ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/365979377

Determination of Aroma and Protein Contents in Organic Lycium barbarum L. and Lycium chinense Miller Fruits in Different Ripening Periods

Article *in* Erwerbs-Obstbau · December 2022

DOI: 10.1007/s10341-022-00775-7

CITATIONS
2

READS
136

6 authors, including:



İlbilge Oğuz

37 PUBLICATIONS **66** CITATIONS

SEE PROFILE



Halil İbrahim Oğuz

Adiyaman University

150 PUBLICATIONS **641** CITATIONS

SEE PROFILE



Sema Atasever

Nevşehir Hacı Bektaş Veli University

25 PUBLICATIONS **110** CITATIONS

SEE PROFILE

Ebru Kafkas

Cukurova University

220 PUBLICATIONS **2,975** CITATIONS

SEE PROFILE

All content following this page was uploaded by İlbilge Oğuz on 03 December 2022.

The user has requested enhancement of the downloaded file.

Erwerbs-Obstbau
https://doi.org/10.1007/s10341-022-00775-7

ORIGINAL ARTICLE / ORIGINALBEITRAG

Determination of Aroma and Protein Contents in Organic *Lycium barbarum* L. and *Lycium chinense* Miller Fruits in Different Ripening Periods

İlbilge Oğuz[1] · Halil İbrahim Oğuz[2] · İpek Ürün[1] · Şule Hilal Attar[1] · Sema Atasever[3] · Nesibe Ebru Kafkas[1]

Received: 28 July 2022 / Accepted: 24 October 2022
© The Author(s), under exclusive licence to Der/die Autor(en), exklusiv lizenziert an Springer-Verlag GmbH Deutschland, ein Teil von Springer Nature 2022

Abstract
Once the benefits to human health of the goji berry plant were understood, the popularity of goji products rapidly increased worldwide due to more studies by researchers and effective marketing strategies. For this reason, goji fruit and its fruit juice are marketed as healthy food products in many countries around the world. This study aimed to detect aroma compounds with a gas chromatography-mass spectrometry (GC-MS) device using two solid-phase microextraction (SPME) fibers for fruit harvested in different ripening periods from three *Lycium barbarum* L. genotypes ('HZR1', 'HZR2', 'HZR3') and compare them with dried fruit from the *Lycium barbarum* L. genotypes. Another aim was to detect the protein contents of fruit harvested in different ripening periods from the 'HZR1', 'HZR2', and 'HZR3' genotypes and the 'M1 ALTUNİ' genotype from the *Lycium chinense* species with the Micro-Kjeldahl method. The study identified 35 volatile aroma compounds. The highest protein amount was found in the 'M1 ALTUNİ' genotype in the green period.

Keywords *Lycium* spp. · Fruit quality parameters · Protein · GC-MS · SPME

Highlights

1. This study is the first scientific research about goji berry in Central Anatolia.
2. Studies about the protein and aroma compounds in goji berry are comparatively limited in Turkey.
3. According to this study, the highest protein content was detected in 'M1 ALTUNİ'.
4. The study identified 35 volatile aroma compounds.
5. The aroma analysis in the study used light blue and red SPME fibers.

Introduction

The *Lycium* spp. fruiting species belongs to the *Solanaceae* family and is called the wolfberry or goji berry in China and many countries. The most common species globally is *Lycium barbarum* L., and the natural distribution areas of the goji berry are China, Tibet, and other Asian countries (Potterat 2010). The highest quality goji fruit in terms of aroma and nutritional properties is produced in the Ningxia region of China (Amagase et al. 2009; Amagase and Farnsworth 2011; Zhang et al. 2016). *L. barbarum* fruit may be consumed fresh or dried, and is consumed as fruit juice or condensed juice. Daily consumption of 5–18 g dried fruits is recommended (Oğuz et al. 2022). Additionally, it is used as fruit juice and drinks in China. For example, fruits are also consumed in beer production, while leaves are consumed as tea (Chen et al. 2015; Oğuz 2019). Especially in China, leading the country producing most goji berry globally, and in some other countries, dry or fresh goji fruits are commonly used in wine production (Yuan et al. 2016; Zhong et al. 2013). The fruit of the plant is a popular drink and snack in Asian countries, while it is also consumed as a functional food (Adams et al. 2006). Goji fruits and products obtained from them are reported to be used as food or food supplements in America and Europe (Oğuz 2019).

✉ Nesibe Ebru Kafkas
ebruyasakafkas@gmail.com

[1] Faculty of Agriculture, Department of Horticulture, University of Çukurova, 01330 Balcalı, Adana, Turkey

[2] Faculty of Agriculture, Department of Horticulture, Adıyaman University, 02040 Adıyaman, Turkey

[3] Department of Computer Engineering, Faculty of Engineering-Architecture, University of Nevşehir Hacı Bektaş Veli, 50300 Nevşehir, Turkey

Published online: 02 December 2022

The dried goji berry fruits contained protein 13.3 ± 0.6 g/100 g and energy 302 kcal/100 g (Rybicka et al. 2021). A study in China performed protein analyses after drying goji fruits obtained from six different regions. When protein in samples from the six regions was investigated, the protein contents varied between 4.12 mg/100 g and 6.17 mg/100 g between the regions. The highest protein content was obtained from the Xinjiang Uygur autonomous region (17 mg/100 g), with the lowest protein content obtained in dried goji berry samples from the Baiyin Gansu province (4.12 mg/100 g) (Lu et al. 2021). In addition to the protein content of goji berry, the aroma properties have attracted the attention of both consumers and researchers due to important benefits for human health. Although many things are known about *Lycium* spp. as an important nutrient source for people, there is currently still inadequate information about the aroma quality. Research shows that knowing the aroma content of fruit is an important criterion in goji berry breeding. Aroma compounds have great importance for acceptable food products. Factors affecting the presence of aroma compounds include proteins, presence of salts, and their interactions (Pozo-Bayon et al. 2008; Kafkas et al. 2018).

Chen et al. (2015) performed analyses with headspace-trap gas chromatography (GC) in a study to determine volatile compounds in *Lycium barbarum* L. fruits. They identified 193 aroma compounds in this study. They stated that most of the dominant compounds in the research were ester compounds. Also, they identified 56 volatile compounds through linear retention index (LRI), mass spectrometry (MS), and retention index (RI), and these compounds included 17 aldehydes, five alcohols, five terpenoids, eight esters, 11 terpenes, six ketones, two furans, and three acids. In conclusion, they identified that the 56 volatile aroma compounds identified in goji berry obtained from the Ningxia region in China comprised 70–94% of total volatile compounds, with hexanal and (E)-2-hexenal dominant in goji fruit. They reported that in terms of gas chromatography-olfactometry and odour activity values, the most common characteristic volatile aroma compounds in Ningxia goji berry were hexanal, (E)-2-hexenal, nonanal, isoamylol, 1-hexanol, 1-octen-3-ol, hexyl acetate, methyl salicylate, ethyl octanoate, o-cymene, d-limonene, linalool, β-cyclocitral, β-elemene, and 2-pentylfuran. In the unripe green stage of the fruit, the content of hexyl acetate, linalool, 2-pentylfuran β-cyclocitral, and β-elemene significantly increased, while there was a reduction in other compounds in later stages. As a result of this study, they reported that Ningxia goji berry varieties may be an important breeding material in terms of aroma compounds.

A study by Kim and Chung (2009) identified 130 volatile compounds in *Lycium chinense* Miller fruit; among these were eight acids, 21 alcohols, 23 aldehydes, 10 alkanes, five aromatics, 15 esters, seven furans, 21 ketones, three diverse compounds, two naphthalins, three phenols, two pyrazines, and 10 terpenes. The basic components in oil from the fruit of *L. barbarum* were identified as hexadecenoic acid (47.5%), β-elemene (5.4%), myristic acid (4.2%), and ethyl hexadecanoate (4.0%). The essential oil of *L. ruthenicum* contained heptacosane (14.3%), ethyl linoleate (10.0%), hexacosane (7.0%), nonacosane (6.2%), and ethyl hexadecanoate (5.8%) among basic components.

A study in China identified varying rates of volatile compounds in raw goji berry material after pressing and glycosidase application to fresh and dry goji berry for wine production. In this study, they reported no significant difference between volatile compound contents in both fresh and dry goji berry material. Additionally, while there were 31 volatile compounds in wine fermented from fresh goji berry, they identified 56 volatile compounds in wine fermented from dry goji fruit. They reported there were more odour and aroma compounds in wine fermented from the dry goji berry. Also, while floral, fruity, and caramel odors were dominant among properties determining the basic aromatic character of wines fermented with dry goji berry, chemical compounds were higher for wines fermented with fresh wolfberry. As a result of the study, they reported that glycosidase administration did not affect the aroma content of fermented goji berry wine.

