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A comprehensive study of qualitative and biochemical characteristics of dried seedless barberry fruits from different regions of South Khorasan Province, Iran

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ABSTRACT

Purpose: There is no report regarding the physicochemical properties of dried barberry fruits from main production regions of the South Khorasan Province, Iran. **Research Method**: Therefore, we investigated the nutritional quality and bioactive compounds of dried, seedless barberry fruits from different regions of South Khorasan Province, Iran. Dried barberries were evaluated after being purchased and collected. **Findings:** The highest total soluble solids (TSS) and the highest taste index (TSS/TA) were obtained for the barberries from the Birjand region, which indicates that the barberries from this region have better and sweeter tastes than those from other regions. However, the barberry fruits of the Qaen region had the greatest amount of titratable acidity (TA) and the lowest amount of TSS, which indicates that the fruits of this region are more sour than those of other regions. The examination of color indices (*L**, *a**, *b**, *Hue* and *chroma*) showed that the lowest values of *a** (redness) and chroma were related to the dried barberry of the Darmian region. Additionally, the highest total phenol content and anthocyanin content were detected in fruits from the Birjand region. However, barberry fruits from the Darmian region had the lowest phenol content and the lowest levels of anthocyanin and vitamin C. Positive strong correlations revealed between anthocyanin and TSS (r = 0.82), anthocyanin and phenol (r =0.95), anthocyanin and vitamin C (r =0.77), and anthocyanin and chroma (r =0.81). **Research limitations:** No limitations were found. **Originality/Value:** In general, it can be concluded that the dry, seedless barberry fruits from the Birjand region had higher quality and nutritional value than those from other regions. Nevertheless, the barberries of the Zirkoh and Qaen regions also had acceptable quality and nutritional value. However, it seems necessary to control and review the storage and drying conditions of barberry fruits in the Darmian region.

INTRODUCTION

Seedless barberry (*Berberis integerrima* cv. Zereshk bidaneh), is a small fruit and contain essential nutrients, minerals, and health-promoting phytochemicals, including the treatment of liver and vascular problems and the prevention of many diseases (Sarraf et al., 2019; Khayyat, 2022). One of the most important functional compounds in the barberry plant is berberine, which is present in various parts of the plant. Studies have shown that berberine in barberries reduces cholesterol and blood glucose (Sarraf, et al., 2019). It can help prevent Alzheimer's disease and neoplastic diseases. In addition, barberry fruits have antimicrobial and antifungal effects (Rahimi Kakolaki et al., 2024), and are rich source of natural antioxidant substances (Sun et al., 2021; Sarraf et al., 2019).

Investigations have indicated that preharvest factors (Zeraatgar et al., 2019) and harvest time significantly influence on the fruit quality at postharvest stage (Amiri, et al., 2022; Tatari et al., 2022; Tatari, 2023; Moradinezhad et al., 2008; Shikwambana et al., 2023). In the research conducted by Alavi and Mazloumzadeh (2012), different methods of collecting barberries (branch-cutting, cluster picking and impact force), harvesting times (mid-September-late October to mid-November) and drying methods (shade drying, sun drying and industrial drying) were investigated to determine the effects of these treatments on achieving optimal production conditions and quality. They found that the highest quality of barberry fruit was obtained when they were harvested at late October, harvested in clusters and dried in the shade. In another study conducted by Moghaddam et al. (2013), the effects of harvest date (September 9, September 20, November 1, and November 13), harvest time (07:00, 10:00, 13:00, 16:00, and 19 00:00), picking method (branching and berry picking) and drying method (sun drying and shade drying) on the quantity and quality of seedless barberry fruits were investigated. They found that the best harvesting time is November 13, which is the cool hour of the day (07:00), at which the berries are picked and dried in the sun, which increases the quality and preserves the nutritional value of the dried berries.

Approximately 80% of barberries are water. This product is therefore highly perishable, which is why the most common type of barberry used is dried to reduce moisture content and microbial infections (Moradinezhad & Ranjbar et al., 2023), and to prolong its storage life and is available for consumers in all seasons. Barberry fruits are harvested by three methods: branch-cutting, cluster-picking and impact force. The barberry is also dried in three ways: shade-drying, sun-drying and industrial-drying. Traditionally, in the shade-drying approach, harvested fruits are distributed or scattered on wooden or metal scaffolds.

