Original article

Nutritional value and consumer-perceived quality of fresh goji berries (*Lycium barbarum* L. and *L. chinense* L.) from plants cultivated in Southern Europe

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Summary

Introduction – **Goji plants (*Lycium* spp.) are cultivated in subtropical countries under temperate climate, mainly in Asia, and berries are exported to Europe in dried form. This study aimed to evaluate the composition and quality characteristics of fresh berries in crops harvested from seedlings cultivated in Greece, in areas where subtropical trees are grown.** *Materials and methods* – **Six accessions of *Lycium barbarum* L. and one of *L. chinense* L. were compared on several nutritional and quality traits of their fruit. A sensory panel evaluated the consumer liking of the fresh fruit.** *Results and discussion* – **In the studied accessions, the 10-fruit weight ranged 4.2–8.6 g, juice content 69–79% fresh weight (FW) and sugars (fructose, glucose and sucrose) 190–505 mg g^{-1} DW. Ascorbate varied 30–138 mg g^{-1} FW, total carotenoids 4.0–9.5 mg g^{-1} DW, phenolics 4–13 mg g^{-1} DW and the antioxidant capacity (TAC) 38–63 µmol g^{-1} DW. The most abundant mineral was potassium, averaging 1.65% DW. The fruit of *L. chinense* had the highest concentrations of most nutrients, and a strong bitter/astringent taste. Panelists preferred the fresh berries of the two *L. barbarum* accessions that exhibited higher fruit weight, juice and sugar contents and TAC than the other accessions.** *Conclusion* – **The nutritional value and quality of fruit from some goji berry accessions grown in Greece is sufficiently high to worth further study of plant cultivation and fruit marketability even in the fresh form.**

Keywords
Greece, goji, *Lycium* spp., antioxidant activity, fruit quality, functional food, phenolics, sensory evaluation, underutilized species

Résumé

Valeur nutritionnelle et qualité perçue par les consommateurs des fruits frais de goji (*Lycium barbarum* L. et *L. chinense* L.) cultivés au Sud de l'Europe.

Introduction – **Les plants de goji (*Lycium* spp.) sont originaires de pays subtropicaux à climat tempéré, principalement en Asie, et les baies sont exportées en Europe sous forme séchée. Cette étude a visé à évaluer la composition et les caractéristiques qualitatives des baies fraîches récoltées sur des plants issus de semis cultivés en Grèce, dans les zones dans lesquelles poussent des arbres subtropicaux.** *Matériel et méthodes* – **Six accessions de *L. barbarum* L. et une de *L. chinense* L. ont été comparées pour différents paramètres nutritionnels et qualitatifs de leurs fruits. Un panel sensoriel a évalué le goût des fruits frais.** *Résultats et discussion* – **Parmi les accessions étudiées, le poids de 10 fruits était de 4.2 à 8.6 g, la teneur en jus de 69 à 79% de matière fraîche (MF), et la teneur en sucres (fructose, glucose and sucrose) de 190 à 505 mg g^{-1} MS. La teneur en acide ascorbique variait entre 30 et 138 mg g^{-1} MF, celle en caroténoïdes totaux était comprise entre 4.0–9.5 mg g^{-1} MS, et de 4 à 13 mg g^{-1} MS pour les composés phénoliques. La capacité anti-oxydante (TAC) variait entre 38 et 63 µmol g^{-1} MS. Parmi les composés minéraux, le plus abondant était le potassium, avec une moyenne de 1.65% MS. Les fruits de *L. chinense* ont présenté les plus fortes concentrations en la plupart des nutriments et un fort goût amer/astringent. Les panélistes ont préféré les fruits des deux accessions de *L. barbarum* qui pré-**

Significance of this study

What is already known on this subject?
- There are limited compositional data related to fresh goji berries compared to the quality of the dried fruit.

What are the new findings?
- Fresh goji berries of high quality and nutritional value from two accessions can be grown in Southern Europe.

What is the expected impact on horticulture?
- In Southern Europe, a breeding program could be developed for growers to cultivate goji plants and consumers to enjoy fresh berries of high quality.

