstoffen 1. Mitteilung: Wahrnehmungsschwellenwerte und Geruchsqualitäten von gesättigten aliphatischen und alicyclischen Verbindungen mit Sauerstoff–Funktion (Investigations on the structure-activityrelationships of odorous substances. Communication I. Detection thresholds and odour qualities of aliphatic and alicyclic compounds containing oxigen functions). *Zeitschrift für Lebensmittel-Untersuchung und–Forschung*, 187, 215–223.

Selli, S., & Kelebek, H. (2011). Aromatic profile and odour—activity value of blood orange juices obtained from Moro and Sanguinello (*Citrus sinensis* L. Osbeck). *Industrial Crops and Products*, 33, 727—733.

Tahri, K., Tiebe, C., El Bari, N., Hubert, T., & Bouchikhi, B. (2016). Geographical provenience differentiation and adulteration detection of cumin by means of electronic sensing systems and SPME–GC–MS in combination with different chemometric approaches. *Analytical Methods*, 8, 7638–7649.