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ORIGINAL PAPER

Nutritional value, bioactive compounds and antioxidant activities of wild chicory (*Cichorium intybus* L.) from Turkey

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Abstract

Despite being ignored in the modern agricultural approach, wild vegetables have an important use in Turkey and contribute to a balanced diet and food security at the household levels. This study focused on the nutritional content of wild chicory (*Cichorium intybus* L.) that is widely consumed as a vegetable by people living in rural areas in Turkey. The nutritional value and bioactive compounds and antioxidant contents in twenty-one wild chicory populations from Turkey were investigated by analyzing the leaf. The collected chicory seeds were sown in pots and grown in greenhouse conditions. 40 days after sowing, crude protein, mineral matters (Ca, Mg, P, K, Mn, Cu, Fe, Zn) and antioxidant contents were determined. Significant differences were noted among to chicory populations regarding all the investigated parameters. Crude protein content among the population was between 20.45 and 27.89% and averaged 23.65%. Averaged mineral contents over the populations were ordered as follows: K > Ca > Mg > P > Fe > Mn > Cu. The variation was between 15.3 and 25.8 mgGAE/g extract for total phenolic and between 1.43 and 2.55 µgQE for total flavonoid content. Overall results showed that chicory can contribute to a healthier diet and food security by diversification of food sources. In addition, the geographical origin of the population was important in the traits examined, which can shed light on the selection of genotypes for breeders.

Keywords Chicory · Protein · Antioxidant · Vegetable

Introduction

Wild vegetables can contribute to the solution of micronutrient deficiency, which is one of the most important problems of the modern diet, and to make people healthier. Globalization and modernization in agriculture led to changes in food supply and the formation of simple diets with a few staple crops (Welch and Graham 1999), which is deficient in nutrients especially for micronutrient that is necessary for healthy diets. Developments in agriculture and changes in nutritional habits dramatically reduced the consumption of most edible wild species, and some of them were eliminated from the diet (Grivetti 1981). However, wild edible plants are still consumed at different scales due to their taste, health effects and nutritional value, and they constitute an important part of the diet of many people throughout Europe, especially in the Mediterranean basin (Guarrera and Savo 2016). This is due to poverty, famine and sometimes a tradition depending on the circumstances. Today, there is an interest in wild vegetables with increasing awareness on food quality and a more balanced diet, as well as understanding their importance in reducing poverty, ensuring food security, agricultural diversification and income generation. (Zou et al. 2010).

Many wild edible plants are traditionally consumed as vegetable since ancient times. Up to 75 000 plants are edible worldwide and about 7 000 of them are eaten regularly (Myers 1983). The studies on the micronutrient composition of wild vegetables generally indicated their higher mineral and vitamin contents than in cultivated vegetables (Turan et al. 2003). These plants have potential benefits for their content in bioactive compounds, minerals and fibers (Guarrera and Savo 2016). They played an important role in complementing fundamental foods and in contributing human diet as source of macro- and micronutrients (Flyman and

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Afolayan 2006), antioxidant compounds, vitamins and proteins (Antia et al. 2006). Hence, they could make an important contribution to combating micronutrient malnutrition, as well as providing food security (Flyman and Afolayan 2006). Their leaves supply the body with higher values of antioxidant compounds, as well as minerals, vitamins and protein (Antia et al. 2006). Leafy vegetables may also have a role as functional foods, because they contain the rich and various (bioactive) substances such as carotenoids and pigments in the leaves (Zeb 2019). Also, Chicory contains flavonoids, among which luteolin and anthocyanins have been proved to be able to resist oxidative damage of body caused by environmental toxic heavy metals. Heavy metal pollution such as Cd, Hg, Mn, Zn, Cu, Mo and Ni causes obvious health risk for animals and humans (Sundseth et al. 2017). Many researchers have suggested that certain flavonoids have abundant pharmacological activities, including antioxidants, anti-inflammatory and anti-apoptosis (Li et al. 2016; Liu et al. 2018).

Chicory (*Cichorium intybus* L.) is one of the edible wild plants consumed as vegetable in Turkey and abundant in vegetation. Chicory is biennial plant of *Asteraceae* family with various properties and widely distributed in Asia and Europe, especially Turkey, Italy, Greece and Spain. It was cultivated in countries such as USA, UK, France, German, India and Belgium since long years (Bais and Ravishankar 2001). Chicory leaves rich in K, Ca, Mg, P minerals and A, C vitamins are consumed as vegetable meal and salad (Mulabagal et al. 2009).