Our study aimed to identify the aroma compounds in fruit harvested in different ripening periods from three separate *Lycium barbarum* L. genotypes ('HZR1', 'HZR2', 'HZR3') and dried *Lycium barbarum* L. fruit with a gas chromatography-mass spectrometry (GC-MS) device using two different solid phase micro extraction (SPME) fibers. Our second aim was to identify the protein contents in fruit obtained in different ripening periods from 'HZR1', 'HZR2', and 'HZR3' genotypes and the 'M1 ALTUNİ' genotype from the *Lycium chinense* species with the Micro-Kjeldahl method.

Materials and Methods

Material

The samples were collected between the first week of June and September in 2018. Goji berries in different development stages were taken from the plantations. As well as dried fruits, green, unripe, and ripe goji berries were evaluated. Randomized blocks with three replications are used for the experiment. Each replication had 20 plants which were planted at a spacing of 3 × 1.5 m. In each development stage, 500 g of samples were collected. In brief, the testing materials were the green, unripe, ripe, and dried goji berries from two different species and were collected in different

development stages: green (5 days after full flowering), unripe (20 days after full flowering), and ripe (35 days after full flowering) (Oğuz et al. 2021).

'HZR1' Genotype: This is one of three *Lycium barbarum* genotypes that has the least amount of thorns, an oval fruit shape, and red fruit color.

'HZR2' Genotype: This is one of three *Lycium barbarum* genotypes that has the bulkiest and longest fruit characteristics and bulkier leaves.

'HZR3' Genotype: Having grown from the seeds of the 'NQ-1' cultivar, it is one of three *Lycium barbarum* genotypes that has the smallest fruits. The yield of the 'HZR3' genotype was higher compared to the other genotypes. Harvesting this genotype is challenging and it has a slower ripening rate when compared to others (Oğuz et al. 2021).

'M1 ALTUNİ' Genotype: This belongs to the *L. chinense* Miller species and has yellow-colored fruits. The fruit shape is oval and fruit bulkiness is similar to 'HZR2'.

Method

Dry Method Fruit

Racks made with Teflon wires in wooden frames measuring 80 × 90 cm were used for the goji berry fruits maturing during the harvest season. After the harvest, the collected fruits were spread on these racks and kept in the shade for nearly a day. The racks were then transported to drying rooms, where they were set on shelves with a 10-cm spacing between them and the fruits were left to dry. A drying machine (HDSD120B-D, Haiti Sheng Machinery Co. Ltd., Liaoning, China) was used for heating the fruits. This machine warms the air in a hot-blast stove and directs the hot air toward the fresh fruits and this method is known as hot air drying. By using this method, goji berries were heated at 40–45 °C for approximately 6 h with an airflow speed of 0.15 m/s, then at 60 °C for 6 h with an airflow speed of 0.35 m/s, and lastly at 65 °C for approximately 20 h with an airflow speed of 0.25 m/s. Furthermore, by using this approach, the lowest possible cost and large processing capacity were achieved. However, this procedure results in waste and poor quality. (Zhao et al. 2015a, b; Oğuz et al. 2021).

Determination of Aromatic Compounds

Volatile compounds were extracted by solid-phase microextraction (SPME). Then, 1 g of homogenate goji berry was weighed and 1 mL of $CaCl_2$ was added in a headspace vial for 30 min at 40 C. Three replicates were used for each sample. The SPME fiber 85 µm CAR/PDMS (carboxen/polydimethylsiloxane; light blue) and 100 µm PDMS (polydimethylsiloxane; red) (Supelco Co., Bellefonte, PA, USA) were used for analysis. The adsorbed flavor compounds from the goji berry fruits were analyzed using a Shimadzu GC-2010 Plus GC-MS system (Shimadzu Corporation, Kyoto, Japan). HP-Innowax Agilent column (30 m × 0.25 mm i. d., 0.25 µm thickness) was used and helium was the carrier gas. The GC oven temperature was kept at 40 C and programmed to 260 C at a rate of 5 C/min and then kept constant at 260 C for 40 min. The injector temperature was 250 C. The MS were obtained at 70 eV. The mass range was m/z 30–400. The chromatograms and mass spectra were evaluated with GC-MS Postrun Analysis software (Shimadzu, GC-MS-QP2010, Japan). The compounds were tentatively identified by comparing their mass spectra with those in the data system library (NIST08) (Kafkas et al. 2018).

Determination of Protein Percentage

Nitrogen percentage in berries was estimated using the Micro-Kjeldahl method according to the Association of Official Analytical chemists (A.O.A.C., 1990). Protein percentage was calculated according to the following equation: protein percentage = nitrogen percentage (N%) × 6.25 (Kafkas et al. 2020).

Statistical Analyses

JMP data analysis software was used for statistical analyses. The data were gathered for various parameters. Regarding the variance, the analysis was carried out statistically through the data analysis tool of the JMP (5.0.1, SAS Institute, Cary, NC, USA). At a 5% probability level, Fisher's method of protected least significant difference (LSD) was used to compare means (Steel et al. 1997). Data visualization and analyses were conducted using RStudio version 2021.09.2 Build 382 (RStudio 2022; RStudio [version 2021.09.2 Build 382, RStudio, Inc, USA]).

Results and Discussion

The variation in protein content (%) of different wolfberry genotypes according to ripening period is given in Table 1. According to the ripening period, the statistical differences between genotypes were identified to be significant ($p < 0.05$). The genotypes and interaction between genotype X period were found to have statistically significant differences in terms of protein content (%) ($p < 0.05$). The highest protein content determined in fruits obtained in the green period was 23.70 ± 0.17 in the 'M1 ALTUNİ' genotype. The lowest protein content in the ripe period was measured as 8.59 ± 0.44 in the 'HZR1' genotype. In the unripe period, the highest protein content was identified as 22.58 ± 0.41 in the 'M1 ALTUNİ' genotype, while the

Table 1 Protein values (%) for goji berry fruits in different ripening stages

Genotypes		Ripening stages				
		Green	Unripe	Ripe	Dried	Average
Protein (x)	'HZR3'	22.06 ± 0.52 c	17.30 ± 0.39 e	10.41 ± 0.23 ı	14.73 ± 0.32 g	16.13 *C*
	'HZR1'	21.68 ± 0.23 c	18.82 ± 0.20 d	8.59 ± 0.44 j	13.55 ± 0.21 h	15.66 *D*
	'HZR2'	21.72 ± 0.19 c	19.11 ± 0.14 d	9.93 ± 0.06 ı	15.62 ± 0.24 f	16.60 *B*
	'M1 ALTUNİ'	23.70 ± 0.17 a	22.58 ± 0.41 b	16.14 ± 0.34 f	13.19 ± 0.61 h	18.90 *A*
	Average of Stage	22.29 A	19.45 B	11.27 D	14.28 C	–
	LSD	LSD_{gen}* = 0.260 LSD_{stage}* = 0.260 $LSD_{genxstage}$* = 0.521				

The differences between the averages are shown by separate letters
N.S. Not Significant, *LSD* least significant difference
***p 0.001, **p 0.01, *p 0.05

lowest protein content was 17.30 ± 0.39 in the 'HZR3' genotype. In the ripe period, the highest protein content was 16.14 ± 0.34 in the 'M1 ALTUNİ' genotype, while the lowest protein content of 8.59 ± 0.44 in the 'HZR1' genotype (Fig. 1c). Considering the period averages for protein content, the highest protein content of 22.29 was identified in the green period, with the lowest protein content of 11.27 identified in the ripe period (Fig. 1b). When the genotype averages are considered in terms of protein content, the highest was in the 'M1 ALTUNİ' genotype with a value of 18.90, while the lowest was identified as the 'HZR1' genotype with a value of 15.66 (Fig. 1a).