South Khorasan is the main region of seedless barberry production in Iran and in the world (Goodarzi et al., 2018). Although geographical conditions, diverse weather conditions and structural characteristics causes physicochemical changes in the dried barberry fruit in different regions of the province, but literature shows that previous postharvest studies on barberry mainly focused on the effect of harvest method, harvest date and time. In addition, there is no comprehensive study to compare produced and dried barberry fruits from main production regions of the South Khorasan province, Iran. Therefore, this experiment was conducted with the aim of investigating and comparing the physical and biochemical characteristics of dried barberries prepared from different regions of the province as the main production area of seedless barberry in the world.

MATERIALS AND METHODS

Plant material preparation

To conduct this experiment, first, the main areas of barberry planting in South Khorasan Province were determined. Four regions, namely, the Birjand, Zirkoh, Darmian and Qaen were selected. The barberry is dried by the farmers as the following method. To dry fresh seedless barberry, fruit branches were stored traditionally under shade-house during long-term storage from November 2021 to March 2022. Then, from March 10 to 15, 2022, dried barberry fruits were purchased and collected from each region. Four kilos of dried barberry were prepared from each region (one kilo per replicate), for a total of 16 kilos of barberry. Samples were then transferred to the Postharvest Physiology Laboratory, University of Birjand, South Khorasan Province, Birjand, Iran. The method of fruit picking and storage conditions of used shade-house in all studied regions are presented in Table 1. Additionally, analyses of the water, soil, and geographical coordinates of the studied regions (Birjand, Zirkoh, Darmian, and Qaen) in the Khorasan province, and the corresponding data are presented in Table 2. Barberry samples from Birjand, Zirkoh, Darmian, and Qaen regions were collected from the cities of Arian Shahr, Zohan, Qahestan and Mohammad Abad Alam, respectively.

Physicochemical assessments

Total soluble solids (TSS), titratable acidity (TA) and TSS/TA of dried barberry fruits

To prepare the extract from dried barberry fruit, first, 10 grams of dried fruit were weighed and turned into powder through a mortar. Then, 10 ml of water was added, and the mixture was placed in a shaker (Orbital shaker made by IKA Company, Germany; KS260 digital) for 25 minutes at 50 rpm. The solution was passed through filter paper. This prepared extract was used to determine the biochemical characteristics of dried barberry fruit (Niazmand et al., 2021).

Table 1. The type of fruit picking, height of branches mass and storage conditions in the four studied regions of South Khorasan province, Iran.

Regions	Picking fruit	Height of fruit branches mass (cm)	Storage conditions
Birjand	With branches	30	One-row metal drying rack, with ventilation
Zirkoh	With branches	40	Double-row wooden drying rack, with ventilation
Darmian	With branches	10	On the cement floor, no ventilation
Qaen	With branches	40	One-row metal drying rack, with ventilation

Table 2. Characteristics of soil, water, and coordinate of the four studied regions.

Regions	Soil			Water		Coordinates		
	pH	EC (ds/m)	SP (mg)	pH	EC (ds/m)	Latitude	Longitude	Altitude(m)
Birjand	7.98	4.63	37.40	7.84	2.85	59° 17′	33° 19′	1698
Zirkoh	8.39	1.56	48.22	8.24	1.37	59° 47′	33° 24′	1710
Darmian	8.20	2.85	59.31	8.13	2.02	59° 43′	33° 9′	1966
Qaen	7.82	16.51	33.00	7.09	13.15	59° 11′	33° 54′	1471

To determine the TSS, a few drops of the prepared extract were placed on the prism of an optical refractometer (Model RHB-611-made in China), and the desired number was read in the light (Moradinezhad et al., 2013). The TSS data are presented as °Brix. To measure TA, 10 ml of fruit extract was diluted with 100 ml of distilled water and 0.1% NaOH at pH 8.23 (Moradinezhad et al., 2019). The results are expressed as percentages (Mabunda et al., 2023).