Beside carbohydrates, proteins, lipids, and essential minerals, chicory also provides humans a plethora of important phytochemicals, like antioxidant. Antioxidants, which cannot be adequately synthesized by the human body and must be taken with sufficient doses of food daily, have an important biological activity (Morales et al. 2014). Since antioxidants powered the defense system in the human body, they are of great importance in proper nutrition (Jiménez et al. 2008). Free radicals in antioxidants react with lipids, proteins and nucleic acids and prevent causes which leads to various neurological, cardiovascular and some other physiological disorders (Sinkovič et al. 2020). Abbas et al. (2015) determined that due to good phytochemical and antioxidant composition, *C. intybus* L., leaves would play an important role in improving the human health by participating in the antioxidant defense system. In chicory, the highest total phenolic acids concentration was founded in flowers, followed by leaves, roots and stems (Stanciu et al. 2019). Montefusco et al. (2015) determined that there were variation among chicory varieties in terms of antioxidant activity and content of total phenolic and flavonoids.

Acceptance and utilization of wild vegetables are currently constrained by lack of knowledge about their nutritive value, methods of preparation and preservation, as well as their strongly localized importance (Mnzava 1997). Wild edible plants have been used in diet as a source of food from prehistoric times onwards and they are still common in Turkish cuisine. However, studies on the nutritional value of wild chicory are quite limited in Turkey. Therefore, the present study was aimed to determine the variation in twenty-one Turkish origin wild chicory populations within the scope of protein, mineral matter, bioactive compound, antioxidant activity and some morphological characters.

Materials and methods

Twenty-one chicory populations were collected from different regions of Turkey in the autumn of 2018 (Table 1). Each population was seeded, to plastic pots ($50 \times 17 \times 15$ cm) filled with 75% soil and 25% peat mixture. The seedlings were thinned to 15 per pot, and the plants harvested 40 days after sowing. The experiment was arranged in randomized block design with three replications and carried out in May–June 2019 in greenhouse conditions at the Agriculture Faculty of Yozgat Bozok University, Turkey (Fig. 1).

Determination of morphological *characters*

Forty days after sowing, the leaf length (cm), root length (cm), root width (mm), dry weight (g) were determined on randomly selected five plants and averaged for each pot. The

Table 1 List of the chicory populations collected from Turkey

Location	Name
Amasya	*Amy*
Aydin	*Ayd*
Balikesir	*Bks*
Bilecik	*Blc*
Bursa	*Brs*
Corum-C	*Crm1*
Corum-Y	*Crm2*
Eskisehir	*Eks*
Izmir	*Imr*
Konya	*Kny*
Kirikkale	*Krk*
Kayseri	*Kys*
Manisa	*Mns*
Nigde	*Ngd*
Nevsehir	*Nvs*
Samsun-Kampüs B	*Sm1*
Samsun-Kampüs	*Sm2*
Samsun-Carsamba	*Sm3*
Samsun-Vezirkopru	*Sm4*
Yozgat-Camlik	*Ygt1*
Yozgat-Yerkoy	*Ygt2*

Fig. 1 Distribution of the locations where plants are collected over Turkey (There is more than one population in some locations)

general view of the seedling, root and leaf of the chicory can be seen in Fig. 2. Leaf length was measured on the first true leaf, while the root width at the top widest part of the root. The dry weight included the total leaves of five plants. The leaves were oven-dried at 60 °C for 48 h and weighed.

Crude protein analysis

The leaves randomly taken from pot were dried and finely powdered (1 mm) for protein, mineral matter and antioxidant analysis. Crude protein content (%) of chicory leaves was determined in near infrared reflectance spectroscopy (Foss 6500) (Foss NIRSystems, Inc., Silver Spring, MD, USA) with IC-0904FE software.

Mineral matter analysis

1 g of the powdered leaf sample was ashed in the furnace for 3 h at 550 °C. After cooling, 4 ml of 3 N HCl was added to each sample. After waiting for 30 min, the samples were filtered and diluted with 50 layers of distilled water. The determination of mineral matters (Ca, Mg, P, K, Mn, Fe and Cu) in prepared liquid samples was performed by inductively coupled plasma mass spectrometry (ICP-MS) using a Thermo ScientificiCAPQc (Bremen, Germany).

Fig. 2 General view of the chicory forty days after sowing

Determination of antioxidant activities

Preparation of samples for analysis

For the extraction, chicory leaves were dried under shade and mechanically ground with a blender. 4 g (three replicate) of each grounded plant materials was extracted individually in 40 mL of 100% methanol at 40 °C for 24 h. The resulting solutions were filtered through Whatman paper, and the solvent was removed on a rotary evaporator at temperature below 40 °C (Yaman et al. 2020). Extract amounts of chicory populations of each location were calculated in %.

Total phenolic contents

The total phenolic contents (TPC) in extracts of the chicory were measured using the Folin-Ciocalteu method (Singleton et al. 1999). Briefly, 0.2 mL Folin-Ciocalteu and 9 mL distilled water were added into the 200 µL of each extract of the chicory. Finally, 0.6 mL of 20% sodium carbonate solution was added, and the total volume was adjusted to 10 mL. After the mixtures were kept in the dark for 2 h at room temperature, absorbance measurement was read at 760 nm. The results were represented as mg gallic acid equivalent (GAE)/g extract. The calibration curve was created using nine different concentrations of the gallic acid standard ($y = 0.002x - 0.0068$; $R^2 = 0.9995$).