A study in China identified 7.63% protein in dried goji berry (Gan et al. 2004). Niro et al. (2017) analyzed fresh and dried goji berries (g/100 g) for protein contents and found 2.5 ± 0.12% and 10.2 ± 0.22% protein content, respectively. Another study measured 9.57 ± 0.05% protein content in organic goji berry and 9.72 ± 0.03% protein in conventional goji berry among the quality and nutritional properties of goji fruit from organic and conventional goji berry cultivation (Pedro et al. 2019). Ilić et al. (2020) found the content of protein to be 1.98 ± 0.06 for red goji, 2.24 ± 0.30 for yellow goji, and 1.68 ± 0.01 for black goji. They observed slightly higher protein content in the yellow goji berry fruits. Covaci et al. (2020) found mean protein values of 15.9 ± 2.7%. Talay et al. (2021) determined the protein content of goji berry as 13.18%. A study in Poland stated that dried goji berry had a protein content of 13.3 ± 0.6% (Rybicka et al. 2021). Our study identified a protein content in the interval of 8.59 ± 0.44–16.14 ± 0.34% for fresh goji berry and 13.19 ± 0.61–15.62 ± 0.24% for dried goji berry. The data obtained in our study were identified to be generally higher compared to previous literature data.

In the study, fruit samples in different ripening periods from the 'HZR1', 'HZR2', and 'HZR3' goji berry genotypes were investigated with GC-MS for aroma content using two different SPME fibers (light blue, red), and this data is given in Tables 2 and 3. According to Table 2, the volatile contents in analyses with the blue SPME fiber identified 2 octenal, 2.4-hexadienal, 2-furancarboxaldehyde, 2-hexenal, heptanal, and pentanal from the aldehyde group; 1-hexanol, 2-ethyl-1-hexanol, 1-octen-3-ol, 1-pentanol, 3-methyl-1-butanol, 3-hexen-1-ol, and phenol from the alcohol group; 2-propanone, and 6-methyl-5-heptane-2-one from the ester group; acetic acid, ethyl ester, benzoic acid, and 2-hydroxy-methyl ester from the ketone group; and methyl-benzene and l-limonene from the terpene group. As seen in Table 2, considering the different ripening periods for goji berry, in the aldehyde group the highest values for 2-hexenal were 61.72% ('HZR1')–65.21% ('HZR2') in the green period, 63.19% ('HZR1')–68.5% ('HZR2') in the unripe period, 62.76% ('HZR3')–67.2% ('HZR1') in the ripe period, 67.69% ('HZR3')–71.35% ('HZR1') in dried samples. The highest hexenal value was determined in 'HZR1' genotype as 71.35% in the dried samples. For the aldehyde group considering all ripening periods in goji berry genotypes, the lowest value was for 2.4-hexadienal aldehyde, with a minimum value of 0.07% identified in dried samples from the 'HZR2' genotype. Considering the alcohol group in goji fruit from different ripening periods, the highest value was for 1-hexanol, with values of 8.57% ('HZR2')–8.95% ('HZR3') in the green period, 10.55% ('HZR3')–13.04% ('HZR1') in the unripe period, 14.96% ('HZR3')–15.91% ('HZR1') in the ripe period, 9.27% ('HZR1')–11.49% in the dried samples from the 'HZR2' genotype. For the alcohol group considering all ripening periods for goji berry genotypes, the lowest value was for 1-octen-3-ol, with highest value for 1-hexanol. The highest 1-hexanol value was in the ripe period at 15.91% in fruit from 'HZR1' genotype. For the ketone group considering the different ripening periods of goji fruit, the highest value was for 2-propanone with values of 2.14% ('HZR1')–2.86% ('HZR3') in the green period, 2.03% ('HZR2')–2.23% ('HZR1') in the unripe period, 2.21% ('HZR2')–2.85% ('HZR3') in the ripe period, 1.37% ('HZR3')–1.62% ('HZR1') in the dried samples from the 'HZR1' genotype. The lowest value for the ketone group considering all ripening periods in goji berry genotypes was for 6-methyl-5-heptane-2-one, with highest value identified for 2-propanone. The highest 2-propanone value was

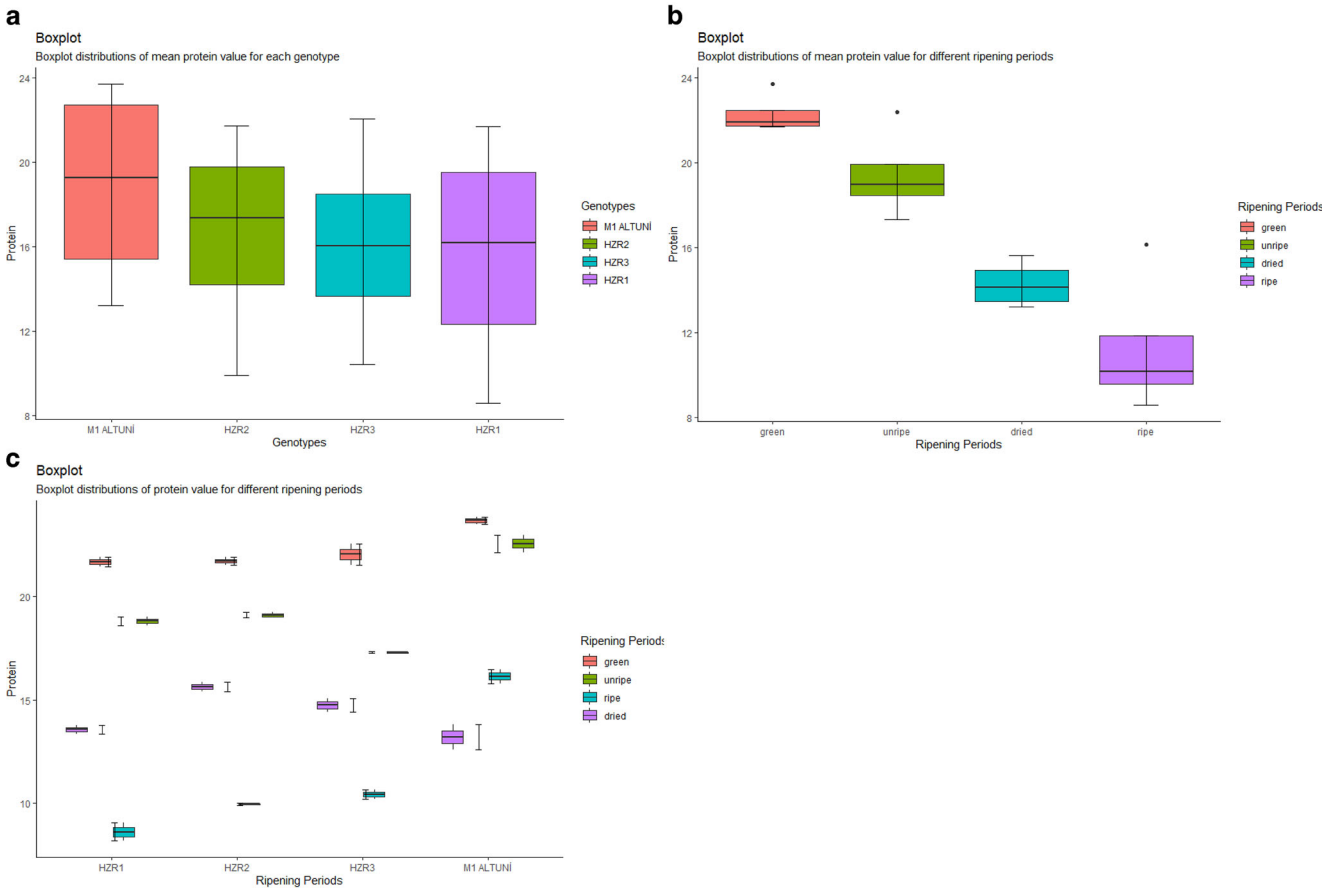


Fig. 1 Boxplot distributions of mean protein value for each genotype and ripening periods. When the genotype averages are considered in terms of protein content, the highest was in the 'M1 ALTUNİ' genotype, while the lowest was identified in the 'HZR1' genotype (**a**). Considering the period averages for protein content, the highest protein content was identified in the green period, with lowest protein content identified in the ripe period (**b**). The highest protein content determined in fruits was obtained in the green period for the 'M1 ALTUNİ' genotype. The lowest protein content in the ripe period was for the 'HZR1' genotype (**c**)

2.86% in the green period in samples from 'HZR3' genotype. In terms of esters, considering all ripening periods in goji berry genotypes, the lowest value was for benzoic acid, with the highest value for 2-hydroxy-methyl ester and acetic acid identified. The highest acetic acid, ethyl ester value was determined as 2.32% in the 'HZR2' genotype in the unripe period. Additionally, the highest value for acetic acid, ethyl ester in the ester group considering different ripening periods for goji fruit were 1.49% ('HZR3')–1.8% ('HZR1') in the green period, 1.78% ('HZR3')–2.32% ('HZR2') in the unripe period, 1.07% ('HZR3')–1.75% ('HZR1') in the ripe period, 1.07% ('HZR3')–1.75% in the dried samples from the 'HZR1' genotype. For the terpene group considering all ripening periods for goji berry genotypes, the lowest value was for 1-limonene, with the highest value identified for methyl-benzene. The highest methyl-benzene value was identified as 2% in the green period for the 'HZR1' genotype. For the terpene group considering different ripening periods for goji berry fruit, the highest value was for methyl-benzene with values identified as 1.52% ('HZR3')–2% ('HZR1') in the green period, 1.45% ('HZR2')–1.81% ('HZR3') in the unripe period, 1.29% ('HZR2')–1.74% ('HZR1') in the ripe period, 1.45% ('HZR1')–1.80% in the dried samples from the 'HZR2' and 'HZR3' genotypes.