Color indices (L, a*, b*, Hue° and Chroma) of dried barberry fruits*

The color indices of the samples were measured based on *a**, *b** and *L** components by a HUNTER LAB colorimeter (Model TES-135A, Taiwan TES Company).

*L** indicates a dark or light color, ranging from L* = 0 (dark) to L* = 100 (white). The indicators *a**+ (red) and −*a** (green), +*b** (yellow), and −*b** (blue) are shown. Chroma describes the luminosity, intensity, and degree of color purity. Hue represents the degree of color being displayed (McGuire, 1992).

Total phenol (TPC), total anthocyanin and vitamin C contents of the dried barberry fruits

The TPC was measured according to Samadi et al. (2020) method. 300 µL of the extract was added to 1.2 mL of 7.5% sodium carbonate and 1.5 mL of 10% Folin-Ciocalteu solution. The reaction mixtures were placed in the dark for 30 min and then measured at 765 nm via a spectrophotometer (Model UV/Vis 2100, 200-1000 nm; UNICO, USA) and compared to a gallic acid calibration curve to estimate the mg of gallic acid/g extract. For the blank, all processes were the same and 300 µL of methanol was added instead of plant extract. The data are presented as mg.100 g^{-1} DW.

To evaluate the total anthocyanin content, we utilized the pH differential approach of the AOAC, as explained by (Brito et al., 2014; Abbasi Bastami et al., 2022). Potassium chloride buffer with a pH of 1.0 was employed for the evaluation of the absorbance at 510 nm, and sodium acetate buffer (pH 4.5) was utilized for the evaluation of the absorbance at 700 nm. The pigment level (mg cyanidin 3-glucoside equivalents (CGE) per 100 g) was calculated according to the following equations (1 and 2) and expressed as mg.100 g^{-1} DW.

$$A=(A_{510}-A_{700})_{\text{pH 1}}-(A_{510}-A_{700})_{\text{pH 4.5}} \quad (1)$$

$$\text{Total anthocyanin content}= (A\times MW\times DF\times 100)/(\varepsilon\times L) \quad (2)$$

MW= the molecular weight (449.2 g/mol), DF= dilution factor, Ɛ= molar extinction coefficient for cyanidin 3-O b-D-glucoside (26.900 L/mol cm), and L= cuvette path length (cm).

The vitamin C concentration was determined by the titration method described by Rangana (1979). For this purpose, 10 ml of extract was diluted with 3% metaphosphoric acid to a volume of 100 ml and filtered. Then, 10 ml of the prepared solution was titrated using 2,6-dichlorophenol indophenol until a blue color appeared. The following formula (3) was used to calculate the observed vitamin C content.

$$\text{Ascorbic acid (mg. 100 g}^{-1}\text{ DW)} = \frac{F\times T\times 100}{D\times S}\times 100 \quad (3)$$

T= Solution (Dye) taken for the burette (mm), F= Dye factor, S= Fruit juice (g) used in dilution, and D=Diluted sample used for titration (mm).

Statistical analysis

Analyses were performed by JMP statistical software, Discovery Pro V. 13.2.1, and Excel Ver. 2019 software. Additionally, comparisons of the means were performed based on the least significant difference (LSD) test at the 5% probability level. The statistical plan used for this experiment was a completely randomized design with four replications, and the data were analyzed. To assess the correlation between evaluated traits the Pearson's correlation coefficient was used.

RESULTS AND DISCUSSION

The results of the analysis of variance of the data showed that the contents of TSS, TA and TSS/TA in the different regions significantly differed (Table 3). A comparison of the averages revealed that the greatest amount of TSS was obtained from dry barberries in the Birjand region (6.96±0.27 °Brix), followed by those in the Zirkoh region (5.33±0.26 °Brix). Additionally, the lowest amount of TSS was obtained from the samples prepared from the Qena region (3.76±0.24 °Brix). By examining the TA values of dry barberries, it was found that the highest and lowest TA values were obtained from the Qaen region (3.60±0.11%) and Darmian region (2.82±0.15%), respectively .The results obtained from the comparison of TSS/TA in different regions indicated that the highest value of this trait was related to the samples from the Birjand region (2.14±0.29), followed by those from the Zirkoh region (1.76±0.27). Additionally, there was no statistically significant difference in the amount of TSS/TA between the Birjand region, Zirkoh region and Darmian region (1.48±0.24).