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sentaient les valeurs les plus élevées de poids des fruits, de teneur en jus et en sucres, et de TAC. *Conclusion* **– La valeur nutritionnelle et la qualité des fruits de quelques accessions de goji cultivées en Grèce sont suffisamment élevées pour justifier la poursuite des recherches sur la culture des plantes et la commercialisation des fruits frais.**

Mots-clés
Grèce, goji, *Lycium* spp., capacité anti-oxydante, composés phénoliques, espèce sous-utilisée, évaluation sensorielle, fonctionnel aliment, qualité du fruit

Introduction

Fruit trees are familiar to a wide cross-section of human society, both as a common food and for their spiritual importance. They have been used by people for food, either as edible products, or for culinary ingredients, and for medicinal use for a long time. They are a genetically very diverse group and play a major role in modern society end economy. Fruits are natural sources of vitamins, phytochemicals and minerals as well (Benjak *et al.*, 2005; Canan *et al.*, 2016; Rop *et al.*, 2014; Zorenc *et al.*, 2016). Goji fruits are recognized to have bioactive compounds and classified as functional food. Goji berries (synonym: wolfberry) are fruits from genotypes of mainly two closely related plant species, *Lycium barbarum* L. and *L. chinense* L., originating from China and traditionally used in the Chinese medicine throughout the centuries (Amagase and Farnsworth, 2011). In warm and humid areas in China, vegetative tissues from *L. chinense* are used for beverages, whereas fruits are used from both *Lycium* spp. grown in colder and semi-arid areas, with Ningxia being a well-known area for *L. barbarum* berries (Hu, 2005). The beneficial properties of goji berries have been highlighted by many studies, revealing significant hypolipidemic effects, antioxidant activity (Luo *et al.*, 2004), positive effects on macular characteristics (Bucheli *et al.*, 2011), strong anti-ageing activity (Chang and So, 2008) and the feeling of general improved stamina (Amagase and Farnsworth, 2011).

These health-promoting properties can mostly be attributed to the elevated concentration of antioxidants (such as b-carotene, ascorbate and flavonoids), minerals and polysaccharides (Jin *et al.*, 2013; Liorent-Martinez *et al.*, 2013). Due to these valuable properties are widely marketed in Europe and the United States in many different forms, such as dried fruits, dietary supplements, jams, juices and other beverages and foodstuffs (Karioti *et al.*, 2014; Liorent-Martinez *et al.*, 2013).

Goji berries trading outside Asia, mostly concerns dried fruit of *L. barbarum* genotypes. Recently, the cultivation of principally *L. barbarum* L. species has been spread to farmlands throughout the world. Sufficient data discuss the composition and nutritional value of individual genotypes of *L. barbarum* species. In contrast, only limited data exist concerning *L. chinense* genotypes or differences in quality between the two species (Potterat, 2010).

The aim of this study was to obtain information about the nutritional value and to evaluate the marketability of fruits of accessions belonging to the two mentioned goji species grown in Peloponnese, in areas where trees considered subtropical, such as citrus and olives are cultivated. Differences in the levels of total soluble solids (TSS), pH, acidity, ascorbate, total carotenoids (TC), total phenolics (TP), total antioxidant capacity (TAC), major soluble sugars and minerals along with peel color, fruit weight and juice content of fresh fruits were studied in the six accessions of *L. barbarum* and the one of *L. chinense*. Moreover, the consumer's acceptance or liking was performed by a taste panel. A combination of objective results with the subjective ones was expected to give information for the marketability of the selected goji fruit in various forms.

Materials and methods

Source and handling of fruit

Fruits were harvested from six seedlings per accession, including six accessions of *L. barbarum*, A321/S, A514/S, A606/S, B213/S, A405/S and M123/S, and one accession of *L. chinense*, C123/S, all being four years old. Each accession corresponded to seedlings derived from dried fruits from different retail markets in Europe and originated from China.

All seedlings were rooted and cultivated under the same conditions on a property in Vrahati, Korinthia, Greece (37°57'N, 22°48'E, altitude 9 m a.s.l.). The soil was classified as clay-loam (CL) with a $CaCO_3$ content of approximately 15% (w/w), organic matter 1.8% (w/w), pH 7.8 and cation exchange capacity (CEC) 20 $cmol_{(+)}$ kg^{-1} soil. The objective determinations, apart from minerals, were carried out on fruits harvested on 17 July 2015 and transferred to the Laboratory of Pomology, Agricultural University of Athens. Berries were randomly divided in 8 lots of approximately 30 berries each. Four lots (replicates) were stored at -80 °C for analyses of phytochemicals within one month after harvest, whereas the rest were used for determinations on fresh fruit. Fruit harvested on 5 September 2015 were used for sensory test and mineral analyses.

Peel color

Peel color was determined on fruit layers in open petri dish (60 mm diameter), with a Minolta chromatometer (CR-300, Minolta, Ahrensburg, Germany), in the dark. Five measurements were conducted per replicate. Color is expressed L^*, hue angle (h^o) and chroma (C^*) (McGuire, 1992).