Results of the present study showed that the genotypes differ from each other in terms of the contents of VOCs. For example, the 'HZR1' cultivar was dominant with total alcohol, total ester, and total terpene, while the 'HZR2' cultivar was dominant with total aldehydes. Also, the highest percentage of total ketone was 'HZR3' (Fig. 2a). The average total aldehyde content increases as the fruit ages (Fig. 2b).

For different ripening stages of the 'HZR1' genotype, the total terpene, total alcohol, and total ester contents were highly correlated with each other, while negatively correlated with total aldehyde ($p < 0.05$) (Fig. 3a). "Total Terpene" and "Total Alcohol" were negatively correlated for the 'HZR2' genotype with different ripening stages (green, unripe, ripe, dried) for Table 2 ($p < 0.05$) (Fig. 3b). Further-

Table 2 Volatile compounds of goji berry with blue solid-phase microextraction (SPME) (%)

Compound name	'HZR1' Green Blue	'HZR2' Green Blue	'HZR3' Green Blue	'HZR1' Unripe Blue	'HZR2' Unripe Blue	'HZR3' Unripe Blue	'HZR1' Ripe Blue	'HZR2' Ripe Blue	'HZR3' Ripe Blue	'HZR1' Dried Blue	'HZR2' Dried Blue	'HZR3' Dried Blue
Aldehyde (-al)												
2 Octenal	0.33	0.77	0.50	0.20	0.15	0.30	0.58	0.44	0.50	0.29	0.17	0.46
2.4-Hexadienal	0.49	0.44	0.82	0.41	0.08	0.27	1.51	0.99	1.03	0.19	0.07	–
2-Furancarboxaldehyde	–	0.23	–	–	0.50	–	0.40	0.40	0.41	0.32	0.26	0.39
2-Hexenal	61.72	65.21	63.02	63.19	68.5	64.94	67.20	64.11	62.76	71.35	68.03	67.69
Heptanal	0.37	0.40	0.51	0.23	0.14	0.22	0.98	0.52	0.75	0.2	0.25	0.24
Pentanal	4.56	3.95	4.57	4.39	2.11	4.83	3.50	5.08	5.8	1.84	2.95	2.75
Total Aldehyde	**67.47**	**71.00**	**69.42**	**68.42**	**71.48**	**70.56**	**74.17**	**71.54**	**71.25**	**74.19**	**71.73**	**71.53**
Alcohol (-ol)												
1-Hexanol	8.92	8.57	8.95	13.04	10.61	10.55	15.91	15.6	14.96	9.27	11.49	9.46
2-ethyl-1-Hexanol	0.82	0.5	0.5	0.91	0.2	0.25	0.78	0.52	0.90	0.25	1.10	0.27
1-Octen-3-ol	1.65	2.79	2.94	1.52	1.49	1.24	0.13	0.61	0.50	1.20	1.50	1.45
1-Pentanol	0.65	0.93	0.94	0.7	0.8	0.59	–	0.8	0.72	0.75	0.42	0.83
3-methyl-1-Butanol	1.25	1.61	1.50	1.28	1.76	1.41	1.00	1.2	1.10	1.26	1.50	1.46
3-Hexen-1-ol	9.59	5.81	6.22	4.98	4.7	5.78	–	1.85	1.74	5.51	2.74	5.89
Phenol	0.78	0.78	0.95	0.86	0.70	0.60	0.66	0.82	0.81	0.96	1.82	1.67
Total Alcohol	**23.66**	**20.99**	**22.00**	**23.29**	**20.26**	**20.42**	**18.48**	**21.40**	**20.73**	**19.20**	**20.57**	**21.03**
Keton (-one)												
2-Propanone	2.14	2.40	2.86	2.23	2.03	2.08	0.32	1.21	1.19	1.62	1.60	1.36
6-Methyl-5-hepten-2-one	0.64	0.60	0.53	0.43	0.87	1.14	2.65	2.21	2.85	0.47	1.17	1.37
Total Ketone	**2.78**	**3.00**	**3.39**	**2.66**	**2.90**	**3.22**	**2.97**	**3.42**	**4.04**	**2.09**	**2.77**	**2.73**
Ester (-ate)												
Acetic acid, ethyl ester	1.8	1.65	1.49	1.99	2.32	1.78	1.75	1.34	1.07	1.66	1.68	1.61
Benzoic acid. 2-hydroxy-methyl ester	0.95	0.89	1.44	0.52	0.30	0.42	–	–	–	0.30	0.55	0.33
Total Ester	**2.75**	**2.54**	**2.93**	**2.51**	**2.62**	**2.20**	**1.75**	**1.34**	**1.07**	**1.96**	**2.23**	**1.94**
Terpen (ene-ane)												
Methyl-Benzene	2.00	1.75	1.52	1.8	1.45	1.81	1.74	1.01	1.51	1.45	1.80	1.80
l-Limonene	1.34	0.72	0.74	1.32	1.29	1.79	0.89	1.29	1.4	1.11	0.90	0.97
Total Terpene	**3.34**	**2.47**	**2.26**	**3.12**	**2.74**	**3.60**	**2.63**	**2.30**	**2.91**	**2.56**	**2.70**	**2.77**

Table 3 Volatile compounds of goji berry with red solid-phase microextraction (SPME) (%)

Compound name	'HZR1' Green Red	'HZR2' Green Red	'HZR3' Green Red	'HZR1' Unripe Red	'HZR2' Unripe Red	'HZR3' Unripe Red	'HZR1' Ripe Red	'HZR2' Ripe Red	'HZR3' Ripe Red	'HZR1' Dried Red	'HZR2' Dried Red	'HZR3' Dried Red
Aldehyde (-al)												
Beta.-Cyclocitral	3.03	2.09	3.93	7.70	7.09	7.67	1.28	1.53	1.16	6.54	2.40	2.50
2-Furancarboxaldehyde	0.54	0.50	0.50	2.79	2.97	2.81	1.20	0.71	1.50	2.20	1.71	2.50
2-Hexenal	50.20	52.00	49.81	45.98	45.41	45.68	59.62	60.47	58.91	50.00	57.99	58.25
Dodecanal	3.87	3.11	2.18	2.47	2.30	2.07	3.64	2.84	4.59	3.21	1.25	2.5
Nonanal	2.87	2.31	2.28	2.61	2.90	1.23	3.28	3.67	3.67	2.48	2.70	2.00
Total Aldehyde	**60.51**	**60.01**	**58.70**	**61.55**	**60.67**	**59.46**	**69.02**	**69.22**	**69.83**	**64.43**	**66.05**	**67.75**
Alcohol (-ol)												
1-Hexanol	18.61	18.86	18.91	18.6	19.04	19.22	17.5	18.72	16.52	17.91	20.07	21.12
3-Hexen-1-ol	2.27	2.74	2.25	2.5	2.72	2.65	2.44	2.31	2.57	2.65	1.10	1.91
3-methyl-1-Butanol	3.37	3.5	3.30	0.8	0.74	0.80	1.89	1.71	1.71	0.7	0.91	0.66
L-Lınalool	1.16	1.02	1.89	1.2	1.70	1.9	0.7	0.52	1.08	1.67	1.99	2.25
Phenol	1.4	2.92	2.5	3.22	3.76	3.08	0.46	0.54	0.61	2.34	1.78	1.06
Total Alcohol	**26.81**	**29.04**	**28.85**	**26.32**	**27.96**	**27.65**	**22.99**	**23.80**	**22.49**	**25.27**	**25.85**	**27.00**
Keton (-one)												
4-methyl-6-Hepten-3-one	2.06	1.27	2.05	1.6	1.19	1.63	1.07	1.49	1.095	1.12	1.48	1.14
Neryl Acetone	0.74	0.50	0.87	0.7	0.80	0.97	0.28	0.24	0.51	0.91	0.74	0.62
Total Ketone	**2.79**	**1.77**	**2.92**	**2.30**	**1.99**	**2.60**	**1.35**	**1.73**	**1.60**	**2.03**	**2.22**	**1.76**
Ester (-ate)												
3-Hexen-1-ol. acetate	1.23	1.21	1.20	1.6	1.73	1.77	0.95	0.67	0.97	1.30	0.93	0.68
Benzoic acid, 2-hydroxy-methyl ester	3.94	3.37	3.78	2.41	2.04	2.91	1.5	1	1.28	2.05	2.41	0.5
Total Ester	**5.17**	**4.58**	**4.98**	**4.01**	**3.77**	**4.68**	**2.45**	**1.67**	**2.25**	**3.35**	**3.34**	**1.18**
Terpenler												
l-Limonene	4.71	4.61	4.54	5.8	5.60	5.61	4.19	3.57	3.84	4.92	2.52	2.31
Total Terpene	**4.71**	**4.61**	**4.54**	**5.80**	**5.60**	**5.61**	**4.19**	**3.57**	**3.84**	**4.92**	**2.52**	**2.31**