Table 3. Comparison of the effect of different regions on total soluble solids (TSS), titratable acidity (TA) and taste index (TSS/TA) of dried barberry fruit.

Regions	TSS (°Brix)	TA (%)	TSS/TA
Birjand	6.96^{a}±0.27	3.24^{b}±0.11	2.14^{a}±0.29
Zirkoh	5.33^{ab}±0.26	3.01^{c}±0.17	1.76^{a}±0.27
Darmian	4.20^{b}±0.21	2.82^{d}±0.15	1.48^{ab}±0.24
Qaen	3.76^{b}±0.24	3.60^{a}±0.11	1.05^{b}±0.20
LSD	1.80	0.18	0.45
The significance level	*	**	*

Means ± SEs followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤ 0.05) according to the LSD test. * and ** indicate significance levels at 1% and 5%, respectively.

Table 4. Comparison of the effect of different regions on of color indices (*L**, *a**, *b**, *Hue*° and *Chroma*) of dried barberry fruit.

Regions	*L*	*a*	*b*	*Hue°*	*Chroma*
Birjand	34.43^{a}±3.28	20.72^{a}±2.02	0.55^{a}±0.09	1.54^{a}±0.31	20.72^{a}±2.24
Zirkoh	37.52^{a}±4.03	20.30^{a}±1.23	0.60^{a}±0.11	1.71^{a}±0.33	20.30^{a}±2.21
Darmian	37.60^{a}±3.68	16.34^{b}±1.28	0.57^{a}±0.10	2.01^{a}±0.35	16.35^{b}±1.87
Qaen	36.34^{a}±1.34	20.86^{a}±2.87	0.71^{a}±0.11	1.47^{a}±0.18	20.90^{a}±2.91
LSD	5.39	4.26	0.31	0.94	4.24
The significance level	ns	**	ns	ns	**

Means ± SEs followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤ 0.05) according to the LSD test. *,** and ns indicate significance at 1%, 5% and non-significance levels, respectively.

The level of total soluble solids (TSS) accumulation in fruit can change under the influence of various conditions, including soil and climate, fruit yield and degree of ripeness. The dominant effect of weather factors on fruit TSS accumulation compared to other factors has been proven (Serdyuk et al., 2020). In a study, it was shown that in southern Ukraine, sweet cherry fruit contained 12.1-19.9% soluble solids, while in the central part of the country, the same variety contained only 11.3-12.8% soluble solids (Bublyk et al., 2014; Ivanova et al., 2019). Several scientists have related changes in the biochemical composition of fruits to different ripening conditions and cultivation areas (Basanta et al., 2014; Long et al., 2018). Caprio and Quamme (2006) showed that one of the most important and influential climatic factors in the accumulation of total soluble solids in fruits are the difference between day and night temperatures. In other words, the greater the temperature differences between night and day, the greater the amount of TSS accumulation in the fruit. In the present research, the highest amount of TSS accumulation was found in the fruits of the Birjand region. This increase in TSS may be justified by the presence of warm days and cool nights in this region. In addition, water and soil salinity are likely other mechanisms for changing fruit quality in different regions. Studies have shown that when crops are irrigated with saline water, the macromolecular substances in the cells (such as sucrose) tend to be hydrolyzed to soluble sugars to regulate osmosis and increase the protoplasm's protective ability (Li et al., 2022; Munns and Tester, 2008), which increases solids. Li et al. (2022) showed that with increasing irrigation water salinity (salinity level, 1 and 2 g/liter), the amount of glucose in tomato plants increased with increasing irrigation water salinity, which shows that an appropriate increase in salt concentration in irrigation water is favorable for the formation of fruit glucose. However, when the salinity reached 3 grams per liter, the amount of fruit sugars decreased especially glucose and fructose, which was probably due to ion toxicity at this level of salinity. They stated that the maximum acceptable amount of water salinity in terms of tomato quality characteristics is 2 mg/L. According to Table 1, in this study, the water and soil salinities in the Birjand region were greater than those in the Zirkoh region and Darmian region, which is likely because this level of salinity is tolerable for barberry plants and has increased to increase the osmotic regulation of dissolved solids. And improves the quality of the fruit. For this reason, the taste index (TSS/TA) of fruits from the Birjand region was greater than that of fruits from other regions. However, the salinity levels of the soil and water in the Qaen region are high, which likely causes a decrease in water absorption in the roots and a decrease in soluble solids, which ultimately reduces the taste quality of barberry fruits. As shown in Table 3, the fruits from the Qaen region had the lowest taste indices. The results of the present study agreed with the results of other researchers (Ivanova et al., 2021; Li et al., 2022; Yang et al., 2019) in this regard. Additionally, in the present study, the TA of barberry fruit was greater in the Qena region than in other regions. Studies have shown that with increasing water salinity, the amount of TA in fruits increases (Zhang et al., 2017; Van Meulebroek et al., 2015).

