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Original Research Article

# Evaluation of fruit characteristics of various organically-grown goji berry (*Lycium barbarum* L., *Lycium chinense* Miller) species during ripening stages

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ABSTRACT

The fruits of three *Lycium barbarum* genotypes (HZR1, HZR2, HZR3) and a *Lycium chinense* genotype (M1 ALTUNİ) harvested at various ripening stages (green, unripe, ripe) were compared based on some pomological properties (fruit length, width, weight, colour, total soluble solid content and titratable acidity) and chemical compounds (sugars, organic acids, vitamin C). Glucose was the predominant sugar followed by fructose and sucrose, respectively, except at the green maturation stage. The results suggest that the best results for all genotypes and ripening stages were provided by the M1 ALTUNİ genotype in terms of sugar contents. Succinic acid was the most abundant acid followed by citric and malic acid in all goji berry genotypes. If goji berry fruits are to be used for pharmacologic purposes, the most appropriate consumption stage is the green stage for organic acids and the dried stage for sugar, total soluble solids and L-ascorbic acid content.

## 1. Introduction

Goji berry (*Lycium barbarum* L.), also known as "Wolfberry", is native to China, and is most commonly grown in Tibet, Mongolia and the Himalayas. The goji berry fruit has a high capacity in terms of both nutrients and antioxidants; hence, it is a fruit consumed for human health and nutrition (Amagase and Nance, 2008; Kulczyński and Michałowska, 2016; Oğuz et al., 2019). From a botanical point of view, it is a member of the *Solanaceae* family and the most common species are *Lycium barbarum, Lycium chinense,* and *Lycium ruthenicum* (Jing et al., 2004). The interest in the berries was also popularised because of increased awareness about possible health benefits, as they are rich sources of aromatic compounds, micronutrients and phytochemicals, such as organic acids, sugars, and phenolic compounds (Mikulic-Petkovsek et al., 2012).

Organic acids contribute to the organoleptic characteristics of food and beverages by providing flavour, colour and aroma (Derouich et al., 2020; Flores et al., 2012). Once the effect of goji berry on human health and nutrition became globally recognised, several studies were conducted about the pomological and biochemical contents of this fruit. The antioxidants in goji berry (*Lycium* spp.) fruits might provide health-protective effects by reducing oxidative stress (Donno et al., 2015). Goji berries are perfect sources of carotenoids, mainly zeaxanthin, that represents 31–56 % of total carotenoids. The berries have lower amounts of neoxanthin, cryptoxanthin, and ß-carotene (Peng et al., 2005; Wang et al., 2010), which are natural pigments responsible for yellow, orange, and red colours (Amagase et al., 2009). Furthermore, goji berries are rich in L-ascorbic acid (Llorent-Martínez et al., 2013), thiamine and vitamins E, B1, B2, and B6 (Wojdyło et al., 2018). The aim of this study was to evaluate two organically-grown goji berry species (*L. barbarum* L., *L. chinense* Miller) based on some pomological features (fruit length, fruit width and fruit weight, fruit colour, total soluble solid content and titratable acids) and chemical compounds (sugars, organic acids and vitamin C).

## 2. Samples and methods

### 2.1. Samples

Sampling began in the first week of June 2018 and lasted until September 2018. Fruit samples were collected from the goji berry plantation at different ripening stages (green, unripe, ripe) and also dried fruits were examined. The plantation experimental design was in randomised blocks with 3 replications and 20 plants in each replication and a planting interval of 3 × 1.5 m. Samples weighing 500 g were harvested in each stage and analysed at the Instrumental Analysis

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Laboratory of the University of Çukurova Faculty of Agriculture Department of Horticulture within a cold chain. The green, unripe, ripe and dried fruit samples from 2 goji berry species were used as experimental materials. The materials were harvested at green (5 days after full flowering date), unripe (20 days after full flowering date) and ripe (35 days after full flowering date) stages (Fig. 1).

#### 2.1.1. HZR1 genotype

This belongs to *L. barbarum* L. species and has the least amount of thorns, an oval fruit shape, and red fruit colour.

#### 2.1.2. HZR2 genotype

This belongs to *L. barbarum* L. species and has the bulkiest and longest fruit characteristics and bulkier leaves.

#### 2.1.3. HZR3 genotype

This belongs to *L. barbarum* L. species produced from the seeds of NQ-1 cultivar. It has the smallest fruits. It has a higher yield compared to the other genotypes. It has a high prickliness rate, is difficult to harvest and ripens later than the other genotypes.

#### 2.1.4. M1 ALTUNİ genotype

This belongs to *L. chinense* Miller species and has yellow-coloured fruits. The fruit shape is oval and fruit bulkiness is similar to HZR2. It is also an early riser and has average prickliness level.

Goji berry fruits maturing in the harvest season were spread on racks made with Teflon wires in wooden frames with size 80 × 90 cm after harvesting. These fresh fruits were left in the shade on these racks for nearly 1 day. Later the racks were taken to drying rooms, placed on shelves with 10 cm gaps between them and left to dry. Hot air drying is a method of drying with a drying machine (HDSD120B-D, Haiti Sheng Machinery Co. Ltd., Liaoning, China) which heats the air in a hot-blast stove and sends the hot air toward the fresh fruits. Goji berries were first heated at 40–45 ℃ with an air flow speed of 0.15 m/s for about 6 h, then at 60 ℃ with an air flow speed of 0.35 m/s for 6 h, and finally at 65 ℃ with air flow speed of 0.25 m/s for about 20 h. Above all, this method has the advantages of low cost, large processing capacity and easy operation, but also causes losses and low quality (Zhao et al., 2015a,b).

### 2.2. Methods

The pomological properties of the samples were determined from 100 fruit samples collected from each replicate and weighed to 0.01 mg precision. The fruit width (mm) and fruit length (mm) were measured by using a calliper device (Insize Range 1123−150A, USA). Colour measurement was performed by a Chroma meter (Konica-Minolta CR 400, Japan) by employing the L* (lightness), a* [from green (−) to red (+)], b* [from blue (−) to yellow (+)], C (chroma), and hue° (hue angle) values of Bakker et al. (1986). Fruits were homogenized in a mortar with liquid nitrogen and immediately frozen and stored at -80 ℃ before analysis. The same homogenates were used for further analysis in each replicate.

#### 2.2.1. Determination of sugar, organic acids, vitamin C analysis by HPLC

For sugars, approximately 500 g of each fresh and dry sample was used and each replicate was prepared separately from this homogenized material. A sample of 1 g was weighed and powdered with liquid nitrogen in a mortar and then transferred to a screw cap Eppendorf tube with 20 mL of aqueous 80 % ethanol. The reaction mixture was placed in an ultrasonic bath and sonicated for 15 min at 80 °C, then filtered and the extraction procedure was repeated three times more. All the filtered extracts were combined and evaporated to dryness on a steam bath. The residue was dissolved with 2 mL of distilled water and filtered before HPLC analysis (Miron and Schaffer, 1991). From the same homogenate described above, 1 g of fresh and dry samples were weighed and powdered with liquid nitrogen in a mortar and mixed with 20 mL of aqueous meta-phosphoric acid (3%) at room temperature for 30 min using a shaker for carboxylic acid and vitamin C detections. The acidic extract was filtered and made up to 25 mL with the same solvent, then used for HPLC analysis (Bozan et al., 1997). Sugars and organic acids were identified and quantified by high-performance liquid chromatography (HPLC) (Shimadzu LC 10A vp) coupled to RID and UV detectors. Individual sugars were detected using a Nucleosil $NH_2$ analytical column (150 mm × 4.6 mm i.d., 5 µm) (Shimadzu, Japan) at room temperature with a flow rate of 1 mL/min using 75 % aqueous acetonitrile. For organic acids, a 250 mm × 4.6 mm i.d., 5 µm, reversed-phase Ultrasphere ODS analytical column (Beckman, USA) operating at room temperature with a flow rate of 1 mL/min was used with 0.5 % aqueous meta-phosphoric acid as the eluent. Sugars and acids, together with small amounts of dissolved vitamins, as well as fructans, proteins, pigments, phenolics, and minerals, are commonly referred to as soluble solids. The total soluble solids in samples were detected using a hand refractometer as “degrees Brix” (Brix), which is equivalent to percentage (%). In these experiments, total soluble solids (%) of samples were measured using the same samples as those used in HPLC experiments after extraction.