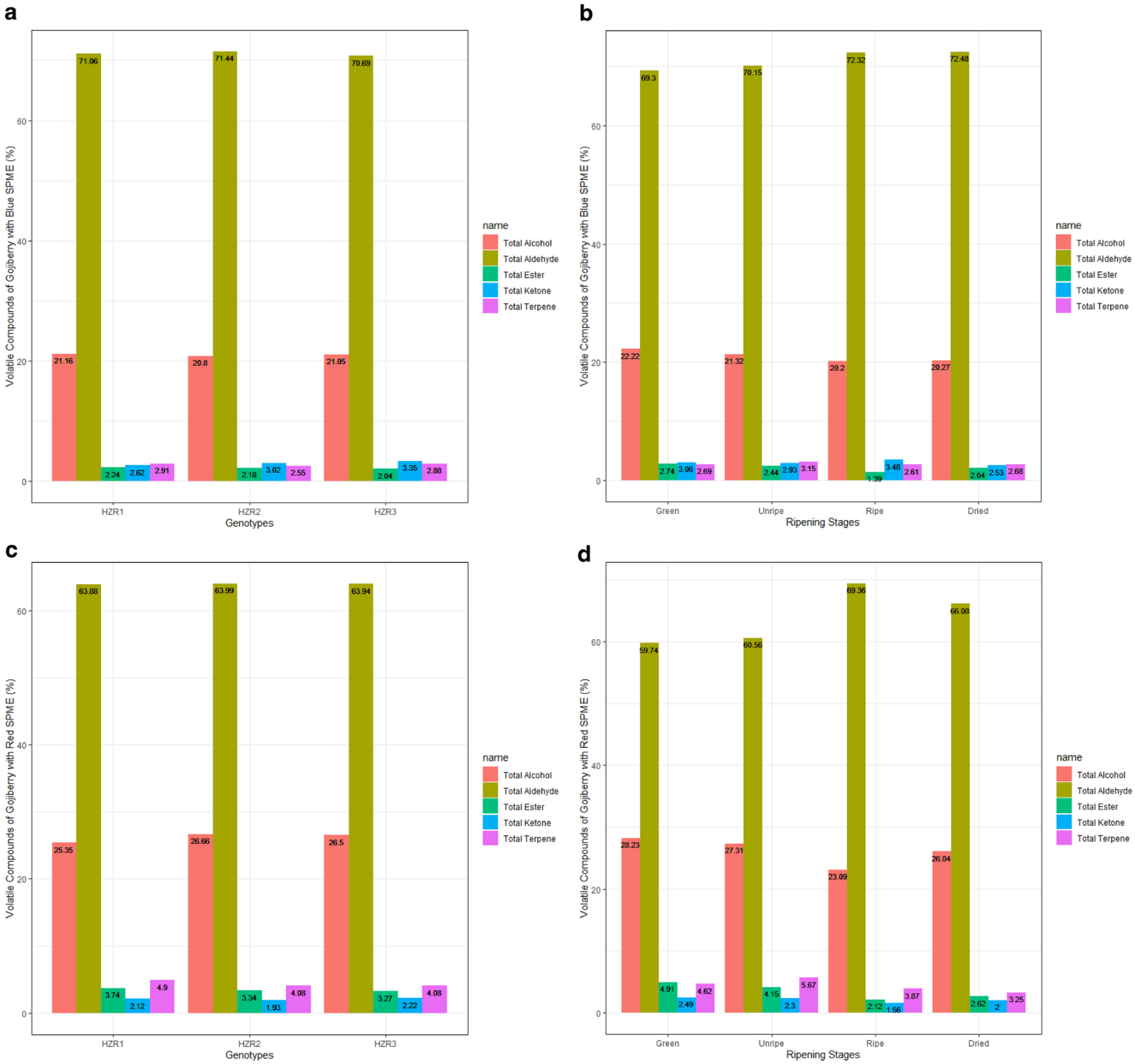


Fig. 2 Results of the present study showed that the genotypes differ from each other in terms of the contents of volatile organic compounds (VOCs). For example, the 'HZR1' cultivar was dominant with total alcohol, total ester, and total terpene, while the 'HZR2' cultivar was dominant with total aldehydes. Moreover, the highest percentage of total ketone was in "HZR3" (**a**). The 'HZR1' cultivar was dominant for total ester and total terpene, while the 'HZR2' cultivar was dominant for total aldehydes and total alcohol. The highest percentage of total ketone was "HZR3" (**c**). Results of the present study showed that the ripening stages differ from each other in terms of the contents of VOCs (**d**). The average total aldehyde content increases as the fruit ages (**b**). **a** Comparison average *Total Aldehyde*, *Total Alcohol*, *Total Ketone*, *Total Ester*, and *Total Terpene* results for different genotypes for Table 2. **b** Comparison average *Total Aldehyde*, *Total Alcohol*, *Total Ketone*, *Total Ester*, and *Total Terpene* results for different ripening stages for Table 2. **c** Comparison average *Total Aldehyde*, *Total Alcohol*, *Total Ketone*, *Total Ester*, and *Total Terpene* results for different genotypes for Table 3. **d** Comparison average *Total Aldehyde*, *Total Alcohol*, *Total Ketone*, *Total Ester*, and *Total Terpene* results for different ripening stages for Table 3

more, we have found a negligible correlation for 'HZR3' genotype with different ripening stages for Table 2 (Fig. 3c).

Table 3 shows the volatile compound proportions measured with SPME to be 100 um PDMS in goji berry. The basic components in the table are aldehydes, alcohols, ketones, esters, and terpenes. As seen in Table 3, considering the different ripening periods of goji fruit, the highest value in the aldehyde group was 2-hexenal comprising 49.81% ('HZR3')–52% ('HZR2') in the green period, 45.41% ('HZR2')–45.98% ('HZR1') in the unripe period, 58.91% ('HZR3')–60.47% ('HZR2') in the ripe period, 50.00% ('HZR1')–58.25% in the dry samples of the 'HZR3' geno-

type. The highest hexenal value was 60.47% in the ripe period identified in the 'HZR2' genotype. Considering all ripening periods for goji berry genotypes, the lowest value in the aldehyde group was for 2-furancarboxaldehyde and the lowest value was measured in the green period at 0.50% in the 'HZR2' and 'HZR3' genotypes. Additionally, the highest value in the alcohol group was for 1-hexanol with values of 18.61% ('HZR1')–18.91% ('HZR3') in the green period, 18.60% ('HZR1')–19.22% ('HZR3') in the unripe period, 16.52% ('HZR3')–18.72% ('HZR2') in the ripe period, and 17.91% ('HZR1')–21.12% ('HZR3') in the dry samples from the 'HZR3' genotype. The highest 1-hexanol value was measured as 21.12% in the 'HZR3' genotype in the dried samples. Considering all ripening periods for the goji berry genotypes, the lowest value in the alcohol group was for phenol with a minimum value of 0.46% identified in the 'HZR1' genotype in the ripe period. For the ketone group, the highest value was for 4-methyl-6-heptane-3-one with values of 1.27% ('HZR2')–2.06% ('HZR1') in the green period, 1.19% ('HZR2')–1.63% ('HZR3') in the unripe period, 1.07% ('HZR1')–1.49% ('HZR2') in the ripe period, and 1.12% ('HZR1')–1.48% in the dry samples from the 'HZR2' genotype. The highest 4-methyl-6-heptane-3-one value was measured in 'HZR1' genotype as 2.06% in the green period. Considering all ripening periods for goji berry genotypes, the lowest value in the ketone group was for neryl acetone, with a minimum value identified as 0.97% in the 'HZR3' genotype in the unripe period. In the ester group, the highest value was for benzoic acid, 2-hydroxy-methyl ester, with values of 3.37% ('HZR2')–3.94% ('HZR1') in the green period, 2.4% ('HZR2')–2.91% ('HZR3') in the unripe period, 1% ('HZR2')–1.5% ('HZR1') in the ripe period, and 0.5% ('HZR3')–2.41% ('HZR2') in the dried samples from the 'HZR2' genotype. The highest benzoic acid, 2-hydroxy-methyl ester, the value was 3.94% measured in the 'HZR' genotype in the green period. Considering all ripening periods of goji berry genotypes, the lowest value in the ester group was for 3-hexene-1-ol acetate, with a minimum value identified at 0.68% in the 'HZR3' genotype in the dried samples.