The results presented in Table 4 show that *a** and color chroma of the barberry fruits significantly differed among the different regions. The lowest *a** value for dry barberries was obtained from the Darmian region. Since the values of *b** (fruit yellowness) in barberry fruits ranged from 0.55 to 0.71, the values of *a** and chroma were similar. The color of the products is an important quality factor because the consumer evaluates the products by observing the color in the first stage. In addition, the color of fruits reveals several nutritional parameters. It has been proven that anthocyanin compounds are responsible for the red color of barberry fruits. Therefore, it can be concluded that the redder the barberry fruit is, the more anthocyanin it contains. The color of the products is an important quality factor because the consumer evaluates the color of the products in the first step. In addition, the color of fruits indicates several nutritional parameters. Anthocyanin compounds have been proven to be responsible for the red color of barberry fruits (Sarraf et al., 2019; Moradinezhad et al., 2018). Therefore, it can be concluded that the redder the barberry fruit is, the more anthocyanin it contains (Kamiab et al., 2023). The bright red color of the fresh barberry gradually turned dark red with dehydration. Additionally, by destroying and changing the pigment compounds of barberries, especially anthocyanins, barberries turn brown or dark (Ardestani et al., 2013). The effects of enzymes, oxidation, light and heat may change pigments into other components and reduce the appearance quality of barberries. Valipoor Motlagh et al. (2013) showed that with increasing oxidation and storage temperature of dry barberry fruit, the red color of the fruit decreased. Sharifi and Hassani (2012) showed that as the storage temperature of barberries increases, red pigments are degraded. In other words, increasing the storage temperature changes the color of barberry fruits from red to brown. In the present study, the barberries in the Darmian region had the lowest amount of redness, which was probably due to the high temperature and lack of ventilation during product storage. The numerical ranges obtained for the values of *L** (34.43-37.60), *a** (16.34-20.86), *b** (0.55-0.71), *Hue°* (1.47-20.1) and *Chroma* (16.35-20.90) for dry cranberry fruit were in accordance with the ranges reported by other researchers (Serdaroğlu et al., 2023; Nadali et al., 2022; Alavi & Mazloumzadeh, 2012).