Juice percentage and moisture content of fruit

For the juice content, berries were homogenized using a food processor, then centrifuged at 4,000 × g for 5 min and the volume of the supernatant juice was measured. Moisture was determined by drying approximately 10 g berries at 60 °C for 3 days and then at 105 °C for 3 h.

Total soluble solids (TSS), pH and titratable acidity

Juice was used for the estimation of total soluble solids (TSS), using a refractometer (HI 96801, Hanna Instruments Inc., Woonsocket, Rhode Island, USA) and expressed as °Brix. pH and titratable acidity(TA) measurements were also measured in the juice. TA was determined by titration with 0.1 N NaOH to pH 8.2 and expressed as citrate % (w/w). All assays were conducted twice per replicate.

Determination of ascorbate content

Ascorbate content was estimated according to Tsantili *et al.* (2002). In detail, 10 g berries were homogenized with oxalic acid 0.5% (w/v) (10 mL g^{-1} tissue) using a laboratory blender (Model 38BL40, Waring Commercial, New Hartford, USA) and filtered through a Whatman No. 1 paper (Whatman Ltd., Maidstone, UK). One mL of the homogenate was diluted with oxalic acid 0.5% (w/v) in a ratio of 1:10 and titrated with phenolindo-2,6-dichlorophenol. The results were expressed as ascorbate on a fresh weight basis.

Extraction and determination of total phenolics (TP) and total antioxidant capacity (TAC)

The extraction of total phenolics (TP) and total antioxidant capacity (TAC) was performed by homogenizing frozen berries with 80% acetone (v/v) in deionized water (3 mL g^{-1} tissue) in the laboratory blender. The mixture was placed in a super-sonic ice bath at 4 °C under darkness for 15 min and then centrifuged at 4,000 × *g* for 5 min. The procedure was repeated three times and the combined supernatants were used for TP and TAC analysis (Christopoulos and Tsantii, 2012).

The total phenolic (TP) concentration of goji fruit was estimated using the Folin-Ciocalteu colorimetric method with some modifications (Singleton *et al.*, 1999). Briefly, 0.2 mL of diluted extract with DDW (1:2) was added into a tube containing 0.2 mL Folin-Ciocalteu reagent and 2.6 mL deionized water. After stirring the tube was stored at room temperature for 6 min. Then, 2 mL Na_2CO_3 (7%, w/v) were added to the mixture and the absorbance was measured at 750 nm using a spectrophotometer (Heλios Gamma and Delta, Spectronic Unicam, UK) versus a blank, after 90 min incubation at room temperature. The results were expressed as gallic acid equivalents on a dry weight basis.

The total antioxidant capacity (TAC) of goji fruit was evaluated according to Ferric Reducing Antioxidant Power (FRAP) assay (Benzie and Strain, 1999). Particularly, 0.1 mL of extract diluted with DDW (1:2) was added in a screw tap tube containing 3 mL of preheated at 37 °C FRAP reagent. The mixture was incubated at 37 °C for 30 min and the absorbance was read at 593 nm versus a blank. The results were expressed as trolox acid (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) equivalents on a dry weight basis. Three determinations were conducted per replicate in both cases of TP and TAC.

Extraction and determination of total carotenoids (TC)

The total carotenoid (TC) content in goji berries was evaluated according to Nagata and Yamashita (1992). In detail, the extraction was conducted by homogenizing 0.5 g of frozen tissue mixture with a solution (10 mL g^{-1} tissue) of acetone-hexane (4:6 v/v) using an Ultra-Turrax (T25, Kika Labortechnik, Germany) at 9,500 rpm for 1 min. Then, the homogenate was stirred at 450 rpm for 30 min using an orbital shaker and centrifuged at 4,000 × *g* for 5 min. The procedure was repeated three times and the absorbance of the combined supernatants was measured at 663, 645, 505 and 453 nm. The TC concentration was estimated by the equation:

$$TC = 0.216 \times Abs_{663} - 1.22 \times Abs_{645} - 0.304 \times Abs_{505} + 0.452 \times Abs_{453}$$

The results were expressed as total carotenoids on a dry weight basis. Determinations were conducted thrice per replicate.

Extraction and determination of soluble sugars

Sucrose, glucose and fructose concentration in goji berry fruit were determined in juice obtained after a centrifugation at 4,000 × *g* for 6 min. Then, juice was diluted with deionized water in 1:10 ratio, filtered through a nylon syringe filter (0.2 µm pore size) and analyzed by HPLC. The separation of sugars was achieved with a Hamilton HC-75 cation exchange column, calcium form, (Bonaduz, Switzerland) at 80 °C, operating with a Water 510 isocratic pump with a flow of 0.6 mL min^{-1} and connected to a Refractive Index detector in an HP 104 7A HPLC (Hewlett-Packard, Waldbronn, Germany) system. Peaks were identified and quantified with standards using a data processing system (Peak Simple 3.25), and expressed on a dry weight (DW) basis.