The 'HZR1' cultivar was dominant in total ester and total terpene, while the 'HZR2' cultivar was dominant with total aldehydes and total alcohol. The highest percentage of total ketone was in 'HZR3' (Fig. 2c). Results of the present study showed that the ripening stages differ from each other in terms of VOC content (Fig. 2d).

According to the results obtained, the percentages of the different groups of VOCs were found to have a strong negative correlation between "Total Ketone", "Total Aldehyde" and "Total Alcohol" and "Total Aldehyde" ($p < 0.05$). Also, "Total Ketone" and "Total Alcohol" and "Total Ketone" and "Total Ester" were positively correlated for 'HZR1' genotype with different ripening stages (green, unripe, ripe, dried) for Table 3 ($p < 0.05$) (Fig. 3d). "Total Alcohol" and "Total Aldehyde" were negatively correlated ($p < 0.05$), while "Total Ester" and "Total Alcohol" were positively correlated for the 'HZR2' genotype with different ripening stages (green, unripe, ripe, dried) for Table 3 ($p < 0.05$) (Fig. 3e). "Total Ketone" and "Total Aldehyde" were negatively correlated for 'HZR3' genotype with different ripening stages (green, unripe, ripe, dried) for Table 3 ($p < 0.05$) (Fig. 3f).

From the terpene group, 1-limonene was detected at 4.54% ('HZR3')–4.71% ('HZR1') in the green period, 5.60% ('HZR2')–5.80% ('HZR1') in the unripe period, 3.57% ('HZR2')–4.19% ('HZR1') in the ripe period, and 2.31% ('HZR3')–4.91% in the dried samples from the 'HZR2' genotype. The highest 1-limonene value considering different ripening periods was 5.80% in the unripe period measured in the 'HZR1' genotype.

As seen in Table 2, the aroma components identified in goji fruit with blue SPME were reported as 2-hexanol in the aldehyde group and 1-hexanol and 1-octen-3-ol in the alcohol group. Table 2 shows the aroma components in goji fruit detected with red SPME including β-cyclocitral, 2-hexenal, and nonanal from the aldehyde group and 1-hexanol and L-linalool from the alcohol group. In a study about the effect of volatile compounds on raw material used for wine production with dry and fresh goji fruit, pressed and glycosidase goji wine in China, basic component analysis of the wine raw material found 20 esters, nine enzymes, eight aldehydes/ketones, three acids, two alcohols, and six other volatiles. The wine fermented from dried goji fruit contained 56 volatile aromatic components, while wine obtained from the fermentation of fresh goji fruit was identified to contain 31 volatile aromatic compounds (Yuan et al. 2016; Zhong et al. 2013). Research in China to determine the organoleptic and aromatic properties of wine obtained from fermented goji fruit obtained 75 peaks and 57 volatile aroma compounds during analysis with headspace-trap GC using an MS device. The components included compounds like aliphatic alcohol, aliphatic aldehydes, aliphatic ketones, furan, and aliphatic hydrocarbon. Among these 57 compounds, the compounds 1-hexanol, 1-octen-3-ol, limonene, nonanal, and beta-cyclocitral were also identified in our study. Additionally, in this study, acetic acid was the ingredient with the best peak (48.33%), with 1-methoxy-2-propanone (8.84%), 3-hydroxy-2-butanone (9.99%), and ethyl lactate (12.97%) reported as basic compounds. Another study using different SPMEs (PDMS/DVB pink, DVB/CAR/PDMS gray) identified five volatile aroma compounds in goji berry with the aid of headspace SPME-GC isotope ratio mass spectrometry (HSSPME GC-IRMS). The results of the analyses found limonene, tetramethylpyrazine, safranal, geranyl acetone,

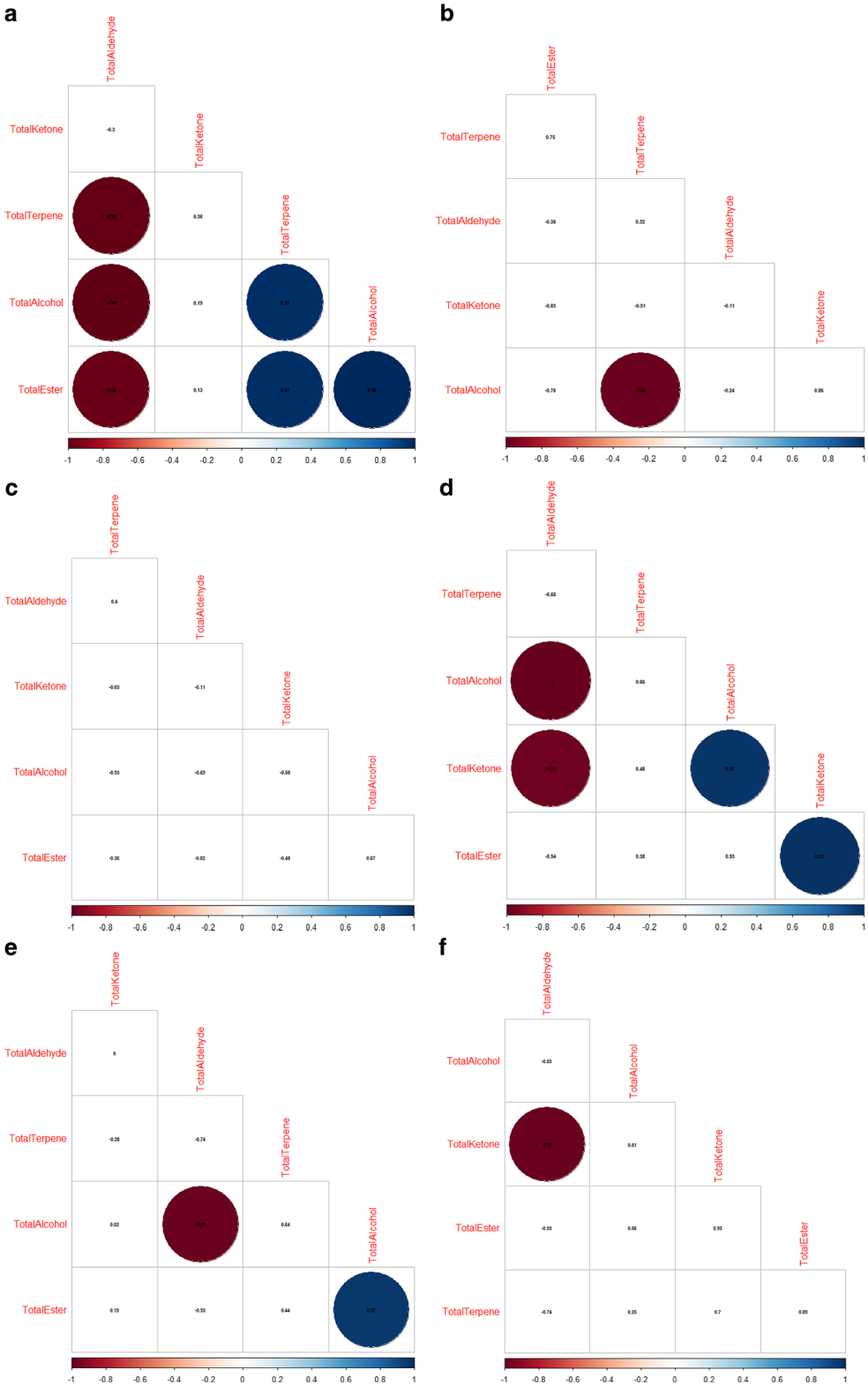

a
TotalAldehyde
TotalKetone
TotalTerpene
TotalAlcohol
TotalEster
b
TotalEster
TotalTerpene
TotalAldehyde
TotalKetone
TotalAlcohol
c
TotalTerpene
TotalAldehyde
TotalKetone
TotalAlcohol
TotalEster
d
TotalAldehyde
TotalTerpene
TotalAlcohol
TotalKetone
TotalEster
e
TotalKetone
TotalAldehyde
TotalTerpene
TotalAlcohol
TotalEster
f
TotalAldehyde
TotalAlcohol
TotalKetone
TotalEster
TotalTerpene
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1