The results of the phenol evaluation of dried barberry fruit in four regions showed that the highest total phenol content (TPC) was obtained from the fruits of the Birjand region (840.3 $mg.g^{-1}$ DW), and the lowest TPC was from the fruits of the Darmian region (134.61 $mg.g^{-1}$ DW) (Fig. 1). Phenolic compounds such as flavonoids, phenolic acids and stilbenes are the main compounds responsible for the high antioxidant activity of fruits, which can help reduce the oxidative damage of free radicals to the human body and strengthen the immune system (Lin et al., 2016). These compounds are not necessary for plant growth. However, to protect plants against various stresses, they are synthesized as secondary metabolites in plants (Vilvert et al., 2024). The synthesis of phenolic compounds, in addition to playing a defensive role in plants, acts as a warning signal for the synthesis of other antioxidants in plants. These compounds are synthesized through the shikimate and phenylpropanoid pathways (Yeshi et al., 2022; Lin et al., 2016). The basic function of phenolic compounds is their antioxidant activity, which leads to the prevention and reduction of oxidative damage by free radicals to vital cellular components such as lipids, proteins and nucleic acids. Phenolic compounds act as hydrogen or electron donors to free radicals, removing and reducing the amount of free radicals (Kalinowska et al., 2014; Vuolo et al., 2019). In the present research, it was shown that the content of total phenol in the fruits of the Darmian region was lower than that in other regions. In this area, fruits may be stored under inappropriate environmental conditions. As mentioned, free radicals are produced in the face of various stresses, and compounds such as phenols are synthesized in plants to address these conditions. Most likely, in the process of reducing free radicals, phenol is consumed, and its accumulation in the plant decreases. In a study on dried barberry, the authors reported that the release of phenolic compounds bound to the cell matrix due to rapid drying and limited exposure to oxygen near the product during processing could maintain total antioxidant activity (Nadali et al., 2023). Nateghi and Kavian (2024) investigated the effect of different drying conditions on the total phenol content of seedless barberry juice. They showed that the application of low temperature (evaporator) and high temperature (microwave) along with increasing pressure leads to the destruction of phenols and reduces the total phenol content. Most likely, the reduction in environmental stresses, especially temperature, during the storage period has a direct effect on the content of total phenol in barberry fruits.

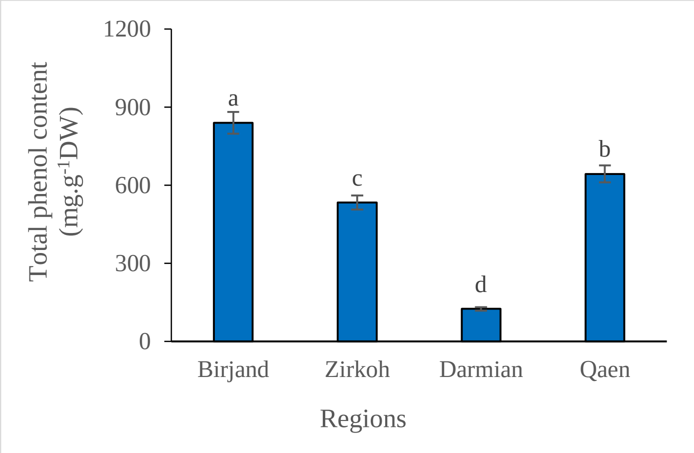

Fig. 1. Comparison of total phenol content of dried barberry fruit from different regions. of South Khorasan province, Iran. Error bars represent the error deviation. Symbols with the same letter are not significantly different between them, at P ≤ 0.05 (LSD test)

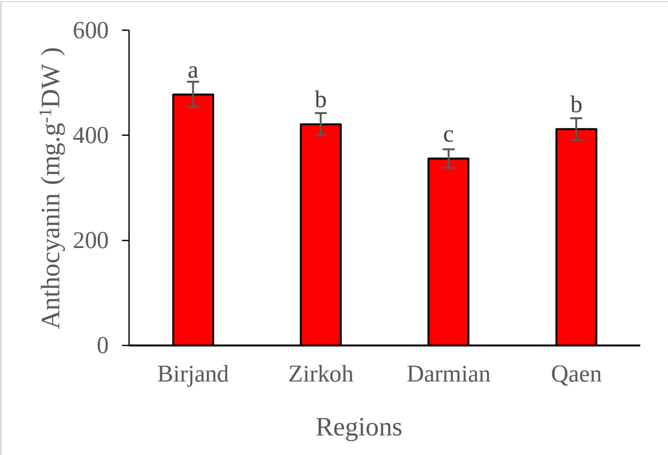

Fig. 2. Comparison of anthocyanin content of dried barberry fruit from different regions of South Khorasan province, Iran. Error bars represent the error deviation. Symbols with the same letter are not significantly different between them, at P ≤ 0.05 (LSD test).