Fruit mineral analysis

Four fruit samples (replicates), each one consisted of about 20 g of fresh goji berries, were used for the analysis. Each sample was washed once with tap water and twice with distilled water, oven-dried at 75 °C for 96 h, then at 105 °C for 5 h, and finally milled to a fine powder that was passed through 50-mesh sieve. More specifically, the ash (1.0 g sample at 550 °C for 8.5 h) was dissolved in 5 mL HNO_3 (65 %, v/v, Carlo Erba) and filtered through a No. 1 paper (MN 615, Macherey-Nagel). The extract was diluted with deionized water up to a final volume of 50 mL (concentrated solution) used for Fe, Mn, Zn, Cu and Na determinations. Extra dilutions of the concentrated solution with deionized water were used for the measurements of K (× 7), Mg (× 50) and Ca (× 50). The concentrations of Ca, Mg, Fe, Mn and Zn were determined by atomic absorption spectrometry (Spectra A300, Varian Inc.), while those of K and Na by flame photometry (PGI 2000, PG Instruments Ltd.).

Sensory evaluation

The sensory panel consisted of 20 people (10 men and 10 women, aged from 25 to 60), all untrained and experienced with fresh goji fruits once previously in the same season. Each panelist individually evaluated 7 independent groups of 12–15 berries each, one group per accession, in succession that were blind labeled with 4 digits codes randomly. During the sensory evaluation each panelist had a glass of room temperature water. For each evaluated characteristic the rating was based only on 3-point scale (1: low intensity; 2: medium intensity; 3: high intensity) due to inexperienced panel to these fruits. The evaluated attributes were: size, peel color, flesh color, texture (firmness/crispiness), agreeable feeling of seeds, sweetness, sourness, bitterness/astringency, overall taste (O.V.T.) and overall acceptance (O.A.A.). Few lines were left blank on the recording sheet for the panelists to write notes.

Statistical analysis

In each accession, all mature fruits from six seedlings were harvested, mixed and divided into 7 lots for further determinations. The accession effect on objectively determined variables was estimated by a one-way analysis of variance. Comparison of means between the variables was based on HSD values (a = 0.05). Juice percentage, TSS, acidity and pH were estimated on three replicates of 35 fruits, the rest objective determinations on four, while the sensory test was evaluated by 20 persons. Kruskal-Wallis non-parametric analysis of variance was used to study the accession effect on sensory attributes. The statistical analyses were made using Sigmaplot 13 (Trial version, Systat Software, San Jose, CA).

Table 1. Color attributes, L^* (Lightness), h° (hue) and C^* (Chroma), juice content, total soluble solid levels (TSS), pH and titratable acidity (TA) of the fruit of goji berry accessions. Data values are means of 3 replicates of 35 berries each. FW: fresh weight.

Accessions	L^*	h°	C^*	Juice content (mL 100 g^{-1} FW)	TSS (°Brix)	pH	TA (% citrate)
A321/S	36.72 a[x]	46.56 b	45.89 ab	71.70 bc	20.03 c	5.33 cd	0.22 d
A514/S	41.38 a	50.11 a	53.33 a	68.96 c	22.56 a	5.53 ab	0.22 d
A606/S	39.28 a	46.92 b	44.33 bc	71.66 bc	22.50 a	5.30 bcd	0.29 bc
B213/S	40.34 a	50.26 a	44.81 bc	73.06 bc	21.90 ab	5.63 a	0.10 e
A405/S	33.04 a	43.65 c	38.03 bc	76.46 a	23.40 a	5.38 bc	0.27 cd
M123/S	39.46 a	46.77 b	38.03 bc	79.66 a	20.60 bc	5.15 d	0.35 b
C123/S	33.06 a	42.47 c	38.03 bc	77.80 a	14.30 d	5.33 bcd	0.42 a
Significance[y]	*	***	***	***	***	***	***

[x] Means in a column with different letters denote significant difference (Tukey's HSD test at P = 0.05).
[y] * : $P < 0.05$; *** : $P < 0.001$.

Table 2. Concentration of total phenolics (TP), Ferric Reducing Antioxidant Power (FRAP) and sugars (glucose, fructose and sucrose) in the fruits of goji berry accessions. Data values are means of 4 replicates of 30 berries each. DW: dry weight.