Homogenized samples of 1 g were weighed and shaken with 10 mL double-distilled water using a horizontal shaker for 5 min at room temperature. Supernatants were filtered using 0.45 µm nylon HPLC filter and measured using an ATAGO PAL 1 digital refractometer (Yoon et al., 2020).

### 2.3. Statistical analyses

The experiment was performed with a completely randomised experimental block design in three replications for four different genotypes and four stages (green, unripe, ripe, dried) in each replicate. Numerical calculations were performed with Microsoft® Office Excel for Mac®, version 11.1, 2004 (Microsoft® Corporation, Redmond, WA). The data were analysed with the statistical program JMP version 5.0.1 (SAS Institute Inc., Cary, NC, USA). ANOVA was performed to determine the effects of the genotypes on certain pomological and chemical parameters. A least significant difference test (LSD) was performed to examine the differences among genotypes and comparisons of pomological and chemical compounds and $p \leq 0.05$ was considered




**Fig. 1.** Fruits of HZR1, HZR2, HZR3, M1 ALTUNI genotypes in different ripening stages.

statistically significant. In addition, correlations among all the obtained results were examined with multivariate methods with the statistical program JMP version 5.0.1, with $p \leq 0.05$ as a threshold (Steel et al., 1997).

## 3. Results and discussion

### 3.1. Changes in pomological characteristics during ripening stages

The results for fruit width, fruit length and fruit weight values of goji berry genotypes in different ripening stages are given in Table 1. A statistically significant difference was observed among the genotypes based on their ripening stages in terms of their fruit width, fruit length and fruit weight values ($p < 0.05$). Furthermore, a statistically significant difference was observed between genotypes and genotype X stage interaction in terms of fruit width (mm), fruit length (mm) and fruit weight values (g/100 fruit) ($p < 0.05$).

As indicated in Table 1, when fruits were harvested at the green ripening stage, fruit widths were 4.04 mm (HZR3) - 4.59 mm (HZR2); fruits collected in the unripe stage had fruit widths of 5.88 mm (HZR3) - 7.76 mm (M1 ALTUNİ); while fruits collected in the ripe stage had fruit widths of 8.23 mm (HZR3) - 12.0 mm (HZR1). In a study conducted in Denizli during 2015–2017 by Çolak et al. (2019), the fruit width for ripe *L. barbarum* was determined to be 11.17 mm. In an earlier study, Donno et al. (2015) examined the pomology characteristics of ripe fruits of 3 genotypes from *L. barbarum* and *L. chinense* and reported fruit width values ranging from 6.98 to 10.30 mm. In this respect, our study arrived at similar conclusions as in the previous literature. A study conducted in Romania by Mencinicopschi and Bălan (2013) on goji berry varieties found $V_1$ had a fruit width of 7 mm, while $V_2$ had a fruit width of 8 mm, similarly to our findings. Çatav (2019) reported fruit width values ranging between 8.55–9.66 mm. Our fruit width findings acquired from the genotypes analysed in our study are similar to those published in the previous literature.

**Table 1**
Fruit width (mm), fruit length (mm) and fruit weight values (g/100 fruit) for goji berry fruits in different ripening stages.

| | Genotypes | Ripening Stages | | | |
|---|---|---|---|---|---|
| | | Green | Unripe | Ripe | Average |
| Fruit width (mm) | HZR3 | 4.04 ± 0.20 h | 5.88 ± 0.88 g | 8.23 ± 0.97 d | 6.05 **D** |
| | HZR1 | 4.55 ± 0.32 h | 7.13 ± 0.68 ef | 12.0 ± 1.1 a | 7.89 **A** |
| | HZR2 | 4.59 ± 0.23 h | 6.67 ± 0.86 f | 9.04 ± 0.98 c | 6.77 **C** |
| | M1 ALTUNİ | 4.21 ± 0.42 h | 7.76 ± 0.47 de | 9.83 ± 0.10 b | 7.27 **B** |
| | Average of Stage | 4.34 C | 6.86 B | 9.77 A | |
| | LSD | $LSD_{gen}$* = 0.384 $LSD_{stage}$* = 0.332 $LSD_{genxstage}$* = 0.666 | | | |
| Fruit Length (mm) | HZR3 | 12.4 ± 2.7 g | 18.7 ± 1.8 e | 13.5 ± 1.4 g | 14.9 **C** |
| | HZR1 | 19.2 ± 2.2 cde | 22.2 ± 2.5 ab | 22.4 ± 2.0 ab | 21.3 **A** |
| | HZR2 | 18.8 ± 1.9 de | 21.0 ± 3.3 bc | 23.5 ± 1.6 a | 21.1 **A** |
| | M1 ALTUNİ | 15.5 ± 2.1 f | 19.1 ± 2.1 cde | 20.6 ± 1.7 bcd | 18.4 **B** |
| | Average of Stage | 16.5 B | 20.2 A | 20.0 A | |
| | LSD | $LSD_{gen}$* = 1.105 $LSD_{stage}$* = 0.957 $LSD_{genxstage}$* = 1.914 | | | |
| Fruit Weight (g/100 fruit) | HZR3 | 8.40 ± 0.01 ı | 24.4 ± 0.0 h | 45.7 ± 0.0 d | 26.2 **D** |
| | HZR1 | 16.0 ± 0.0 L | 34.2 ± 0.0 e | 84.5 ± 0.0 a | 44.9 **A** |
| | HZR2 | 15.3 ± 0.0 j | 30.1 ± 0.0 g | 67.1 ± 0.6 b | 37.5 **B** |
| | M1 ALTUNİ | 12.3 ± 0.1 k | 31.3 ± 0.0 f | 65.9 ± 0.6 c | 36.7 **C** |
| | Average of Stage | 13.2 C | 30.0 B | 65.8 A | |
| | LSD | $LSD_{gen}$* = 0.227 $LSD_{stage}$* = 0.196 $LSD_{genxstage}$* = 0.393 | | | |

(1): The differences between the averages are shown by separate letters.
(2): N.S.: Not Significant ***:$p < 0.001$; **:$p<0.01$; * :$p < 0.05$.