Total flavonoid content

The total flavonoid contents (TFC) of the extracts were measured using the method developed by Arvouet-Grand et al. (1994) with minor modifications. Each extract of the chicory (200 µL) was mixed with 10% aluminum nitrate (100 µL) and 1 M potassium acetate (100 µL). The total volume was adjusted to 5 mL with 99% ethanol. After the mixtures were incubated in the dark for 40 min at room temperature, absorbance measurement was performed at 417 nm. The total flavonoid contents of the extracts were calculated as µg quercetin equivalent (QE) using calibration curve ($y = 0.0004x + 0.0087$; $R^2 = 0.9925$) of quercetin standard.

DPPH free radical scavenging activity

The effect of the extracts of the chicory on 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical was tested according to (Yaman et al. 2020). The sample (200 µL) was added to a 3.2 mL of a 0.004% methanol solution of DPPH. After the mixtures were incubated in the dark for 30 min at room temperature, absorbance measurement was performed at 517 nm. According to the graph of trolox standard ($y = 0.0066x - 0.0192$; $R^2 = 0.9998$), the DPPH radical scavenging activities of the extracts were expressed as µg trolox equivalent (TE).

ABTS free radical scavenging activity

ABTS was used for evaluation of radical cation scavenging activity according to the method described by (Re et al. 1999). In this method, the stock solution of $ABTS^{\bullet+}$ was obtained directly by reaction of 30 mg ABTS and 6.6 mg potassium per sulfate in 7.8 mL of distilled water, and allowing the mixture to stand for 12–16 h in dark at the room temperature. Then, the ABTS solution was diluted with methanol to an absorbance of 0.700 ± 0.020 at 734 nm using a UV–visible spectrophotometer. 2.8 mL of ABTS solution was added on 100 µL of solutions of all tested extracts and mixed. The absorbance was recorded at 734 nm after 30 min incubation at room temperature in the dark. The ABTS free radical scavenging activities of all tested extracts were calculated as µg trolox equivalent (TE) using calibration curve ($y = 0.0087x + 0.0122$; $R^2 = 0.9996$) of quercetin standard.

Statistical analysis

Data collected were *subjected to analysis* of variance (*ANOVA*), and means among treatments were separated by Duncan's multiple range test. Some results are expressed as mean with standard deviations (± SD) and coefficient of variation (CV%). The principal component analysis (PCA) was used to evaluate the associations between the traits and populations.

Results and discussion

Morphological characters

Data on the morphological characters of chicory populations are given in Figs. 3 and 4. Based on the observations made on forty-day-old plants, the leaf length was averaged of 15.84 cm with a significant ($p < 0.05$) differences between the chicory populations. Population *Bks* had the highest leaf length with 18.53 and was in the same group with *Amy*, *Ayd*, *Crm1*, *Eks*, *Imr*, *Mns*, *Nvs*, *Sm2*, *Sm3* and *Ygt1*. The lowest leaf length was determined in the populations *Sm4* (13.97 cm) and *Kys* (14.19 cm) (Fig. 3).

The average dry weight over the populations was measured as 1.26 g. Dry weight was significantly ($p < 0.01$) affected by populations and was the highest in the population of *Bks* (2.24 g) (Fig. 3). Accordingly, *Bks* population had the highest values in terms of leaf length and dry weight.

Differences in root length and root width were significant ($p < 0.01$) among the populations (Fig. 4). At the end of 40 days, the root length was varied from 10.07 (*Cmr2*)