Accessions	TP (mg g^{-1} DW)	FRAP (µmol g^{-1} DW)	Sugars (mg g^{-1} DW)		
			Glucose	Fructose	Sucrose
A321/S	6.94 ab[x]	41.48 b	153.57 cd	192.96 c	15.26 ab
A514/S	4.49 c	37.91 b	133.38 d	159.03 c	13.59 cd
A606/S	4.94 c	45.25 b	170.65 bc	197.49 bc	17.63 a
B213/S	5.01 bc	45.83 ab	204.53 ab	234.65 ab	16.04 abc
A405/S	7.78 ab	41.64 b	189.73 ab	239.88 a	12.05 d
M123/S	7.30 ab	46.29 ab	213.04 a	275.21 a	13.89 bcd
C123/S	13.40 a	63.53 a	74.59 f	104.28 d	17.20 ab
Significance[y]	***	***	***	***	***

[x] Means in a column with different letters denote significant difference (Tukey's HSD test at P = 0.05).
[y] *** : $P < 0.001$.

Table 3. Concentration of minerals (on a dry weight basis) in the fruits of goji berry accessions. Data values are means of 4 replicates of 20 berries each. K: potassium; Ca: calcium; Mg: magnesium; Na: sodium; Zn: zinc; Cu: copper; Mn: manganese; Fe: iron.

Accessions	K (%)	Ca (%)	Mg (%)	Na (%)	Zn (µg g^{-1})	Cu (µg g^{-1})	Mn (µg g^{-1})	Fe (µg g^{-1})
A321/S	1.61 b[x]	0.08 bc	0.14 a	0.31 b	28 b	28 a	14 b	36 ab
A514/S	1.17 c	0.05 c	0.09 cd	0.23 e	20 d	15 e	5 d	28 c
A606/S	1.16 c	0.04 d	0.09 cd	0.26 c	30 b	23 b	5 d	36 ab
B213/S	1.22 c	0.08 b	0.10 c	0.45 a	23 c	20 cd	8 c	38 a
A405/S	1.26 c	0.05 cd	0.12 b	0.14 e	24 c	21 c	8 c	17 d
M123/S	1.14 c	0.05 c	0.08 d	0.30 b	22 cd	19 d	3 e	31 bc
C123/S	2.42 a	0.12 a	0.15 a	0.03 f	37 a	24 b	17 a	27 c
Significance[y]	***	***	***	***	***	***	***	***

[x] Means in a column with different letters denote significant difference (Tukey's HSD test at P = 0.05).
[y] *** : $P < 0.001$.

Results and discussion

Fruit weight, juice content and color

The weight of ten fruits ranged from 4.20 to 8.6 g (Figure 1A). Fruits from the seedlings M123/S and A405/S, belonging to *L. barbarum* species, showed similar weight values, but higher than the rest berries. The lowest weight was found in C123/S that belongs to *L. chinense*. The juice content in fruits varied between 79.4% (v/w) in M123/S and 68.6% (v/w) in A514/S (Table 1), being in agreement with other goji works (Amagase and Farnsworth, 2011; Lim, 2013; Potterat, 2010). Although the fruits of the C123/S seedling were low in fresh weight and had smaller size than those belonging to *L. barbarum*, the juice content, an important quality attribute, was notably high, being comparable to M123/S and A405/S. The large fruits is a desirable quality trait, primarily for the fresh fruits and secondly for the dried ones, rendering them more attractive to consumers. Besides, the relatively large size of goji fruit is also very important because it facilitates the harvest of these small and sensitive fruits. All fruits had obtained an orange color in the peel (Table 1). However, the fruits of *L. chinense* had an orange-reddish color (lowest h^o, lowest L^* and low C^*, being approximately 33, 43 and 38, respectively) and followed by the A405/S accession with a deep orange color. The brightest color was observed in fruits of A514/S (highest h^o and C^*, and high L^*). The orange to orange-red color of goji fruits depends mostly on their carotenoid accumulation, with zeaxanthine dipalmitate being the major carotenoid in goji (Amagase and Farnsworth, 2011). Minor differences in weight, juice and color were detected among the other accessions of *L. barbarum*.