In consideration of the ripening stage of different genotypes, the largest fruit length value was observed in the ripe stage HZR2 genotype at 23.5 mm. A comparison of fruit lengths in green stage indicated average fruit lengths ranging between 12.4 mm (HZR3) - 19.2 mm (HZR1). Çolak et al. (2019) conducted a study in Denizli in 2015–2017 and reported 21.50 mm fruit length for fresh fruit samples of a *L. barbarum* cultivar. In their study in Italy, Donno et al. (2015) reported the fruit length of 3 genotypes from *L. barbarum* and *L. chinense* ranged between 10.01–12.57 mm. Another study by Oğuz and Erdoğan (2016) in Adıyaman province reported a fruit length of 15.78 mm in the NQ1 variety and 11.57 mm in the Damaye variety. Çatav (2019) reported fruit length values ranging between 15.09 mm – 25.89 mm. The fruit length values acquired from the genotypes in our study are similar to those reported in the literature.

As indicated in Table 1, the average fruit weights in the green, unripe and ripe stages ranged from 8.40 g/100 fruit (HZR3) to 16.0 g/100 fruit (HZR1), from 24.4 g/100 fruit (HZR3) to 34.2 g/100 fruit (HZR1), and from 45.7 g/100 fruit (HZR3) to 84.5 g/100 fruit (HZR1), respectively. Çolak et al. (2019) observed an average fruit weight of 132 g/100 fruit. A study in Adıyaman province reported fruit weight values of 70 g/100 fruit for NQ1 and 43 g/100 fruit for the Damaye varieties (Oğuz and Erdoğan, 2016). Another study conducted in Romania by Mencinicopschi and Bălan (2013) on $V_1$ and $V_2$ goji berry varieties indicated a fruit weight average of 30 and 40 g/100 fruit for the $V_1$ and $V_2$ variety, respectively. Çatav (2019) reported *L. barbarum* fruit weight values ranging between 66 g and 112 g/100 fruit. Concerning the whole literature, the fruit weights of the genotypes used in our study were sometimes different than those mentioned in the literature, but most of the time, they were similar. The reasons for this could be the genotypes, ecology, maintenance conditions and different practices.

### 3.2. Changes in colour characteristics during ripening stages

Based on the ripening stages of different wolfberry genotypes, the L*, a*, b*, C external colour density, external colour hue angle changes and external colour brightness values in fruit are given in Table 2. A statistically significant difference was observed between genotypes in terms of L*, a*, b*, C external colour density, external colour brightness values and external colour hue angle changes ($p < 0.05$). Furthermore, a statistically significant difference was observed between genotypes and genotype X stage interaction in terms of fruit external colour brightness L*, a*, b*, external colour density C and external colour hue angle values ($p < 0.05$).

As indicated in Table 2, the average L* values ranged from 35.4 (M1 ALTUNİ) to 40.8 (HZR1) in green stage fruits, from 35.4 (HZR1) to 40.3 (M1 ALTUNİ) in the unripe stage, from 33.0 (HZR3) to 40.1 (M1 ALTUNİ) in the ripe stage and from 26.4 (HZR2) to 30.0 (M1 ALTUNİ) in the dried stage. Adiletta et al. (2015) reported the L* value as 51.38 in fresh fruits and 51.93 in dried fruits. In our study, the highest L* value in fresh (ripe) fruits was observed as 40.13 which is lower than reported in the earlier literature. The possible reasons for this could be the soil type, different maintenance and drying methods among other factors. In a study undertaken by Çatav (2019), the L* value of *L. barbarum* fresh fruits were reported to vary from 31.84 to 36.78 and this is parallel to our findings and the earlier studies.

As seen in Table 2, the average external colour a* values ranged from -7.52 (HZR2) to -5.19 (M1 ALTUNİ) in the green stage fruits, from 29.6 (M1 ALTUNİ) to 44.6 (HZR2) in the unripe stage fruits, from 33.1 (M1 ALTUNİ) to 44.2 (HZR1) in the ripe stage fruits, and from 18.1 (HZR2) to

**Table 2**
Fruit external colour brightness values (L*), a, b, C and hue values identified in different ripening stages of goji berry fruits.

| Fruit external colour brightness values | Genotypes | Ripening Stages | | | | |
|---|---|---|---|---|---|---|
| | | Green | Unripe | Ripe | Dried | Average |
| L* values | HZR3 | 39.1 ± 1.7 abc | 37.2 ± 0.3 cd | 33.0 ± 1.2 e | 27.3 ± 0.4 g | 34.1 **C** |
| | HZR1 | 40.8 ± 0.5 a | 35.4 ± 1.1 d | 35.2 ± 2.1 d | 29.8 ± 0.6 f | 35.3 **B** |
| | HZR2 | 39.7 ± 1.1 ab | 37.1 ± 1.1 cd | 38.4 ± 2.3 bc | 26.4 ± 1.3 g | 35.4 **FAB** |
| | M1 ALTUNİ | 35.4 ± 1.1 d | 40.3 ± 1.6 ab | 40.1 ± 4.1 ab | 30.0 ± 1.9 f | 36.5 **A** |
| | Average of Stage | 38.8 A | 37.5 B | 36.7 B | 28.4 C | |
| | LSD | $LSD_{gen}$*= 1.051 $LSD_{stage}$*= 1.051 $LSD_{genxstage}$* = 2.102 | | | | |
| a* values | HZR3 | −7.17 ± 0.15 h | 42.2 ± 1.2 b | 43.7 ± 1.3 a | 19.5 ± 1.0 f | 24.5 **A** |
| | HZR1 | −6.70 ± 0.29 h | 41.5 ± 1.0 b | 44.2 ± 1.2 a | 21.0 ± 0.4 e | 25.0 **A** |
| | HZR2 | −7.52 ± 0.35 h | 44.6 ± 0.5 a | 44.2 ± 1.0 a | 18.1 ± 2.6 f | 24.9 **A** |
| | M1 ALTUNİ | −5.19 ± 0.15 g | 29.6 ± 1.0 d | 33.1 ± 2.0 c | 28.7 ± 0.4 d | 21.5 **B** |
| | Average of Stage | −6.64 D | 39.5 B | 41.3 A | 21.8 C | |
| | LSD | $LSD_{gen}$*= 0.710 $LSD_{stage}$*= 0.710 $LSD_{genxstage}$* = 1.420 | | | | |
| b* values | HZR3 | 27.0 ± 0.3 g | 40.4 ± 1.8 ef | 40.1 ± 1.9 ef | 15.1 ± 0.8 ı | 30.7 **C** |
| | HZR1 | 27.1 ± 0.9 g | 39.1 ± 0.9 f | 41.6 ± 1.9 de | 15.9 ± 0.4 ı | 30.9 **C** |
| | HZR2 | 26.7 ± 1.2 g | 43.4 ± 0.9 d | 46.5 ± 3.2 c | 14.5 ± 1.1 ı | 32.8 **B** |
| | M1 ALTUNİ | 26.0 ± 0.5 g | 50.5 ± 0.9 b | 56.6 ± 3.8 a | 23.9 ± 0.8 h | 39.2 **A** |
| | Average of Stage | 26.7 C | 43.3 B | 46.2 A | 17.3 D | |
| | LSD | $LSD_{gen}$*= 1.031 $LSD_{stage}$*= 1.031 $LSD_{genxstage}$* = 2.062 | | | | |
| C values | HZR3 | 28.0 ± 0.2 ı | 58.4 ± 2.0 ef | 59.3 ± 2.2 de | 24.6 ± 1.2 jk | 42.6 **D** |
| | HZR1 | 29.0 ± 0.6 ıh | 57.0 ± 1.2 f | 60.7 ± 2.0 cd | 26.3 ± 0.6 ıj | 48.3 **A** |
| | HZR2 | 27.8 ± 1.3 ı | 62.3 ± 0.9 bc | 64.2 ± 1.9 ab | 23.2 ± 2.7 k | 44.4 **C** |
| | M1 ALTUNİ | 26.5 ± 0.4 ıj | 58.5 ± 1.1 def | 65.5 ± 4.2 a | 37.4 ± 0.6 h | 47.0 **B** |
| | Average of Stage | 32.8 C | 59.0 B | 62.4 A | 27.9 D | |
| | LSD | $LSD_{gen}$*= 1.113 $LSD_{stage}$*= 1.113 $LSD_{genxstage}$* = 2.226 | | | | |
| Hue° values | HZR3 | 104.8 ± 0.4 a | 43.8 ± 0.7 e | 42.5 ± 0.6 f | 37.8 ± 0.8 hı | 57.2 **C** |
| | HZR1 | 100.6 ± 0.9 b | 43.3 ± 0.4 ef | 43.2 ± 1.0 ef | 37.1 ± 0.2 ı | 39.3 **D** |
| | HZR2 | 105.7 ± 0.2 a | 44.2 ± 0.4 e | 46.4 ± 2.5 d | 38.8 ± 2.0 gh | 58.8 **B** |
| | M1 ALTUNİ | 101.3 ± 0.5 b | 59.6 ± 0.9 c | 59.7 ± 0.7 c | 39.7 ± 1.1 g | 65.1 **A** |
| | Average of Stage | 86.4 A | 47.7 B | 48.0 B | 38.3 C | |
| | LSD | $LSD_{gen}$*= 0.639 $LSD_{stage}$*= 0.639 $LSD_{genxstage}$* = 1.279 | | | | |