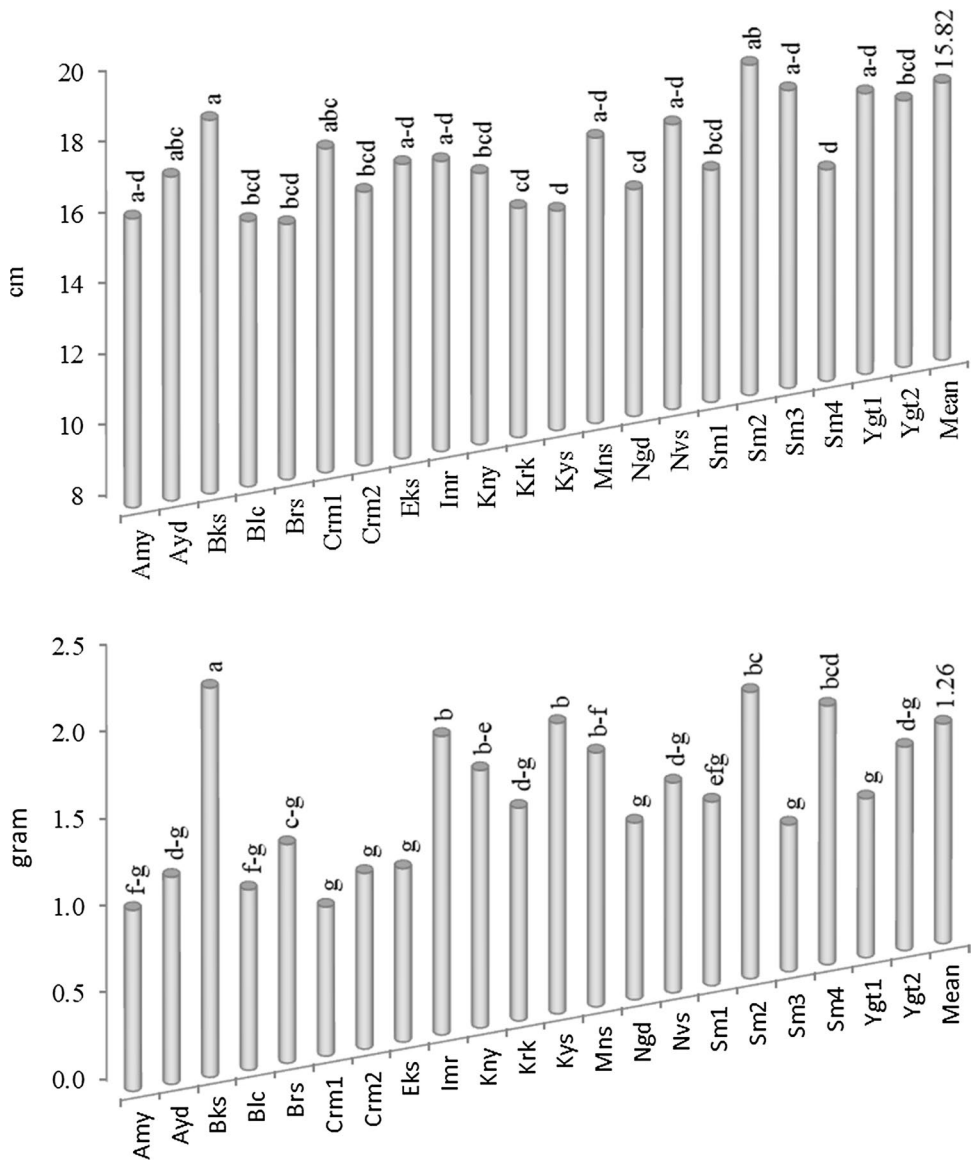

Fig. 3 The leaf length* (upper) and dry weight** (below) of chicory populations. There is no difference between the means shown with same letters ($p < 0.05$), *$p < 0.05$, **$p < 0.01$

to 21.33 cm (*Imr*). The highest root length was detected in populations *Imr*, *Amy* and *Kny*. The population *Mns* had the largest root width (4.35 mm) and placed in the same group with the populations *Imr*, *Bks*, *Kys* and *Sm2* (Fig. 4). According to this result, the population Imr came forward in terms of root development.

Leaf length, root length and fresh weight of chicory were previously reported as 21.6 cm, 32.3 cm and 4.70 g/plant, respectively, under greenhouse condition after 16 days of sowing (Tzortzakis 2009). Kumari et al. (2007) stated that the leaf fresh and dry weight of three-month-old chicory is approximately 50 and 20 g. Doorenbos and Riemens (1959) detected 10.3–11.9 cm of leaf length and 60–85 g of fresh weight in chicory end of three months.

In the present study, partially negative relationship between the subsoil and aboveground development of the chicory was determined. This may be related to the physiology of the plant. Chicory is a physiologically biennial plant needing vernalization. First year, plant develops mainly root and forms a rosette of leaves. The winter cold induces the plant to flower and formation of a stalk (bolting) (Mathieu et al. 2014). Therefore, root development of chicory in the first year may be related to second year performance. Naturally, populations with better aboveground development in the first year can be preferred for the selection of vegetable types genotypes.