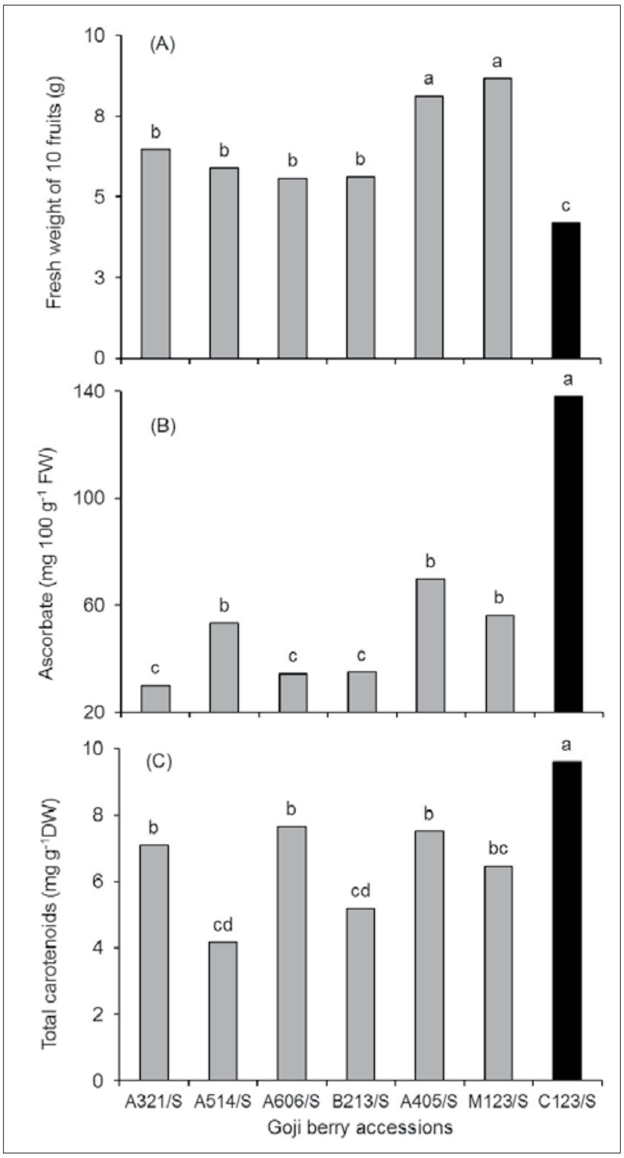

Figure 1. Fresh weight of ten fruits (A), and concentration of ascorbate (B) and total carotenoids (C) of goji berry accessions. In (A), (B) and (C), $P < 0.001$. Different letters denote significant difference following Tukey's HSD test at $P = 0.05$ (4 replicates of 30 berries). FW: fresh weight; DW: dry weight.

Total soluble solids (TSS), titratable acidity and pH

Small differences in the TSS (°Brix) were detected among the accessions of *L. barbarum*, ranging from 20.03 to 23.40 °Brix, whereas the C123/S, accession of *L. chinense,* exhibited the lowest TSS value (14.30 °Brix) (Table 1). On the contrary, the highest acidity was determined in C123/S (0.43) followed by that in M123/S and A606/S accessions (Table 1). Differences in pH values, although statistically significant, were only, ranging from 5.15 to 5.63 (Table 1). The levels of TSS, especially in relation to acidity are important components of the quality of several fruits, jams and juices (Zhao *et al.*, 2015). The considerably lower levels of TSS of C123/S accession suggest that they are more appropriate for processed products, such as jams or mixed juices (Table 1). Furthermore, the higher TSS and lower acidity in *L. barbarum* accessions could justify, up to a point, the popularity of this species in the fresh and dried fruits and in juices in the global market (Potterat, 2010; Zhao *et al.*, 2015). Interestingly, values of TSS and acidity similar to the present ones in both species were reported by another study of goji fruits (Zhang *et al.*, 2016), implying that the cultivation in different parts of the world plays a minor role in the levels of these important fruit characteristics.

Ascorbate, total carotenoids (TC), total phenolics (TP) and total antioxidant capacity (TAC)

The fruits of *L. chinense* contained significantly higher levels of ascorbate and TC than all accessions of *L. barbarum* (Figure 1B–C). In particular, in C123/S ascorbate reached the level of 138 mg 100 g^{-1} FW, while TC that of 9.59, being approximately 2.45-fold and 1.51-fold higher than the averaged ascorbate and TC in the rest fruits, respectively. Low and similar ascorbate values were found in A321/S, A606/S and B213/S accessions, while medium values were observed in A514/S and B213/S. Total phenolic concentrations and TAC levels, as FRAP, were also highest in C123/S, reaching 13.4 mg g^{-1} DW and 63.53 µmol g^{-1} DW, respectively, but not statistically different from the TP concentrations in A405/S, M123/S and A321/S, and from the FRAP values in B213/S and M123/S (Table 2).