(1): The differences between the averages are shown by separate letters.
(2): N.S.: Not Significant ***:p < 0.001; **:p<0.01; * :p < 0.05.

28.7 (M1 ALTUNİ) in dried stage fruits. Adiletta et al. (2015) reported a* value of 30.95 ± 2.25 and 31.28 ± 2.76 in fresh and dried fruits, respectively. In our study, the highest a value in fresh (ripe) fruits was 44.2 (HZR1) and in dried fruits was 28.7 (M1 ALTUNİ). The a* values of the ripe fruit samples in our study are higher than the fresh fruit a* values in mentioned the literature. The a* values of the dried fruits were lower than those in the literature possibly due to differences in the techniques applied during this stage. Çatav (2019) reported a* values ranging from 40.31–45.75 in the fresh fruits of *L. barbarum*. As indicated in Table 2, samples collected in the green stage had fruit external colour b* values ranging from 26.0 (M1 ALTUNİ) to 27.1 (HZR1), whereas those collected in the unripe stage had values ranging from 39.1 (HZR1) to 50.5 (M1 ALTUNİ). Those collected in the ripe stage had values ranging from 40.1 (HZR3) to 56.6 (M1 ALTUNİ) and those collected in the dried stage had values ranging from 14.5 (HZR2) to 23.9 (M1 ALTUNİ). Adiletta et al. (2015) reported a b* value of 42.42 ± 4.46 for fresh fruits and a b* value of 38.90 ± 5.66 for dried fruits. Our study of the M1 ALTUNİ genotype fresh (ripe) fruits yielded a b* value of 56.6, whereas this value decreased to 23.9 in the dried fruits. Results from our ripe samples yielded higher b* values than the fresh fruit outcomes reported in the literature. Samples from the dried stage had lower b* values compared to earlier outcomes reported in the literature. The possible reason for the lower b* values obtained in the dried stage could be due to different drying techniques, as well as the different cultivars and growth media. Çatav (2019) reported external b* values for fresh fruits of *L. barbarum* ranging from 43.88 to 46.32. The relevant findings in this study reveal similarities with the outcomes in the literature.

As indicated in Table 2, the C values from fruits collected in the green stage ranged from 26.5–29.0 for the genotypes of M1 ALTUNİ and HZR1, respectively. However, this value varied from 57.0–62.3 in the green stage of the HZR1 and HZR2 genotypes. The ripe stage values were higher compared to the green stage varying from 59.3–65.5 in HZR3 and M1 ALTUNİ, and in contrast were much lower in the ripe stage varying from 23.2–37.4 in HZR2 and M1 ALTUNİ genotypes, respectively. Jatoi et al. (2017) in a study during the 2015–2016 period in Croatia applied 3 different dosages (1, 5 and 10 g $L^{-1}$) of lecithin to fresh fruits of *L. barbarum* and examined the colour changes. The highest C value was obtained from the samples with 10 g $L^{-1}$ application (39.06 ± 2.82) in that study, while the highest C value in our study was obtained in the ripe fruit samples of the M1 ALTUNİ (65.5) genotype. The reason for the higher C value obtained in our study could be due to the higher levels of illumination in the Central Anatolian region, particularly during the ripening stage of the fruits.

As indicated in Table 2, the fruit external colour hue° values of samples collected during the green stage varied from 100.6 (HZR1) to 105.7 (HZR2), from 43.3 (HZR1) to 59.6 (M1 ALTUNİ) in the unripe stage, from 42.5 (HZR3) to 59.7 (M1 ALTUNİ) in the ripe stage and from 37.1 (HZR1) to 39.7 (M1 ALTUNİ) in the dried stage. Three different lecithin dosages (1, 5 and 10 g $L^{-1}$) were applied to fresh fruits of

*L. barbarum* in order to determine the colour changes in the fruits by Jatoi et al. (2017) who determined the highest hue value (54.38 ± 3.98) in the control group. In this respect, the hue values measured in our study from the samples collected in the ripe stage are similar to the hue values reported in the literature.

### 3.3. Changes in sugar contents during ripening stages

The changes in the sucrose contents of different goji berry genotypes, based on their ripening stages, are given in Table 3. A statistically significant difference was observed between genotypes in terms of sucrose, glucose, fructose, total sugar contents (g/100 g) and soluble solid contents (%) ($p < 0.001$) based on their ripening stages. The differences between genotypes and genotype X stage interaction were found to be significant in terms of sucrose (g/100 g) and total soluble solid contents (%) ($p < 0.05$). As given in Table 3, the sucrose contents varied from 1.02 g/100 g (HZR2) to 1.50 g/100 g (HZR3) in the green stage, from 0.65 g/100 g (M1 ALTUNİ) to 1.67 g/100 g (HZR2) in the unripe stage, from 0.58 g/100 g (M1 ALTUNİ) to 0.74 g/100 g (HZR1) in the ripe stage and from 1.48 g/100 g (M1 ALTUNİ) to 2.14 g/100 g (HZR3) in the dried samples. Making a comparison between genotype averages in terms of sucrose contents, the HZR3 (1.46 g/100 g), HZR2 (1.27 g/100 g), and HZR1 (1.26 g/100 g) genotypes were categorized in the same group. An assessment of the ripening stage averages in terms of sucrose contents yielded a statistically significant priority for sucrose content in the dried stage.