According to the results presented in Figure 2, the anthocyanin contents of the barberries prepared from different regions were significantly different from each other. The highest content of anthocyanin was obtained from barberry fruits in the Birjand region (477.92 $mg.m^{-1}$ DW), and the lowest amount was related to samples prepared from the Darmian region (355.81 $mg.m^{-1}$ DW). Anthocyanins are vital indicators of the nutritional and commercial value of fruits. Anthocyanin biosynthesis is affected by various environmental factors (Zhao et al., 2023). Plants have developed an efficient system for anthocyanin production as a protective mechanism against environmental stressors (Bendokas et al., 2020). Two very important factors in the synthesis of anthocyanins are light and temperature. High temperature inhibits the synthesis of anthocyanins, and low temperatures cause the accumulation of these compounds (Gouot et al. 2019). In addition to its role in disrupting anthocyanin biosynthesis, high temperature causes anthocyanin degradation in fruit due to increased peroxidase activity (Movahed et al., 2016). The main anthocyanins in seedless barberries are delphinidin-3-glucoside (D-3-G) and pelargonidin-3-glucoside (P-3-G) (Berenji Ardestani et al., 2016). Laleh et al. (2006) evaluated the effect of temperature on the amount of anthocyanin in four varieties of barberry (*B. integerima*, *B. vulgaris*, *B. khorasanica* and *Orthobotrys*) at temperatures of 5, 15, 25 and 35°C. The authors reported that the anthocyanin content decreased significantly with increasing storage temperature. In this regard, in the present study, it was shown that the barberry fruits prepared from the Darmian region had the lowest anthocyanin content, while the fruits prepared from the Birjand region had the greatest amount of anthocyanin. These results were probably due to the good ventilation and favorable storage conditions in the Birjand region, which decreased the storage temperature and caused the accumulation of anthocyanin in the seedless barberry fruit. As mentioned in the section on fruit color results in this experiment, anthocyanins are responsible for the red color of barberry fruits. In the present research, the results obtained from the fruit color indices and anthocyanin content was consistent with each other.

An examination of vitamin C in barberry fruit showed that the lowest level of vitamin C was related to fruits prepared from the Darmian region. Additionally, vitamin C levels in the Birjand region, Zirkoh region and Qaen region were not significantly different and were greater than those in the Darmian region. The most important vitamin in fruits and vegetables for human nutrition is vitamin C (Santos & Silva, 2008). Fruits and vegetables meet more than 90% of the body's need for vitamin C (Rasanu et al., 2005). Vitamin C is defined as the general term for all compounds that exhibit the biological activity of L-ascorbic acid (AA) (Lee & Kader, 2000). The vitamin C content in fruits and vegetables can be affected by various factors, such as preharvest weather conditions, maturity, harvesting methods and postharvest storage methods (Mditshwa et al., 2017). The greater the light intensity during the growing season is, the greater the vitamin C content in the plant tissue (Mditshwa et al., 2017). Temperature management after harvesting is the most important factor for preserving vitamin C in fruits and vegetables (Magwaza et al., 2017, Kumar et al., 2024). With increasing temperature and duration of storage, more vitamin C products are exposed to degradation. Vitamin C is a plant compound that is sensitive to high temperatures, and very low temperatures are also effective at increasing the loss of vitamin C in fruits (Wang et al., 2017). It should be noted that a significant amount of vitamin C in barberries is lost during the drying process. However, by keeping the product at the right temperature, the loss of vitamin C during the drying period can be reduced. In the postharvest phase, the amount of O_2 and CO_2 around the product increases with the breathing of the product, this leads to the oxidation and severe reduction of vitamin C (Mditshwa et al., 2017; Kader et al., 2000). Therefore, researchers have concluded that to store products for a long time, optimal ventilation and appropriate temperature are necessary to maintain the nutritional value of the products. In one study, the effect of different drying conditions on the level of vitamin C in kiwi fruits was investigated (Kaya et al., 2010). The test is performed using air temperatures of 35, 45, 55 and 65 °C, average velocities of 0.3, 0.6 and 0.9 m/s and relative humidity values of 40%, 55%, 70% and 85%. Their results showed that increasing the temperature of the drying air causes more loss of vitamin C in dried fruits, while increasing the relative humidity of the drying air decreases the degradation of vitamin C. The results obtained from the present research showed that the majority of vitamin C losses were related to barberries prepared from the Darmian region. Most likely, these results were obtained due to unfavorable storage conditions (including temperature, humidity and ventilation) in the Darmian region. Similar results were reported by other researchers (Talebzadeh et al., 2022; Santos and Silva, 2008; Mengyun et al., 2018).