Ascorbate and polyphenols have been reported to have beneficial antioxidant, anti-microbial and anti-inflammatory properties (Amagase and Farnsworth, 2011; Kris-Etherton *et al.*, 2002), and goji berries are considered to be good sources for both. Accordingly, Mocan *et al.* (2014) reported elevated phenolic content and antioxidant activity in the leaf extracts of *L. chinense* in comparison to those of *L. barbarum*. *Lycium chinense* synthesized/accumulated higher levels of TP and other antioxidants in its organs than *L. barbarum* (Table 3). However, it should be noted that the accessions belonging to *L. barbarum* used to have relatively high antioxidant activity in comparison to other 'super-foods' (Donno *et al.*, 2015; Wu *et al.*, 2004). Goji berries are also rich sources of carotenoids and other antioxidants, and *L. chinense* appeared to be richer in TC by about 20–22% compared with A405/S and M123/S accessions.

Regarding *L. barbarum*, it appears that M123/S and A405/S fruits exhibited high TAC and contained comparably high levels of the antioxidants examined in this study. Interestingly, Zhang *et al.* (2016) reported rather comparable levels of FRAP and TC, but considerably higher levels of TP in goji berry genotypes that were cultivated in China. However, the present TP results are in close agreement with other findings, such as of Mikulic-Petkovsek *et al.* (2012), while those of TC with the work of Lin *et al.* (2011).

According to Wang *et al.* (2010), flavonoids of goji berries exhibited the most profound effect in scavenging free radicals, while zeaxanthin was more effective in scavenging the hydroxyl- and superoxide-free radicals. Moreover, zeaxanthin provides protection to the skin from oxidation by the extensive exposure to the sun and by other oxidative processes. It is noteworthy that goji contains higher carotenoids than carrots (Fuentes *et al.*, 2012) and considerably higher levels of total antioxidants than other berries. However, they are mostly consumed dried, and therefore, it is of particular interest that losses of TC during drying of the fruit are not high (Amagase and Farnsworth, 2011; Wen-Pig *et al.*, 2008).

Concentration of major sugars

Significant differences were detected among different goji berry accessions in the accumulation of simple sugars (Table 2), although the results are in general agreement with previous findings (Mikulic-Petrovsek *et al.*, 2012) The M123/S, A405/S and B213/S accessions of *L. barbarum* accumulated high levels of glucose and fructose, averaged 202.0 and 249.9 mg g^{-1} DW, respectively, while exhibited levels of sucrose similar to the other genotypes (Table 2). The accession A514/S exhibited the lowest concentrations of glucose and fructose among *L. barbarum* accessions, being 133.4 and 159 mg g^{-1} DW, respectively. These results are comparable to those of Zheng *et al.* (2010), reporting that fluctuation existed in the sugar levels of different accessions of *L. barbarum*. The concentration of simple sugars probably affects the accumulation of polysaccharides, which are glycoproteins made of simple sugars. It is suggested that these glycoproteins are playing a key role in the organoleptic characteristics of the fruit (Zhao *et al.*, 2015). By contrast, here, the accession of *L. chinense* exhibited the lowest levels of both glucose and fructose (74.5 and 104.3 mg g^{-1} DW, respectively), whereas it accumulated comparably high levels of sucrose (17.2 mg g^{-1} DW). Indeed, Zheng *et al.* (2010) and Zhao *et al.* (2015) found differences in sugar levels in various genotypes and during fruit development, while sucrose was at lower levels than glucose and fructose in ripe fruits. In contrast, Kafkas *et al.* (2007) reported elevated levels of sucrose in comparison with other sugars during ripening. According to Zheng *et al.* (2010) such differences could be attributed to ecological factors and to field management.

Concentration of mineral elements

The C123/S accession of *L. chinense* exhibited higher concentrations of several mineral elements than most accessions of *L. barbarum*, with sodium being the exception and reached the lowest observed level of 0.03 μg g^{-1} DW (Table 3). In particular, fruits of C123/S exhibited 2.42% DW, 0.12% DW, 37 μg g^{-1} DW and 17 μg g^{-1} DW concentrations of potassium, calcium, zinc and manganese, respectively, being the highest observed for the respective minerals. Potassium concentrations were also high in all fruits of *L. barbarum* accessions, but lower than in C123/S by 1.9-fold, in average. Mean values of calcium, zinc and manganese concentration in *L. barbarum* were lower than in C123/S by 2.00-, 1.51- and 2.40-fold, respectively. Sodium content, however, was 56-fold higher in *L. barbarum* fruits, in average, than in C123/S ones, and this comprised the most prominent difference between the two species studied. These results suggest that considerable differences in mineral elements exist between the two species of goji (Table 3). Among the *L. barbarum* accessions, A321/S exhibited the highest potassium, magnesium, copper and manganese concentrations. However, the differences in most minerals found among the accessions of *L. barbarum* were minor.