A study conducted by Zhao et al. (2015a,b) on fresh fruits harvested in the green stage yielded sucrose quantities of 0.56 ± 2.89 g/100 g for Damaye and 0.98 ± 1.47 g/100 g for the NQ1 cultivar. Zheng et al. (2008) found that sucrose content of ripe fruit from *L. barbarum* L. reached a minimum (2.8 g/100 g). Also, Kosińska-Cagnazzo et al. (2017) reported that sucrose in the dried stages of six goji cultivars was lower at 0.04–0.29 g/100 g. However, Montesano et al. (2016) found that sucrose content of sixteen goji berries ranged from 1.37 to 3.6 g/100 g. Moreover, Sung et al. (1994) studied the dried fruits of some cultivars (IIbon I, Chungyang, Jungguk II, Jindo I, Yousung I) of *L. chinense* Mill in Korea and reported sucrose contents ranging from 2.59 g/100 g (IIbon I) to 4.39 g/100 g (Chungyang). The sucrose contents from the samples collected in the dried stage in this study yielded lower values than those determined in the earlier literature. A possible reason for this is organic production performed due to ecological conditions.

As indicated in Table 3, the glucose contents varied from 0.75 g/100 g (M1 ALTUNİ) to 1.26 g/100 g (HZR2) in the samples collected in the green stage, whereas the glucose contents varied from 4.26 g/100 g (HZR1) to 5.88 g/100 g (HZR2), from 6.14 g/100 g (HZR2) to 8.55 g/100 g (HZR3) and from 16.7 g/100 g (HZR2) to 19.0 g/100 g (M1 ALTUNİ) in the unripe, ripe and dried stages, respectively. A comparison of stage averages in terms of glucose contents indicated higher glucose content for the dried stage than the other stages. A study by Yajun et al. (2019) reported that glucose content in the dried stage ranged from 7.67 to 27.57 g/100 g. Furthermore, Zhao et al. (2020) reported that the fresh wolfberry glucose content ranged from 4.49 (NQ0901) to 6.84 (NQ5) g/100 g. Sung et al. (1994) reported glucose contents varying from 3.54 g/100 g (Jungguk II) to 6.18 g/100 g (Yousung I) in some cultivars (IIbon I, Chungyang, Jungguk II, Jindo I, Yousung I) of the *L. chinense* Mill species in Korea. Moreover, Kosińska-Cagnazzo et al. (2017) reported that glucose in the dried stages of six goji cultivars in Switzerland varied from 4.15–23.22 g/100 g. The glucose contents determined in the dried stages of the genotypes analysed in this study are higher than those given in the literature, most likely due to the ecologic conditions.

As indicated in Table 3, the fructose contents of the samples collected in the green stage ranged from 0.24 g/100 g in M1 ALTUNİ to 0.36 g/100 g in HZR2 genotype. Whereas the fructose contents ranged from 2.66 g/100 g in M1 ALTUNİ to 3.29 g/100 g in HZR3 in samples collected in the unripe stage, from 3.37 g/100 g in HZR2 to 4.57 g/100 g in HZR3 in the ripe stage and from 8.15 g/100 g in HZR2 to 9.43 g/100 g

**Table 3**
Sucrose, glucose, fructose, total sugar (g/100 g) and total soluble solid contents (%) determined in different ripening stages of goji berry genotypes.

| Sugar Contents | Genotypes | Ripening Stages | | | | |
|---|---|---|---|---|---|---|
| | | Green | Unripe | Ripe | Dried | Average |
| Sucrose (g/100 g) | HZR3 | 1.50 ± 0.14 bc | 1.55 ± 0.03 bc | 0.66 ± 0.19 e | 2.14 ± 0.11 a | 1.46 **A** |
| | HZR1 | 1.36 ± 0.19 bcd | 1.44 ± 0.14 bcd | 0.74 ± 0.18 e | 1.51 ± 0.84 bc | 1.26 **A** |
| | HZR2 | 1.02 ± 0.20 de | 1.67 ± 0.21 bc | 0.62 ± 0.04 e | 1.77 ± 0.43 ab | 1.27 **A** |
| | M1 ALTUNİ | 1.29 ± 0.18 cd | 0.65 ± 0.18 e | 0.58 ± 0.06 e | 1.48 ± 0.14 bc | 1.00 **B** |
| | Average of Stage | 1.29 B | 1.33 B | 0.65 C | 1.72 A | |
| | LSD | $LSD_{gen}$*= 0.230 $LSD_{stage}$***= 0.230 $LSD_{genxstage}$* = 0.459 | | | | |
| Glucose (g/100 g) | HZR3 | 1.05 ± 0.41 | 5.87 ± 1.00 | 8.55 ± 2.12 | 17.8 ± 2.6 | 8.31 |
| | HZR1 | 0.81 ± 0.06 | 4.26 ± 0.72 | 7.35 ± 2.03 | 17.1 ± 2.5 | 7.39 |
| | HZR2 | 1.26 ± 0.44 | 5.88 ± 0.24 | 6.14 ± 0.23 | 16.7 ± 1.6 | 7.50 |
| | M1 ALTUNİ | 0.75 ± 0.26 | 5.01 ± 0.85 | 6.80 ± 3.03 | 19.0 ± 1.2 | 7.89 |
| | Average of Stage | 0.97 D | 5.25 C | 7.21 B | 17.6 A | |
| | LSD | $LSD_{gen}$= N.S $LSD_{stage}$***= 1.270 $LSD_{genxstage}$= N.S | | | | |
| Fructose (g/100 g) | HZR3 | 0.26 ± 0.03 | 3.29 ± 0.23 | 4.57 ± 1.20 | 8.93 ± 1.27 | 4.26 |
| | HZR1 | 0.29 ± 0.05 | 2.30 ± 0.32 | 4.10 ± 1.09 | 8.90 ± 0.76 | 3.90 |
| | HZR2 | 0.36 ± 0.05 | 3.08 ± 0.14 | 3.37 ± 0.10 | 8.15 ± 0.63 | 3.74 |
| | M1 ALTUNİ | 0.24 ± 0.06 | 2.66 ± 0.52 | 3.56 ± 1.52 | 9.43 ± 0.52 | 3.97 |
| | Average of Stage | 0.29 D | 2.83 C | 3.90 B | 8.85 A | |
| | LSD | $LSD_{gen}$= N.S $LSD_{stage}$***= 0.598 $LSD_{genxstage}$= N.S | | | | |
| Total sugar (g/100 g) | HZR3 | 2.81 ± 0.41 | 10.7 ± 1.3 | 13.8 ± 3.3 | 29.0 ± 3.9 | 14.1 |
| | HZR1 | 2.47 ± 0.16 | 7.80 ± 1.17 | 12.2 ± 3.3 | 27.7 ± 3.1 | 12.6 |
| | HZR2 | 2.64 ± 0.32 | 10.6 ± 0.3 | 10.1 ± 0.4 | 26.8 ± 2.5 | 12.6 |
| | M1 ALTUNİ | 2.28 ± 0.10 | 8.34 ± 1.24 | 11.0 ± 4.5 | 30.0 ± 1.8 | 12.9 |
| | Average of Stage | 2.55 D | 9.42 C | 11.8 B | 28.4 A | |
| | LSD | $LSD_{gen}$= N.S $LSD_{stage}$***= 1. 876 $LSD_{genxstage}$= N.S | | | | |
| Total soluble solid content (%) | HZR3 | 6.17 ± 0.58 ı | 13.2 ± 2.3 h | 25.8 ± 0.3 d | 42.0 ± 2.0 a | 21.8 **A** |
| | HZR1 | 6.33 ± 0.29 ı | 12.3 ± 0.3 h | 23.7 ± 0.8 e | 40.0 ± 1.0 b | 20.6 **B** |
| | HZR2 | 6.83 ± 0.29 ı | 15.5 ± 1.3 g | 23.0 ± 1.0 e | 32.0 ± 1.0 c | 19.3 **C** |
| | M1 ALTUNİ | 7.17 ± 0.29 ı | 19.2 ± 2.6 f | 22.5 ± 0.0 e | 31.0 ± 0.0 c | 20.0 **BC** |
| | Average of Stage | 6.63 D | 15.0 C | 23.8 B | 36.3 A | |
| | LSD | $LSD_{gen}$***= 0.970 $LSD_{stage}$***= 0.970 $LSD_{genxstage}$*** = 1.939 | | | | |