Nutritional value

The crude protein and mineral matter contents of twenty-one chicory populations are given in Table 2. Crude protein content was significantly ($p < 0.01$) affected by

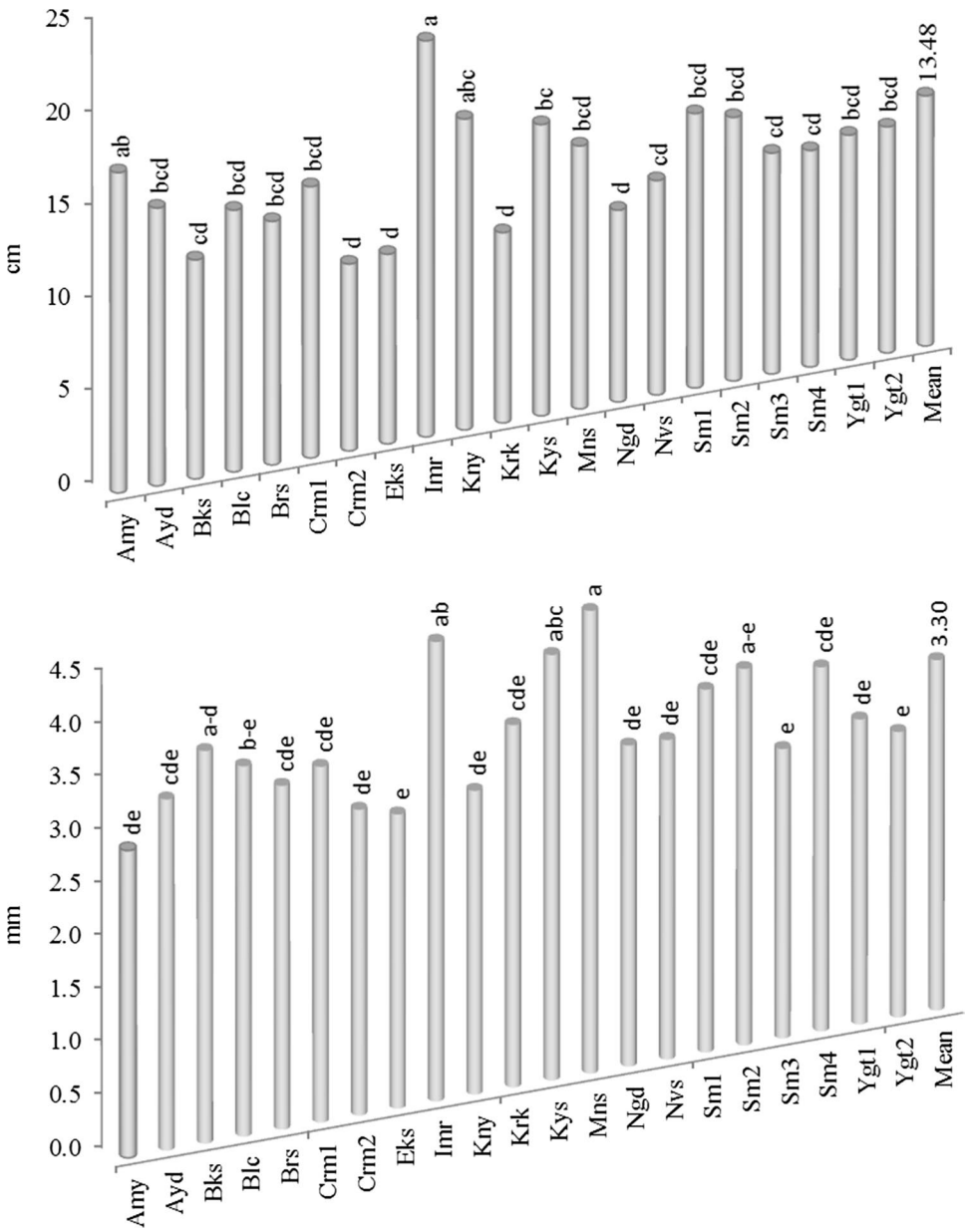

Fig. 4 The root length** (upper) and root width** (below) of chicory populations. There is no difference between the means shown with same letters ($p < 0.05$). **$p < 0.01$

population and averaged 23.65%. The highest crude protein content was detected in population *Sm1* with 27.89%, followed by population *Bks* (27.26%) and *Mns* (25.74%). The lowest crude protein content (20.45%) was in population *Blc*. For the later stages of the plant, protein content reported by Jan et al. (2011) as 14.10%, by Shad et al. (2013) as 14.13% and by Ozturk et al. (2006) as 13.10%. Caunii et al. (2010) reported that protein content of chicory leaf was about 25% higher than in lettuce. James and Emmanuel (2011) found lower protein content in Malabar spinach and lettuce than our study. Additionally, García-Herreraa et al. (2014) reported that crude protein of chicory was lower than *Chondrilla juncea* but higher than *Taraxacum obovatum*.