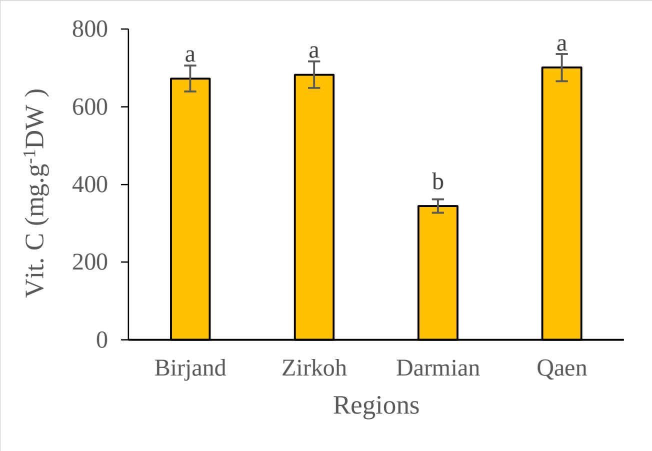

Fig. 3. Comparison of vitamin C of dried barberry fruit from different regions of South Khorasan province, Iran. Error bars represent the error deviation. Symbols with the same letter are not significantly different between them, at $P \leq 0.05$ (LSD test).

Correlation coefficients of evaluated traits

Significant strong correlations found among investigated variables. The results showed positive significant correlations between anthocyanin and TSS (r = 0.82), anthocyanin and phenol (r =0.95), anthocyanin and vitamin C (r =0.77), anthocyanin and an index (r =0.81), and anthocyanin and chroma (r =0.81). Also negative significant correlations between L index and anthocyanin (r = -0.85), and L index and phenol (r = -0.82) were observed.

Previous studies on barberry fruits also have been reported significant correlations. Total antioxidant activity correlates significantly with total flavonoids, soluble solid content, pH, and brightness (L value) in barberry fruit genotypes from Sivasli, Usak, Turkey (Okatan & Çolak, 2019). Further, barberry fruits from CKNP region of Pakistan show correlations between pH, TSS, acidity, sugars, proteins, antioxidants, and phytochemicals like carotenoids, flavonoids, phenolics, and anthocyanins (Awan et al., 2014). However, barberry yield negatively correlated with fruit length, titratable acidity, anthocyanin, DPPH, and phenol (Tavakoli-Kaghaz et al., 2023).

CONCLUSION

The results of this experiment show that fruits from different regions have different tastes and food qualities. The highest TSS and the highest taste index (TSS/TA) were obtained for the barberries from the Birjand region, which indicates that the barberries from this region have better and sweeter tastes than those from other regions. The examination of color indices (*L**, *a**, *b**, Hue and Chroma) showed that the lowest color quality was related to dry barberry in the Darmian region. Additionally, the highest amount of total phenol and anthocyanin was obtained from the fruits of the Birjand region. However, the lowest amount of phenol and the lowest amount of anthocyanin and vitamin C were detected in the Darmian region, and in general, it can be concluded that the dry, seedless barberry fruits of the Birjand region have greater quality and nutritional value than those of other regions. It seems that the drying and storage conditions of barberry fruit have a direct relationship with the nutritional value of this product. Therefore, according to the results obtained and the comparisons made between different regions of barberry cultivation, in the Darmian region, the type of fruit picking and the conditions of drying and keeping the fruit need more supervision and control. However, in the Birjand region, Zirkoh region and Qaen region, the conditions for drying and storing dry barberries are optimal.

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Conflict of interest
The authors declare that there is no conflict of interest.

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