(1): The differences between the averages are shown by separate letters.
(2): N.S.: Not Significant ***:p < 0.001; **:p<0.01; * :p < 0.05.

in M1 ALTUNİ in the dried stage. A study by Zhao et al. (2015a,b) examined fruits harvested in the green stage and reported fructose contents of 0.25 ± 0.243 g/100 g in NQ1 and 0.07 ± 0.055 g/100 g in Damaye. The fructose contents in our study were 0.26 g/100 g for HZR3 and 0.36 g/100 g for HZR2 in the green stage and contents were higher than those determined in the earlier studies. The fructose values in fruits collected in the unripe stage were reported to be 0.182 ± 0.142 g/100 g in Damaye and 0.382 ± 0.086 g/100 g in NQ1. In terms of the unripe stage, the highest fructose content in our study was determined in the HZR3 genotype as 3.29 g/100 g and the lowest was in the HZR1 genotype as 2.30 g/100 g. With regards to the ripe stage, the same authors reported fructose contents of 4.908 ± 1.837 g/100 g for Damaye, and 4.07 ± 3.760 g/100 g for NQ1. The highest fructose content in the ripe stage was determined in the HZR3 genotype as 4.57 g/100 g, and the lowest content was determined in the HZR2 genotype as 3.37 g/100 g. Zhao et al. (2020) reported that the fructose content of fresh wolfberry ranged from 7.15 (NQ0901) to 9.17 (NQ5) g/100 g. Furthermore, Sung et al. (1994) reported fructose contents ranging from 4.54 g/100 g (Yousung I) to 5.81 g/100 g (Chungyang) in some cultivars (IIbon I, Chungyang, Jungguk II, Jindo I, Yousung I) of *L. chinense* Mill species in Korea. Also, Kosińska-Cagnazzo et al. (2017) reported that fructose in dried stages of six goji cultivars from Switzerland varied from 1.92 to 23.96 g/100 g. A study by Yajun et al. (2019) reported that fructose content in dried stages ranged from 9.16–23.76 g/100 g. The fructose contents determined in the dried stages of the genotypes in this study were higher than the fructose contents reported in earlier studies, which possibly reflects the varying ecological conditions.

As indicated in Table 3, the total sugar contents of the samples collected in the green stage varied from 2.28 g/100 g (M1 ALTUNİ) to 2.81 g/100 g (HZR3), whereas these contents varied from 7.80 g/100 g (HZR1) to 10.7 g/100 g (HZR3) in the unripe stage, from 10.1 g/100 g (HZR2) to 13.8 g/100 g (HZR3) in the ripe stage and from 26.8 (HZR2) g/100 g to 30.0 (M1 ALTUNİ) g/100 g in the dried stage. In this respect, Sung et al. (1994) conducted a study to determine the sugar contents of the dried and fresh fruits of some varieties (IIbon I, Chungyang, Jungguk II, Jindo I, Yousung I) of *L. chinense* Mill species, reporting a total sugar content of 2.24 g/100 g in the fresh fruits and 27.6 g/100 g in the dried fruits. Zhao et al. (2020) determined that the highest content of total sugar in fresh wolfberry was 16.01 g/100 g. Moreover, Wojdyło et al. (2018) conducted a study on the total sugar contents of dried fruits of new goji berry types produced from *L. barbarum,* which varied from 3.19 to 10.71 g/100 g. Sugar content in fresh wolfberry determined in the current study were mostly higher than that reported in literature. These contents were lower than the total sugar contents determined in the dried stage of the genotypes used in this study. This could be due to the use of different drying techniques, characteristics of the species used and ecological factors.

As indicated in Table 3, the total soluble solid contents in the fruits of the green, unripe, ripe and dried stages varied from 6.17 % in HZR3 to 7.17 % in M1 ALTUNİ, from 12.3 % in HZR1 to 19.2 % in M1 ALTUNİ, from 22.5 % in M1 ALTUNİ to 25.8 % in HZR3 and from 31 % in M1 ALTUNİ to 42 % in HZR3, respectively. Statistical analysis yielded a positive relationship between the total soluble solid contents and total sugar (r = 0.914**) as expected. The total soluble solid contents in this study were compared to those reported in the literature and recently a study conducted by Xie et al. (2017) reported a surface soluble solid content of 21 % in the fresh fruits of *L. barbarum*. Zhao et al. (2020) found that NQ5 had the highest total soluble solid content of 23.6 %. Kosińska-Cagnazzo et al. (2017) also reported that the total soluble solid content of six goji cultivars in Switzerland varied from 11.9–24.5%. However, the total soluble solid content of the ripe stage of the HZR3 cultivar (25.8 %) was determined to be slightly higher than the total soluble solid contents mentioned in the literature. The possible reasons could be ecology, type of planting, trimming, shading and other similar production techniques.

### 3.4. Changes in organic acid contents during ripening stages

The changes in malic, citric and succinic acid contents among fruit samples are given in Table 4. In terms of malic acid contents, the differences determined between the genotypes, ripening stages and genotype X stage interactions were found to be statistically significant ($p < 0.001$). In terms of citric acid contents, the differences between different ripening stages and genotype X stage interactions were found to be statistically significant ($p < 0.001$). Furthermore, the differences ripening stages ($p < 0.05$) and genotype X stage interactions were found to be statistically significant ($p < 0.001$) in terms of succinic acid contents.

As indicated in Table 4, the malic acid contents of the samples collected in the green, unripe, ripe and dried stages ranged from 0.07 % in HZR2 to 0.17 % in M1 ALTUNİ, from 0.04 % in HZR1 to 0.11 % in HZR2, from 0.03 % in M1 ALTUNİ to 0.32 % in HZR3 and from 0.31 % in M1 ALTUNİ to 0.40 % in HZR3, respectively. A study by Pires et al.