Over the populations, mean content was 5.61% for K, 1.24% for Ca, 0.55% for Mg, 0.19% for P, 44.21 ppm for Mn, 293.45 ppm for Fe, 7.33 ppm for Cu. Mineral contents were significantly different among the populations. In terms of K content, the superior population was *Ngd* (6.35%) and was in the same group with *Amy*, *Bks*, *Crm1*, *Imr*, *Kny*, *Mns* and *Sm3*. The lowest K content was determined in population *Kys* (4.50%). Ca content was the highest in populations *Sm1* (1.57) and *Ayd* (1.45%). *Mns* and *Sm4* were the highest Mg content populations with 0.72 and 0.68%, respectively. On the other hand, the lowest Ca (0.90%) and Mg (0.44%) contents were noted in the population *Blc*. P content was the highest in population *Sm1* (0.25%) and the lowest in *Krk* (0.14%). Among the micro-minerals, the

Table 2 Crude protein and mineral matter contents of the chicory populations

Population	Crude** protein %	K** %	Ca** %	Mg** %	P** %	Mn** ppm	Fe** ppm	Cu** ppm
Amy	22.50 k	6.26 ab	1.27 c–f	0.62 cde	0.20 b–e	46.09 de	342.82 b–d	6.82 c–f
Ayd	24.10 f	5.71 b–e	1.45 ab	0.59 d–g	0.21 b–d	40.91 e–g	339.07 b–e	7.78 a–e
Bks	27.26 b	5.75 a–d	1.39 b–d	0.56 e–i	0.20 b–e	51.30 bc	332.26 b–f	8.48 ab
Blc	20.45 p	4.98 f–h	0.90 i	0.44 l	0.15 ij	34.45 h	263.96 c–h	5.40 fg
Brs	23.05 j	5.26 d–g	1.08 h	0.46 kl	0.15 ij	39.41 f–h	286.55 b–h	6.50 d–f
Crm1	21.76 n	5.76 a–d	1.16 f–h	0.49 i–l	0.17 gh	39.12 f–h	266.61 c–h	8.04 a–d
Crm2	23.72 h	5.32 d–g	1.18 f–h	0.56 e–h	0.18 f–h	47.63 cd	253.66 d–h	7.20 b–e
Eks	23.21 ij	5.48 d–f	1.19 e–h	0.52 h–k	0.19 d–g	42.31 d–f	459.26 a	6.96 b–f
Imr	23.37 i	6.12 a–c	1.15 f–h	0.65 b–d	0.20 b–e	43.67 d–f	239.83 f–h	8.30 a–c
Kny	25.22 d	6.25 a–c	1.29 c–f	0.53 g–k	0.22 b	42.00 ef	294.89 b–g	8.91 a
Krk	22.44 kl	4.78 gh	1.10 gh	0.46 kl	0.14 j	34.67 h	197.05 h	5.43 fg
Kys	23.30 i	4.50 h	1.14 f–h	0.48 j–l	0.15 ij	33.74 h	272.90 b–h	4.79 g
Mns	25.74 c	6.19 a–c	1.34 b–e	0.72 a	0.21 bc	45.11 de	238.19 f–h	9.33 a
Ngd	22.30 l	6.35 a	1.18 f–h	0.48 j–l	0.22 b	36.21 gh	214.10 gh	7.26 b–e
Nvs	21.14 o	5.72 b–e	1.24 d–g	0.48 j–l	0.17 gh	36.37 gh	240.13 f–h	6.55 d–f
Sm1	27.89 a	5.49 d–f	1.57 a	0.68 a–c	0.25 a	67.59 a	468.84 a	8.05 a–d
Sm2	25.33 d	5.10 e–g	1.28 c–f	0.55 f–j	0.18 e–g	51.64 bc	288.05 b–h	9.04 a
Sm3	23.34 i	6.25 a–c	1.41 bc	0.6 d–f	0.18 fg	67.67 a	360.94 b	9.06 a
Sm4	24.56 e	5.65 b–e	1.38 b–d	0.71 ab	0.19 c–g	54.15 b	354.29 bc	8.17 a–c
Ygt1	23.9 g	5.63 c–e	1.15 f–h	0.53 g–k	0.20 c–f	38.85 f–h	245.88 e–h	5.58 fg
Ygt2	21.96 m	5.17 d–g	1.19 e–h	0.52 h–k	0.16 hi	35.45 gh	203.20 gh	6.23 e–g
Mean	23.65	5.61	1.24	0.55	0.19	44.21	293.45	7.33
CV (/%)	27.57	9.34	12.01	15.09	14.83	22.12	25.38	18.41

There is no difference between the means shown in same letter ($p < 0.05$)

**$p < 0.01$

highest concentration was noted in Fe with the average of 293.45 ppm, and it was high up to 468.84 ppm (*Sm1*) and 459.26 ppm (*Eks*).

Abbas et al. (2015) reported that the amount of Ca is 3.50%, Mg is 0.28%, Na is 0.08%, while Cu is 32 ppm, Zn is 47.2 ppm, Mn is 71 ppm in the leaves of chicory. Mineral content of chicory leaves includes 0.47% P, 2.93% K, 0.35% Mg, 15 ppm Cu, 2926 ppm Fe, 117 ppm Mn and 80.0 ppm Zn (Haag and Mianami, 1988). Jan et al. (2011) reported that chicory leaves included 2.50% Ca, 0.75% Mg, 2.50% K, 25 ppm Cu, 100 ppm Mn and 50.0 ppm Zn.

