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Investigation of effect of different concentration methods on physicochemical properties, phenolic compounds and anthocyanins of barberry juice

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ABSTRACT: *The objective of this study was to investigate the effect of different concentration techniques on the physicochemical properties, phenolic compounds, antioxidants, color and total anthocyanins of the barberry concentrate. Three methods including evaporator (at pressures of 11 kPa and 38 kPa), microwave (at pressures of 11 kPa and 38 kPa), and conventional heating at atmospheric pressure were used to concentrate barberry juice. All experiments were performed in triplicate. The means were compared by Duncan test at the 5% level using Minitab 16 software. The results revealed that the use of low-pressure microwave method decreased the concentration time (20 min), lowered the pH (2.59) and dissolved solids (34.41), preserved color properties (195), and resulted in the highest amount of anthocyanin (19.1), antioxidant (68) and phenolic compounds (1.07). Therefore, the use of low-pressure microwave method increased the quality and nutritional properties of barberry concentrate compared to the mentioned methods.*

KEYWORDS: *Anthocyanin; Barberry juice; Concentration; Phenolic compounds; Physicochemical.*

INTRODUCTION

One of the most important sectors of industry in all countries, which is related to food security, is the food industry. The development of this sector seems necessary due to the lack of food resources and the growing population. A new approach is to use novel technologies in the food industry. Plants are a rich source of phenolics and flavonoids that are among the most important natural antioxidants [1]. The beneficial effects of bioactive compounds (such as phenolics) have been attributed to their important role as antioxidants and also the prevention of several diseases such as cancer [2]. The barberry (*Berberis vulgaris*) is a dicotyledonous plant belonging to the *Berberidaceae* family, related to the *Ranunculaceae* family. It is a robust plant which is stony soil- and drought-tolerant and cultivated in Birjand, Ghaen, Gonabad, Ferdows and Kashmar in South Khorasan province in Iran. Barberry concentrate is one of various products of barberry which is a rich source of anthocyanin [3]. Barberry contains organic acids and phenolic compounds. Other components include minerals, organic compounds, including carbohydrates and a very small amount of protein, lipid, vitamins, anthocyanins, carotenoids, phenolase, polyphenolase and glycosidase enzymes, which vary depending on the irrigation conditions, soil type, maturity and harvesting conditions. Barberry fruit has a high-water content (about 80%). Sugars and acids are water-soluble components. The main sugars of barberry are sucrose, glucose and fructose [4]. The compounds of barberry have biological activities and are used extensively in the food and pharmaceutical industries [5].