Fig. 3 According to the results obtained, the percentages of the different groups of volatile organic compounds (VOCs) were found to have a strong negative correlation between *TotalTerpene* and *TotalAldehyde* and *TotalAlcohol* and *TotalAldehyde* and *TotalEster* and *TotalAldehyde* ($p < 0.05$). Also, *TotalTerpene* and *TotalAlcohol* and *TotalTerpene* and *TotalEster* and *TotalAlcohol* and *TotalEster* were positively correlated ($p < 0.05$) (**a**). *TotalTerpene* and *TotalAlcohol* were negatively correlated for the 'HZR2' genotype with different ripening stages (green, unripe, ripe, dried) for Table 2 ($p < 0.05$) (**b**). Also we have found a negligible correlation for the 'HZR3' genotype with different ripening stages for Table 2 (**c**). We found a strong negative correlation between *TotalKetone* and *TotalAldehyde* and *TotalAlcohol* and *TotalAldehyde* ($p < 0.05$). Also, *TotalKetone* and *TotalAlcohol* and *TotalKetone* and *TotalEster* were positively correlated ($p < 0.05$) (**d**). *TotalAlcohol* and *TotalAldehyde* were negatively correlated ($p < 0.05$), while *TotalEster* and *TotalAlcohol* were positively correlated (**e**). *TotalKetone* and *TotalAldehyde* were negatively correlated ($p < 0.05$) (**f**). **a** Correlation among the volatile compounds of goji berry with blue solid-phase microextraction (SPME) (%) for the 'HZR1' genotype with different ripening stages (green, unripe, ripe, dried) for Table 2. **b** Correlation among the volatile compounds of goji berry with blue SPME (%) for the 'HZR2' genotype with different ripening stages (green, unripe, ripe, dried) for Table 2. **c** Correlation among the volatile compounds of goji berry with blue SPME (%) for the 'HZR3' genotype with different ripening stages (green, unripe, ripe, dried) for Table 2. **d** Correlation among the volatile compounds of goji berry with blue SPME (%) for the 'HZR1' genotype with different ripening stages (green, unripe, ripe, dried) for Table 3. **e** Correlation among the volatile compounds of goji berry with blue SPME (%) for the 'HZR2' genotype with different ripening stages (green, unripe, ripe, dried) for Table 3. **f** Correlation among the volatile compounds of goji berry with blue SPME (%) for the 'HZR3' genotype with different ripening stages (green, unripe, ripe, dried) for Table 3

and β-ionone. In conclusion, the use of DVB/CAR/PDMS gray was reported to provide better results compared to PDMS/DVB pink SPME use (Meng et al. 2019). A study completed by Lu et al. (2017) detected volatile aroma compounds in goji fruit grown in the Ningxia region of China with GC-MS, aroma dilution analysis, and gas chromatography-olfactometry using SPME DVB/CAR/PDMS gray (Supelco Co., Bellefonte, PA, USA). According to this study, of the 56 compounds they identified, 70–94% were hexanal and (E)-2-hexenal. In our study, the results obtained with SPME 85 um CAR/PDMS light blue (Supelco Co., Bellefonte, PA, USA) and SPME 100 um PDMS (Supelco Co., Bellefonte, PA, USA) identified 2-hexenal at the highest level. According to the results of this study, the general characteristic aroma compounds in goji fruit were reported to be hexanal, (E)-2-hexenal, nonanal, isoamylol, 1-hexanol, 1-octen-3-ol, hexyl acetate, methyl salicylate, ethyl octanoate, o-cymene, d-limonene, linalool, β-cyclocitral, β-elemene, and 2-pentylfuran. Kim and Chung (2009) identified 130 volatile compounds in a study on dried *Lycium chinensis* Miller and obtained eight acids, 21 alcohols, 23 aldehydes, 10 alkanes, five aromatics, 15 esters, seven furans, 21 ketones, three miscellaneous compounds, two naphthalenes, three phenols, two pyrazines, and 10 terpenes. A study by Altintas et al. (2006) found hexadecanoic acid (47.5%), β-elemene (5.4%), myristic acid (4.2%), and ethyl hexadecanoate (4.0%) in oil samples obtained from the fruit of *Lycium barbarum,* and heptacosane (14.3%), ethyl linoleate (10.0%), hexacosane (7.0%), nonacosane (6.2%), and ethyl hexadecanoate (5.8%) in the oil of fruit obtained from *L. ruthenicum*. In this study, limonene 0.2% was identified in oil obtained from the *Lycium barbarum* species. The limonene data obtained in our study were found to be higher than in the literature data.

Conclusions

In the study, considering the averages for the periods in terms of protein content, the highest protein was obtained in the green period, with the lowest protein in the ripe period. When averages for genotypes in terms of protein content are considered, the highest was obtained for the 'M1 ALTUNİ' genotype, with the lowest identified in the 'HZR1' genotype. In this study, the genotype emerging in terms of protein was the 'M1 ALTUNİ' genotype.

Volatile compounds identified in goji fruits from different ripening periods measured with the blue SPME fiber identified the aldehyde group. At different ripening periods of goji fruit, the highest value in the aldehyde group was for 2-hexenal in dried samples from the 'HZR1' genotype. Also, for the alcohol group in different ripening periods of the goji fruit, the highest value was for 1-hexanol in the ripe period ('HZR1'). The highest 1-hexanol value was determined in the 'HZR1' genotype in the ripe period. Additionally, for the ketone group considering different ripening periods for goji berry, the highest value was for 2-propanone in the green period ('HZR2'). The highest 2-propanone value was obtained in the 'HZR3' genotype in the green period. The highest acetic acid ethyl ester value was identified in the 'HZR' genotype in the unripe period. Additionally, considering different ripening periods of goji fruit, the highest value for the terpene group was for methylbenzene in the green period ('HZR1').

Considering different ripening periods of goji fruit measured with red SPME, the highest value in the aldehyde group was for 2-hexenal in the green period ('HZR2'). The highest hexenal value was determined in the ripe period of the 'HZR2' genotype. Considering all ripening periods of goji berry genotypes, the lowest value in the aldehyde group was for 2-furancarboxaldehyde, with minimum values identified in the green period in 'HZR2' and 'HZR3' genotypes. Moreover, the highest value in the alcohol group was for 1-hexanol values in the green period ('HZR3'). The

highest was the 1-hexanol value measured in the 'HZR' genotype in the dried samples. For the ketone group, the highest value was for 4-methyl-6-heptane-3-one values in the green period ('HZR1'). The highest 4-methyl-6-heptane-3-one value was measured in the 'HZR1' genotype in the green period. From the ester group, the highest value was for benzoic acid, 2-hydroxy-methyl ester, with a value ('HZR1') in the green period. The highest was benzoic acid, 2-hydroxy-methyl ester value was detected in the 'HZR1' genotype in the green period. From the terpene group, 1-limonene had values in the green period ('HZR1'). The highest 1-limonene value considering different ripening periods was identified in the 'HZR1' genotype in the unripe period.

In conclusion, in terms of volatile compounds, 2-hexanal from the aldehyde group and 1-hexanol and 1-octen-3-ol from the alcohol group were among the leading aroma compounds identified in goji fruit with the blue SPME. For the goji fruit measured with the red SPME, β-cyclocitral, 2-hexenal, and nonanal in the aldehyde group and 1-hexanol and L-linalool from the alcohol group were the leading aroma compounds identified in goji fruit.

Acknowledgements This study was supported by the Scientific Research Projects (BAP) of the University of Çukurova, Project No: FYL-2018-11128 and HZR Nursery Company (Aksaray), Republic of Turkey.

Author Contribution İlbilge Oğuz: Formal analysis, References, Writing—original draft. Halil İbrahim Oğuz: Conceptualization, Investigation. Nesibe Ebru Kafkas: Methodology, Writing—review & editing, Supervision, Project administration. İpek Ürün Değirmenci: Data curation Şule Hilal Attar: Validation Sema Atasever: Visualization.

Declarations

Conflict of interest İ. Oğuz, H.İ. Oğuz, İ.Ü. Değirmenci, Ş.H. Attar, S. Atasever, and N.E. Kafkas declare that they have no competing interests.