Basaran et al. (2019), Stanciu et al. (2019) and Harrington et al. (2006) indicated similar mineral contents in chicory with low differences. Previously, Abbas et al. (2015) reported the mineral matter analysis of chicory leaves contained 3.5% Ca, 0.28% Mg, 32.00 ppm Cu and 71.0 ppm Mn. In the chicory leaves, 2.50% Ca, 0.75% Mg, 2.50% K, 25.00 ppm Cu and 100.00 ppm Mn are determined by Jan et al. (2011). García-Herreraa et al. (2014) shown that chicory contained higher K and Mn than dandelion, but lower Ca, Cu, Fe, Mn. Also, chicory leaves had 30% more Fe, but 50% less Cu than spinach (Lisiewska et al. 2009; Kawashima and Soares 2003). As can be seen from these results, mineral content of chicory can vary considerably, which is attributable to genotype and ecological conditions, maintenance, maturity, as well as the use of wild or cultivars.

Total phenolic, total flavonoids, DPPH and ABTS radical scavenging activities and extract yield

In the present work, the chicory populations in different locations were analyzed for extract yield, total phenolic, total flavonoids, DPPH and ABTS radical scavenging activities, and the results are given in Table 3. According to the results, differences were observed among chicory populations from different locations. The extract yield of the chicory populations that varied from 6.0 to 7.9% was found to be close to each other. The highest extract yield was found in population *Sm4*, whereas the lowest extract yield was found in *Bks*, *Adn* and *Nvs* populations. Dalar and Konczak (2014) reported higher amount of extract yield of ethanol extract of chicory (10%).

The results showed that the total phenolic content in extracts of the chicory populations resulted in the highest amount which determined in population *Mns* (25.8 mg GAE/g extract), followed by *Crm1* (25.7 mg GAE/g extract),

Table 3 Total bioactive content and antioxidant activities of the chicory populations

Populations	Extraction yield (%)	Total phenolic content** mg GAE/g extract		Total flavanoid content** µg QE		DPPH** µg TE		ABTS** µg TE	
Amy	7.4	19.1 ± 0.5	d–f	2.08 ± 0.05	b–d	40.9	ghjk	37.5	gh
Ayd	6.0	21.9 ± 0.9	b–d	2.21 ± 0.02	b	58.0	cd	41.6	ef
Bks	6.0	15.3 ± 0.8	g	1.69 ± 0.04	e–g	26.2	l	26.7	k
Blc	7.3	24.0 ± 0.2	a–c	1.63 ± 0.05	e–g	48.3	e–g	43	de
Brs	7.2	24.5 ± 0.6	ab	1.53 ± 0.04	gh	83.7	a	55.7	a
Crm1	7.5	25.7 ± 0.4	a	1.76 ± 0.03	ef	57.6	cd	48.4	b
Crm2	7.1	21.7 ± 0.7	b–e	2.25 ± 0.07	b	59.9	bc	46.7	bc
Eks	6.6	18.5 ± 0.3	ef	2.02 ± 0.04	cd	35.8	k	36.5	h
Imr	6.9	20.2 ± 0.3	d–f	1.70 ± 0.05	e–g	42.3	ghjk	37.9	gh
Kny	6.5	20.1 ± 1.5	d–f	1.43 ± 0.02	h	34.9	k	37.5	gh
Krk	6.2	19.6 ± 0.3	d–f	1.51 ± 0.03	gh	38.9	jk	35.5	h
Kys	6.8	20.0 ± 0.7	d–f	2.55 ± 0.01	a	47.1	e–h	44.7	cd
Mns	7.1	25.8 ± 1.2	a	2.15 ± 0.12	bc	65.7	b	45.7	cd
Ngd	7.0	19.7 ± 0.5	d–f	1.62 ± 0.03	e–h	44.3	fghj	41.1	ef
Nvs	6.0	21.8 ± 1.2	ef	1.61 ± 0.02	e–h	50.4	ef	43	de
Sm1	7.0	18.4 ± 0.6	b–d	1.54 ± 0.03	gh	52.4	de	45.3	cd
Sm2	7.4	21.0 ± 0.3	f	1.78 ± 0.02	e	45.7	efghj	36.5	h
Sm3	6.1	17.9 ± 0.5	c–f	1.61 ± 0.03	e–h	41.2	ghjk	31.3	j
Sm4	7.9	18.6 ± 1.0	fg	1.58 ± 0.01	F–h	43.6	fghj	36.8	h
Ygt1	7.1	19.2 ± 0.7	d–f	1.97 ± 0.05	d	40.3	hjk	39.7	fg
Ygt2	6.5	18.6 ± 0.5	ef	1.76 ± 0.04	ef	41	ghjk	41.1	ef