Mirdehghan and Rahemi (2007) reported much lower concentrations of macro and micro nutrients in the edible part of pomegranates compared with most goji berry accessions examined in our study. Interestingly, *L. barbarum* fruits contained similar levels of potassium to those reported in banana (Hardisson *et al.*, 2001). Llorent-Martínez *et al.* (2013) and Yan *et al.* (2014) determined various minerals in goji accessions, with results of 'Ningqi No. 1' being mostly comparable to ours. The importance of mineral elements in human health is widely known as they are involved in

TABLE 4. Taste panel records for the fresh fruits of goji berry accessions evaluated by 20 persons. Data values are medians. Accession effect was estimated by the H-test (df = 6). OAT: overall taste; OAA: overall acceptance.

Accessions	Size	Peel color	Flesh color	Texture (Firm/crisp)	Agreeable feeling of seeds	Sweetness	Acidity	Bitterness/ astringency	OAT	OAA
A321/S	1.0 c[x]	2.0 ab	2.0 b	2.0	3.0 a	2.0 b	1.0 ab	1.0 b	2.0 a	2.0 a
A514/S	2.0 ab	1.0 c	1.5 bc	2.0	3.0 a	2.0 b	1.0 b	1.0 b	2.5 a	2.0 a
A606/S	2.0 ab	2.0 b	2.0 b	2.0	2.0 a	2.0 b	1.5 ab	2.0 b	2.0 a	2.0 a
B213/S	2.0 ab	1.0 bc	2.0 b	2.0	3.0 a	3.0 a	1.0 b	1.0 b	1.0 b	1.0 b
A405/S	3.0 a	2.0 b	2.0 b	2.0	3.0 a	2.0 b	1.0 b	1.0 b	3.0 a	3.0 a
M123/S	3.0 a	1.0 c	1.0 c	2.0	3.0 a	2.0 b	1.0 ab	1.0 b	2.0 ab	3.0 a
C123/S	1.0 c	3.0 a	3.0 a	2.0	1.0 b	1.0 c	2.0 a	3.0 a	1.0 c	1.0 b
Significance[y]	***	***	***	ns	***	***	***	***	***	***

[x] Medians in a column not sharing the same letter are significantly different (Tukey's HSD test).
[y] ns: not significant; *** : significant at $P < 0.001$.

many biochemical processes including water and electrolyte balance, metabolic catalysis, oxygen binding, and hormone functions (Nile and Park, 2014). Llorent-Martínez *et al.* (2013) underlined the nutritional value of fresh goji berries in comparison with other juices and food supplements.

Taste panel test

The panel could discriminate the smaller size, deeper orange coloration, less agreeable feeling of seeds, less sweetness and higher acidity in C123/S fruits than the rest ones belonging to *L. barbarum* accessions (Table 4). However, a strong bitter/astringent taste was recorded for C123/S by all panelists. Generally, in Greece, it has been observed that all accessions of *L. chinense* exhibited a more or less bitter and astringent taste. After all, the panel accepted all *L. barbarum* fruits tested (Table 4), apart from the B213/S due to an "unbalanced" sensory profile. The panelists showed a clear preference for both A405/S and M123/S probably because of their large size and their "balanced" sensory profile. In contrast, the fruits of *L. chinense* were clearly discarded for fresh consumption as inedible food, because of their low sweetness and high bitterness/astringency besides their small size. The accession effect was highly significant on sensory attributes except for texture. The overall acceptance was rather connected to a large size and an overall good taste of the fruit.

Conclusion

This study gives information related to nutritional value and consumer preference for fruit coming from goji accessions belonging to *L. barbarum* and *L. chinense* species, grown in Greece in areas where traditionally subtropical fruit trees are cultivated. Indeed, growers claim that *Lycium* spp. can be cultivated in the Crete island, bordering a tropical climate. In such conditions, the fruit of C123/S accession of *L. chinense*, was rich in antioxidants, particularly in ascorbate, as well as, in potassium, calcium, zinc and manganese, but they had small size and high bitterness/astringency that render the fresh fruit inedible. However, the possible usage of this species in the food industry, jam preparation, juices mixed with other goji varieties or other fruits, or even used for the preparation of specific products, such as nutrient supplements, should be examined. The fruit of *L. barbarum* was also rich in antioxidants and minerals, being comparable to those produced in China, while most of them were well accepted by the panel. Panelists showed their preference for the berries of M123/S and A405/S accessions, attributed to both large size and good taste of the fruit, indicating they are edible in fresh or dried form provided that the selected accessions will be properly propagated and cultivated. In addition, the selected accessions could be used as a source of genetic material for the production of improved varieties of goji.

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