References

Adams M, Wiedenmann M, Tittel G, Bauer R (2006) HPLC-MS trace analysis of atropine in Lycium barbarum berries. Phytochem Anal 17:279–283. https://doi.org/10.1002/pca.915

Altintas A, Kosar M, Kirimer N, Baser KHC, Demirci B (2006) Composition of the Essential Oils of Lycium barbarum and L. ruthenicum Fruits. Chem Nat Compd 42(1):24–25. https://doi.org/10.1007/s10600-006-0028-3

Amagase H, Farnsworth NR (2011) A review of botanical characteristics, phytochemistry, clinical relevance in efficacy and safety of Lycium barbarum fruit (Goji). Food Res Int 44:10702–11717. https://doi.org/10.1016/j.foodres.2011.03.027

Amagase H, Sun B, Borek C (2009) Lycium barbarum (Goji) Juice Improves in Vivo Antioxidant Biomarkers in Serum of Healthy Adults. Nutr Res 29:19–25. https://doi.org/10.1016/j.nutres.2008.11.005

Chen F, Su Y, Zhang F, Guo Y (2015) Low-temperature headspace-trap gas chromatography with mass spectrometry for the determination of trace volatile compounds from the fruit of Lycium barbarum L. J Sep Science 38(4):670–676. https://doi.org/10.1002/jssc.201400862

Covaci E, Senila M, Leopold LF, Olah NK, Cobzac C, Ivanova-Petropulos V, Frentiu T (2020) Characterization of Lycium barbarum L. berry cultivated in North Macedonia: a chemometric approach. J Berry Res 10(2):223–241. https://doi.org/10.3233/JBR-190450

Gan L, Zhang SH, Yang XL, Xu HB (2004) Immunomodulation and antitumor activity by a polysaccharide-protein complex from Lycium barbarum. Int Immunopharmacol 4(4):563–569. https://doi.org/10.1016/j.intimp.2004.01.023

Ilić T, Dodevska M, Marčetić M, Božić D, Kodranov I, Vidović B (2020) Chemical characterization, antioxidant and antimicrobial properties of goji berries cultivated in Serbia. Foods 9(11):1614. https://doi.org/10.3390/foods9111614

Kafkas E, Sönmez DA, Oğuz İB (2018) Comparison of strawberry (F.× ananassa Florida Fortuna) volatiles using various SPME fibers by GC/MS techniques. In: XXX International Horticultural Congress IHC2018: III International Berry Fruit Symposium 1265, pp 287–292 https://doi.org/10.17660/ActaHortic.2019.1265.40

Kafkas E, Attar SH, Gundesli MA, Ozcan A, Ergun M (2020) Phenolic and fatty acid profile, and protein content of different walnut cultivars and genotypes (Juglans regia L.) grown in the USA. Int J Fruit Sci 20(sup3):S1711–S1720. https://doi.org/10.1080/15538362.2020.1830014

Kim JS, Chung HY (2009) GC-MS analysis of the volatile components in dried boxthorn (Lycium chinensis) fruit. J Korean Soc Appl Biol Chem 52(5):516–524. https://doi.org/10.3839/jksabc.2009.088

Lu J, Li H, Quan J, An W, Zhao J, Xi W (2017) Identification of characteristic aroma volatiles of Ningxia goji berries (Lycium barbarum L.) and their developmental changes. Int J Food Prop 20(sup1):S214–S227. https://doi.org/10.1080/10942912.2017.1295254

Lu Y, Guo S, Zhang F, Yan H, Qian DW, Shang EX, Duan JA (2021) Nutritional components characterization of Goji berries from different regions in China. J Pharm Biomed Anal 195:113859. https://doi.org/10.1016/j.jpba.2020.113859

Meng J, Liu Z, Gou CL, Rogers KM, Yu WJ, Zhang SS, Zhang L (2019) Geographical origin of Chinese wolfberry (goji) determined by carbon isotope analysis of specific volatile compounds. J Chromatogr B 1105:104–112. https://doi.org/10.1016/j.jchromb.2018.12.011

Niro S, Fratianni A, Panfili G, Falasca L, Cinquanta L, Alam MDR (2017) Nutritional evaluation of fresh and dried goji berries cultivated in Italy. Italian J Food Sci. https://doi.org/10.14674/1120-1770/ijfs.v649

Oğuz HI (2019) History, botanical characteristic features, beneficial of human health and general using ways of Wolfberry, 1st edn. Gece Publishing, pp 77–92

Oğuz İ, Oğuz HI, Kafkas NE (2021) Evaluation of fruit characteristics of various organically-grown goji berry (Lycium barbarum L., Lycium chinense Miller) species during ripening stages. J Food Compos Analysis 101:103846. https://doi.org/10.1016/j.jfca.2021.103846

Oğuz İ, Oğuz HI, Kafkas NE (2022) Miracle fruit from a medical perspective: Goji berry (Lycium spp.). Curr Funct Foods. https://doi.org/10.2174/2666862901666220127140658

Pedro AC, Sánchez-Mata MC, Pérez-Rodríguez ML, Cámara M, López-Colón JL, Bach F, Haminiuk CWI (2019) Qualitative and nutritional comparison of goji berry fruits produced in organic and conventional systems. Sci Hortic 257:108660. https://doi.org/10.1016/j.scienta.2019.108660

Potterat OG (2010) Phytochemistry, pharmacology and safety in the perspective of traditional uses and recent popularity. Planta Med 76(1):7–19. https://doi.org/10.1055/s-0029-1186218

Pozo-Bayon MA, Biais B, Rampon V, Cayot N, Le Bail P (2008) Influence of complexation between amylose and a flavored model sponge cake on the degree of aroma compound release. J Agric Food Chem 56(15):6640–6647. https://doi.org/10.1021/jf800242r

https://www.rstudio.com/. Accessed 22 Mar 2022

Rybicka I, Kiewlicz J, Kowalczewski PŁ, Gliszczyńska-Świgło A (2021) Selected dried fruits as a source of nutrients. Eur Food Res Technol 247(10):2409–2419. https://doi.org/10.1007/s00217-021-03802-1

Steel RGD, Torrie JH, Dickey DA (1997) Principles and procedures of statistics: a biometrical approach. 3rd ed. McGraw Hill Book Co. Inc., New York, pp 400–428

Talay R, Erdoğan Ü, Turan M (2021) Physico-chemical Properties, Mineral Matter, Organic Acid, Amino Acid, and Plant Hormones Content of Goji Berry (Lycium barbarum L.) Grown in Turkey. Turk J Agric Sci Technol. https://doi.org/10.24925/turjaf.v9i10.1889-1894.4566

Yuan G, Ren J, Ouyang X, Wang L, Wang M, Shen X, Zhu B (2016) Effect of raw material, pressing and glycosidase on the volatile compound composition of wine made from goji berries. Molecules 21(10):1324. https://doi.org/10.3390/molecules21101324

Zhang Q, Chen W, Zhao J, Xi W (2016) Functional constituents and antioxidant activities of eight Chinese native Goji genotypes. Food Chem 200:230–236. https://doi.org/10.1016/j.foodchem.2016.01.046

Zhao J, Li H, Xi W, An W, Niu L, Cao Y, Yin Y (2015a) Changes in sugars and organic acids in wolfberry (Lycium barbarum L.) fruit during development and maturation. Food Chem 173:718–724. https://doi.org/10.1016/j.foodchem.2014.10.082

Zhao Q, Dong B, Chen J, Zhao B, Wang X, Wang L, Wang Y (2015b) Effect of drying methods on physicochemical properties and antioxidant activities of wolfberry (Lycium barbarum) polysaccharide. Carbohydr Polym 127:176–181. https://doi.org/10.1016/j.carbpol.2015.03.041

Zhong Y, Shahidi F, Naczk M (2013) Phytochemicals and health benefits of goji berries. In: Alasalvar C, Shahidi F (eds) Dried Fruits:Phytochemicals and Health Effects. Blackwell, Oxford, UK, pp 133–144 https://doi.org/10.1002/9781118464663.ch6

Springer Nature oder sein Lizenzgeber (z.B. eine Gesellschaft oder ein*e andere*r Vertragspartner*in) hält die ausschließlichen Nutzungsrechte an diesem Artikel kraft eines Verlagsvertrags mit dem/den Autor*in(nen) oder anderen Rechteinhaber*in(nen); die Selbstarchivierung der akzeptierten Manuskriptversion dieses Artikels durch Autor*in(nen) unterliegt ausschließlich den Bedingungen dieses Verlagsvertrags und dem geltenden Recht.

View publication stats