There is no difference between the means shown in same letter ($p < 0.05$)

**$p < 0.01$

Brs (24.5 mg GAE/g extract) and *Blc* (24.0 mg GAE/g extract). The lowest amount was recorded in population *Bks* (15.3 mg GAE/g extract). Similar amounts of total phenolic contents were reported by Dalar and Konczak (2014) for hydrophilic extracts obtained from root, stem, leaf, flower, and whole plant of *C. intybus.* The total flavonoid contents of the chicory populations ranged from 2.55 to 1.43 µg QE. The higher amount was found in population *Kys*. In chicory leaves, Zeb et al. (2019) and Abbas et al (2015) recorded the higher amount of total flavonoid. Similar amounts of total flavonoid are reported by Denev et al. (2014) for ethanol and water extracts of chicory aerial parts. These differences can be attributed to the location difference (soil, latitude, longitude and altitude) and genetic differences.

The effects of location on the antioxidant activity were measured in terms of radical scavenging activity (DPPH and ABTS) of chicory populations as shown in Table 3. Among all chicory populations in locations, *Brs* was found the strongest antioxidant capacity for both radicals (83.7 µg TE for DPPH and 55.7 µg TE for ABTS), whereas *Bks* was shown the lowest activity (26.2 µg TE for DPPH and 26.7 µg TE for ABTS). Abbas et al. (2015) reported that IC_{50} value of antioxidant activity of chicory leave extract was 67.27 µg/ml.

The loading plot of PCA clearly demonstrated a relationship between the yield, crude protein, mineral, and bioactive-related content of chicory examined in our study (Fig. 5). Accordingly, an inverse relationship between DW and bioactive contents (ABTS, DPPH, TPC, TFC) shows that they were effective in the negative direction in chicory. On the other hand, high DW seems to have been partially associated with mineral content and crude protein. However, mineral content and crude protein content in chicory were determined as closely and positively related. This is promising for improving chicory genotypes that are yielding and high nutritional content. Besides, results indicating that the increase in nutritional value and especially in yield may lead to lower bioactive content and antioxidant activity as well.

Bioactive compounds and antioxidants are secondary metabolites that are mostly related to stress and might be changed by agricultural practice (Sinkovič et al. 2020). So, this negative relationship between the dry weight and antioxidant content or bioactive compounds can be related with the interactions between the populations and experimental conditions. On the other hand, these results can be associated with genetic as distribution of the populations exhibited partially geographical proximity or climatic similarity. In this regard, populations superior in certain characteristics

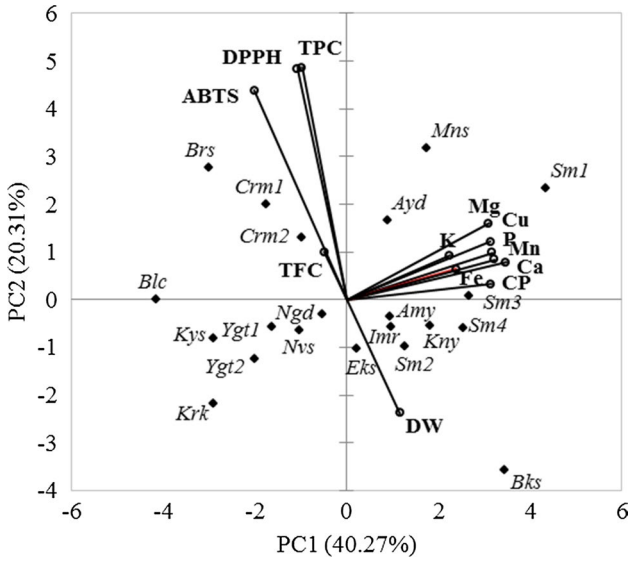

Fig. 5 Representation of the first two principal components of thirteen variables recorded in twenty-one chicory populations

were as follows; population Bls in DW, populations *Brs, Crm1, Crm2* in bioactive component and antioxidant content, population *Sm3* in crude protein and population *Sm1* in mineral contents.

Conclusion

This study clearly showed that Turkey origin wild chicory populations, in terms of nutritional value and antioxidant contents, have a considerable potential in human diet. Especially high protein and mineral contents of chicory have been considered important traits for a balanced diet. The abundance of chicory in nature and its easy accessibility offer economical and quality nutrition opportunities to poor people or contribute food security at least household levels. On the other hand, integration of chicory into the agricultural system seems possible, and in this respect, the significant differences between the populations in terms of the investigated characteristics are very promising to developed vegetable type new cultivars. The overall picture showed that the geographical origins are decisive on the chemical contents of chicory. Chicory populations originated from the regions that close to sea or in the transition zone are superior in nutritional quality and yield, so they may be more suitable for breeding studies aimed at developing vegetable varieties.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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