**Table 4**
Malic, citric and succinic acid contents of goji berry genotypes in different ripening stages (%).

| Organic acids | Genotypes | Ripening Stages | | | | |
|---|---|---|---|---|---|---|
| | | Green | Unripe | Ripe | Dried | Average |
| Malic acid (%) | HZR3 | 0.16 ± 0.00 c | 0.07 ± 0.03 ef | 0.32 ± 0.03 b | 0.40 ± 0.05 a | 0.24 **A** |
| | HZR1 | 0.16 ± 0.01 c | 0.04 ± 0.00 ef | 0.30 ± 0.02 b | 0.36 ± 0.01 ab | 0.22 **AB** |
| | HZR2 | 0.07 ± 0.01 ef | 0.11 ± 0.15 cde | 0.17 ± 0.14 c | 0.37 ± 0.05 ab | 0.18 **BC** |
| | M1 ALTUNİ | 0.17 ± 0.02 c | 0.09 ± 0.03 def | 0.03 ± 0.00 f | 0.31 ± 0.02 b | 0.15 **C** |
| | Average of Stage | 0.14 C | 0.08 D | 0.21 B | 0.36 A | |
| | LSD | $LSD_{gen}$***= 0.037 $LSD_{stage}$***= 0.037 $LSD_{genxstage}$*** = 0.074 | | | | |
| Citric acid (%) | HZR3 | 1.00 ± 0.15 bc | 0.79 ± 0.03 def | 0.42 ± 0.04 hı | 0.40 ± 0.02 hı | 0.65 |
| | HZR1 | 0.75 ± 0.06 efg | 0.88 ± 0.05 cde | 0.50 ± 0.00 h | 0.43 ± 0.02 hı | 0.64 |
| | HZR2 | 0.54 ± 0.15 gh | 1.33 ± 0.40 a | 0.58 ± 0.15 fgh | 0.39 ± 0.04 hı | 0.71 |
| | M1 ALTUNİ | 1.19 ± 0.06 ab | 0.96 ± 0.25 cd | 0.56 ± 0.02 gh | 0.27 ± 0.00 ı | 0.74 |
| | Average of Stage | 0.87 B | 0.99 A | 0.51 C | 0.37 D | |
| | LSD | $LSD_{gen}$= N.S $LSD_{stage}$***= 0.105 $LSD_{genxstage}$*** = 0.209 | | | | |
| Succunic acid (%) | HZR3 | 1.80 ± 0.01 a | 0.65 ± 0.01 cd | 0.38 ± 0.02 efg | 0.56 ± 0.08 de | 0.85 |
| | HZR1 | 1.64 ± 0.19b a | 0.82 ± 0.04 c | 0.31 ± 0.06 fg | 0.48 ± 0.07 def | 0.81 |
| | HZR2 | 1.68 ± 0.17 a | 1.10 ± 0.34 b | 0.42 ± 0.12 defg | 0.47 ± 0.16 def | 0.92 |
| | M1 ALTUNİ | 1.66 ± 0.45 a | 1.06 ± 0.26 b | 0.39 ± 0.08 efg | 0.19 ± 0.13 g | 0.83 |
| | Average of Stage | 1.69 A | 0.91 B | 0.38 C | 0.43 C | |
| | LSD | $LSD_{gen}$= N.S $LSD_{stage}$***= 0.119 $LSD_{genxstage}$* = 0.238 | | | | |

(1): The differences between the averages are shown by separate letters.
(2): N.S.: Not Significant ***:p < 0.001; **:p<0.01; * :p < 0.05.

(2018) reported the lack of malic acid in goji berry fruit samples, whereas our study had a range of 0.31 % and 0.40 % for malic acid contents in dried samples. The reason for the determination of malic acid in our study could be due to the variety of the genotype used and ecological conditions. Furthermore, a study by Zhao et al. (2015a,b) reported malic acid quantities of 0.08 % (Damaye) and 0.14 % (NQ1) in fruit samples collected in the green stage. In fruit samples collected in the unripe stage, they reported malic acid quantities of 0.13 % (Damaye) and 0.19 % (NQ1), while in the ripe stage, they reported the amounts were 0.02 % (Damaye) and 0.03 % (NQ1).

As indicated in Table 4, the citric acid contents in fruits collected in the green, unripe, ripe and dried stages ranged from 0.54 % in HZR2 to 1.19 % M1 ALTUNİ, from 0.79 % in HZR3 to 1.33 % in HZR2, from 0.42 % in HZR3 to 0.58 % in HZR2 and from 0.27 % in M1 ALTUNİ to 0.43 % in HZR1, respectively. Furthermore, a study by Zhao et al. (2015a,b) reported citric acid contents of 1.31 % (Damaye) and 1.32 % (NQ1) in fruits harvested in the green stage, whereas citric acid contents in fruits harvested in the unripe stage were reported to be 1.44 % (Damaye) and 1.38 % (NQ1) and in the ripe stage they were reported to be 1.69 % (Damaye) and 1.39 % (NQ1). Percentage assessment indicates that literature findings are higher than those reported in this study. Moreover, a study in Italy by Donno et al. (2015) about the fresh fruits of 3 genotypes of *L. barbarum* and *L. chinense* reported citric acid content ranging from 0.20 % to 0.29 %. The higher contents of citric acid in the genotypes analysed in our study compared to the ones studied earlier are most likely due to the irrigation and shading techniques.

As indicated in Table 4, the succinic acid contents in fruits collected in the green, unripe, ripe and dried stages varied from 1.64 % in HZR1 to 1.80 % in HZR3, from 0.65 % in HZR3 to 1.10 % in HZR2, from 0.31 % in HZR1 to 0.42 % in HZR2 and from 0.19 % in M1 ALTUNİ to 0.56 % in HZR3, respectively. Donno et al. (2016) analysed the succinic acid contents of dried and fresh fruits of *L. barbarum* and *L. chinense* and reported contents of 0.06 % and 0.04 %, respectively. Consequently, the succinic acid contents from our study are higher than those reported in the literature.

The changes between L-ascorbic acid (mg/100 g), total acid, and titratable acidity (%) contents observed in fruits collected in different ripening stages for goji berry genotypes are given in Table 5. The difference between ripening stages ($p < 0.001$) and genotype X stage interactions in terms of L-ascorbic acid and total acid content were found to be statistically significant ($p < 0.05$). In terms of titratable acidity contents of the genotypes, the difference between ripening stages and genotype X stage interactions was found to be statistically insignificant. As indicated in Table 5, the L-ascorbic acid contents of the fruits collected during the green, unripe, ripe and dried stages varied from 12.2 mg/100 g in M1 ALTUNİ to 19.4 mg/100 g in HZR1, from 14.6 mg/100 g in HZR3 to 17.8 mg/100 g in M1 ALTUNİ, from 15.2 mg/100 g in HZR3 to 16.9 mg/100 g in HZR2, and from 19.2 mg/100 g in M1 ALTUNİ - 31.3 mg/100 g in HZR2, respectively. The vitamin C contents of the *L. barbarum* fruit samples harvested in the ripe stage in Northern Italy were determined to be 48.94 mg/100 g (Donno et al., 2015). In our study, vitamin C contents in fruits harvested in the ripe stage ranged from 15.2 mg/100 g to 16.9 mg/100 g. The vitamin C contents acquired from the samples in this study are lower than the vitamin C contents given for some genotypes in the earlier studies and in contrast are higher in some genotypes. In a study in Serbia, Vulić et al. (2016) attempted to determine the bioactive compounds and antioxidant properties of fresh goji berry fruits (*L. barbarum* L.), reporting vitamin C contents of 59.47 mg/100 g.

As indicated in Table 5, the total acid content in fruits collected in the green, unripe, ripe and dried stages varied from 2.28 % in HZR2 to 3.03 % in M1 ALTUNİ, from 1.50 % in HZR3 to 2.54 % in HZR2, from 0.98 % in M1 ALTUNİ to 1.17 % in HZR2 and from 0.76 % in M1 ALTUNİ to 1.36 % in HZR3, respectively. Furthermore, a study conducted by Zhao et al. (2015a,b) reported total acid contents of 2.58 % (Damaye) and 2.30 % (Baihua) in fruits harvested in the unripe stage and 2.46 % (NQ1) in the ripe stage. A percentage-wise assessment of the data in the literature indicates similarities between the total organic acid data in this study and fruits collected in the unripe stages in earlier studies, but not in the ripe stage samples.

**Table 5**
Total acid, titratable acidity (%) and L-ascorbic acid contents (mg/100 g) of goji berry genotypes determined in different ripening stages.

| Organic acids and L-ascorbic acid | Genotypes | Ripening Stages | | | | |
|---|---|---|---|---|---|---|
| | | Green | Unripe | Ripe | Dried | Average |
| L-ascorbic acid (mg/100 g) | HZR3 | 17.6 ± 10.5 c | 14.6 ± 1.6 cde | 15.2 ± 0.9 cd | 27.2 ± 1.3 ab | 18.6 |
| | HZR1 | 19.4 ± 12.5 bc | 15.7 ± 1.3 c | 16.5 ± 0.3f | 30.2 ± 7.7 a | 17.9 |
| | HZR2 | 17.0 ± 0.2 ef | 17.1 ± 2.2 c | 16.9 ± 0.6 c | 31.3 ± 3.7 a | 18.0 |
| | M1 ALTUNİ | 12.2 ± 0.4 cdef | 17.8 ± 0.7 def | 15.9 ± 0.4 c | 19.2 ± 2.0 c | 13.8 |
| | Average of Stage | 14.0 B | 13.8 B | 13.6 B | 27.0 A | |
| | LSD | $LSD_{gen}$= N.S $LSD_{stage}$***= 3.93 $LSD_{genxstage}$* = 7.86 | | | | |
| Total acids (%) | HZR3 | 2.97 ± 0.00 ab | 1.50 ± 0.02 fg | 1.12 ± 0.00 ghı | 1.36 ± 0.16 fgh | 1.74 |
| | HZR1 | 2.54 ± 0.25 bc | 1.74 ± 0.01 ef | 1.11 ± 0.08 ghı | 1.27 ± 0.09 gh | 1.67 |
| | HZR2 | 2.28 ± 0.02 cd | 2.54 ± 0.75 bcd | 1.17 ± 0.28 ghı | 1.23 ± 0.17 gh | 1.81 |
| | M1 ALTUNİ | 3.03 ± 0.12 a | 2.11 ± 0.54 de | 0.98 ± 0.06 hı | 0.76 ± 0.11 ı | 1.72 |
| | Average of Stage | 2.71 A | 1.97 B | 1.10 C | 1.15 C | |
| | LSD | $LSD_{gen}$= N.S $LSD_{stage}$***= 0.217 $LSD_{genxstage}$*** = 0.434 | | | | |
| Titratable acidities (%) | HZR3 | 1.38 ± 0.09 | 1.32 ± 0.25 | 1.25 ± 0.05 | 1.33 ± 0.36 | 1.27 |
| | HZR1 | 1.46 ± 0.01 | 0.88 ± 0.13 | 1.41 ± 0.16 | 1.23 ± 0.04 | 1.24 |
| | HZR2 | 1.27 ± 0.11 | 1.38 ± 0.35 | 0.99 ± 0.00 | 1.35 ± 0.15 | 1.25 |
| | M1 ALTUNİ | 1.35 ± 0.11 | 1.02 ± 0.89 | 1.18 ± 0.19 | 0.80 ± 0.17 | 1.09 |
| | Average of Stage | 1.36 | 1.10 | 1.21 | 1.18 | |
| | LSD | $LSD_{gen}$= N.S $LSD_{stage}$= N.S $LSD_{genxstage}$= N.S | | | | |

(1): The differences between the averages are shown by separate letters.
(2): N.S.: Not Significant ***:$p < 0.001$; **:$p<0.01$; * :$p < 0.05$.

As indicated in Table 5, the titratable acidity content in fruits collected in the green, unripe, ripe and dried fruit stages varied from 1.27 % in HZR2 to 1.46 % in HZR1, from 0.88 % in HZR1 to 1.38 % in HZR2, from 0.99 % in HZR2 to 1.41 % in HZR1 and from 0.80 % in M1 ALTUNİ to 1.35 % in HZR2, respectively. A positive relationship was determined between titratable acidity and citric acid based on correlations in statistical analysis ($r = 0.198$*). In a study in Croatia in 2015–2016 by Jatoi et al. (2017), 3 different doses (1, 5 and 10 g $L^{-1}$) of lecithin were applied to fresh fruits of *L. barbarum* in order to determine the titratable acidity ratio changes in the goji berry fruits. The highest

titratable acidity rate in this study was determined in the sample at 1.39 ± 0.10 with 5 g $L^{-1}$ lecithin application, while in our study the highest titratable acidity rate was 1.46 for the HZR1 genotype with similar findings to those given in the literature.

## 4. Conclusions

In this study, the developmental changes in four sugars, total soluble solid contents and four organic acids, as well as titratable acidity and L-ascorbic acid, were determined in the flesh of fresh and dried wolfberry fruits. With regards to the sucrose contents in the genotypes of all stages, the HZR3, HZR2 and HZR1 genotypes were statistically within the same group, whereas the sucrose contents of the dried stage were determined to be statistically higher than in the other stages. An analysis of stage averages in terms of glucose, fructose, total sugar and soluble solid contents in fruit samples picked in different stages revealed higher glucose, fructose, total sugar and soluble solid contents in the dried stage than in the other stages. In terms of genotype averages, the total soluble solid contents were highest in the HZR3 genotype. In this context, the stage averages for citric acid contents were highest in the unripe stage of the HZR2 genotype. Furthermore, the stage averages for succinic acid content were statistically higher in the green stage, whereas L-ascorbic acid contents were highest in the dry stage of HZR2. Consequently, the total acid contents were highest in the green stage for the HZR3 genotype in the final assessment of the stage averages. In conclusion, examining all genotypes and ripening stages on the basis of organic acid contents revealed higher titratable acidity contents, higher total acid contents and higher succinic acid contents in the HZR1, HZR3 and HZR2 genotype green stages, respectively. The highest citric, malic, and L-ascorbic acid contents were determined in the unripe stage of HZR2, and dried stages of HZR3 and HZR2 genotypes, respectively. In situations where goji berry fruits are to be used for pharmacologic purposes, the most appropriate consumption stage for the genotypes is the green stage for organic acids and the dried stage for sugar, total soluble solid and L-ascorbic acid contents. Finally, examining the genotypes in pomological terms, the genotype with the bulkiest fruits was HZR1. Furthermore, the genotype with the highest L*, a*, b*, C, and hue° colour values for fruits was determined to be the M1 ALTUNİ genotype. The findings suggest that the best results from assessment of all genotypes and ripening stages in terms of sugar contents were provided by the M1 ALTUNİ genotype. Consequently, this study provides beneficial information for developing the flavour and nutritional quality of goji berry fruit.

## CRediT authorship contribution statement

**İlbilge Oğuz:** Software, Formal analysis, Resources, Writing - original draft. **Halil İbrahim Oğuz:** Conceptualization, Investigation, Resources, Visualization. **Nesibe Ebru Kafkas:** Methodology, Writing - review & editing, Supervision, Validation, Project administration, Data curation.

## Declaration of Competing Interest

The authors report no declarations of interest.

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