Barberry contains 5 types of anthocyanin with the main anthocyanin being petonidin-3-glycoside. Nucleic acids extracted from barberry have antioxidant properties, free radical scavenging potential and antibacterial activity against *Bacillus subtilis*, *Pseudomonas aeruginosa* and *Candida albicans* [6]. Various studies have shown that free radicals generated in humans and living organisms cause oxidative damage to different biomolecules including proteins, lipids and nucleic acids. Phenols and other phenolic antioxidants present in vegetables and fruits are able to neutralize free radicals and shows an important role in preventing some diseases [7]. One of the forms of food preservation is concentration. For example, juices, jellies and jams are more resistant to spoilage because the dry matter content affects the environmental conditions for microbial growth. The concentration method can reduce the weight and volume of the product so it is stored in a smaller space, thereby reducing costs of transportation, packaging and distribution of food products. Concentration can improve the sensory properties, and the concentrated products are used as a raw material in the production of secondary products. Almost all liquid foods that need to be dried are concentrated prior to drying. Due to the decrease in water activity, the resistance of food to microbial and chemical spoilage increases [8]. Heat processing is considered as one of the most important procedures of food preservation, which is primarily used to inactivate microorganisms and enzymes and to decrease water activity. To produce juice concentrate, the watery part must be removed without any changes in dry matter as well as the main dry matter components such as fruit sugar, vitamins and minerals. It is a major process in the fruit processing industry and is of crucial importance as a determinant of the quality parameters of the final product such as aroma, taste, color, appearance and mouthfeel [9]. The fruit juices concentrated using conventional methods have a cooked taste and contain carcinogenic compounds for example hydroxymethyl furfural (HMF) or furan compounds. most recently, new concentration methods have gained importance because of the disadvantages of traditional methods. Concentration is considered as the critical stage of the process because of its effects on the quality of the fruit juice as well as the sensory properties such as color, taste, flavor, aroma and appearance. The traditional concentration methods may decrease the valuable bioactive components such as vitamins, antioxidants, phenolic compounds, and flavor compounds as well as the sensory properties such as the color and flavor of the fruit juices [9, 10, 11]. Different non-thermal and thermal techniques can be used to improve the safety and microbial quality of the juices over the storage. Concentration is the thermal process used extensively for extending the shelf life of fruit juices. This process can reduce storage costs and transportation, and also make the juice reconstitution possible in various seasons [12]. Atmospheric and vacuum concentration, vacuum microwave evaporation and thermal evaporation are among the methods used for concentrating various fruit juices. Thermal evaporation is one of the highest energy-consuming processes to remove moisture from the products in the food industry, which uses thermal energy to heat the product, evaporate the water, and compensate the energy losses [13]. Vacuum microwave evaporation (VME) is also a new method of concentration, which results in products of acceptable quality. When food is heated by microwave or dielectric energy, it absorbs the electromagnetic energy, and the reorientation of the dipoles generates heat in the food, leading to water molecular friction and heat generation [14]. The combined use of microwave heating and a vacuum system allows a faster mass and energy transfer at low temperature within a short time. VME system causes more water vapor to separate from the produc at suitable power and vacuum level owing to the rapid heating of the product. It also improves the product quality (flavor, nutritional value and color) and uses energy in a more efficient manner [15]. Yousefi *et al*. [16] compared the effects of microwave and normal heating methods on the rate and quality of evaporation of pomegranate juice (Punica granatum L.). They stated that microwave energy decreased the time as well as the color degradatio. Anthocyanin and antioxidant properties was more important in conventional heating method compared to the microwave heating and that the rate of evaporation increased with increasing process pressure. Other researchers investigated three various concentration processes including rotary vacuum evaporator, open pan and microwave heating for evaporation. They measured the color and phenolic content of blueberry juice. The results showed that the color loss was higher in the open pan method than in the others. Evaporation also affected total phenolic content of blueberry juice. During concentration, total phenolics showed the highest (36.54%) and lowest (34.20%) loss percentages in open pan and microwave heating methods at 200 W, respectively. Therefore, the microwave method could be useful in food industry because of manufacturing blueberry juice concentrate with a superior quality within a short time [17]. Given the fact that the barberry is harvested within a very short period of time (from September to November), not all fresh fruits can be sold in the market and the majority of the crop is dried over long-term storage. Therefore, it is possible to process barberry immediately after harvesting and produce its concentrate by removing or reducing the moisture content in food [18]. The concentrate of barberry is a form of product that is produced by removing water from a solution or suspension (removing water from fruit juice) and turning it into powder or extract. [19]. Considering that Iran is one of the major producers and exporters of barberry in the world, it is necessary to improve health, maintain nutritional value, and strengthen the position of Iranian barberry by processing barberry in the form of concentrate. Therefore, the aim of current study was to investigate the effect of different concentration methods on the physicochemical properties, phenolic compounds and anthocyanins of barberry concentrate.

EXPERIMENTAL SECTION

Materials

Fresh black barberry (*Berberi vulgaris*) belonging to the *Berberiaceae* family was purchased from the Birjand Agricultural Jihad Organization (Iran) in autumn and the chemicals including gallic acid (99.5%), DPPH (95%), methanol (99.85%), normal sodium hydroxide (99%), Folin Ciocalteu (> 95%), sodium carbonate (99.99%), sodium acetate (99%), hydrochloric acid (37%) and potassium chloride (99.99%), from Merck company (Germany).

Methods

Preparation of barberry juice treatments

First, all stems and debris were removed, the barberries were thoroughly washed and soaked for 24-48 h, and then the juice was extracted by a manual press machine and filtered using a cloth. In order to concentrate barberry juice and bring its initial Brix from 12 to 30, three methods including an evaporator (at pressures of 11 and 38 kPa), a microwave (at pressures of 11 and 38 kPa) and conventional heating at 120°C were used. The treatments were compared with control sample coded F (unconcentrated barberry juice without any processing) and the results are presented in Table 1.

Table 1. Treatments characteristics

Treatment code	Concentration method	pressure (kPa)
A	Evaporator	11
B	Evaporator	38
C	Microwave	11
D	Microwave	38
E	Normal Temperature (C)	25
F	Unconcentrated barberry juice (control)	–

Barberry juice concentration

Concentration using microwave under vacuum

Microwave heating was used according to Yousefi *et al*. [16] method as follows: a domestic programmable microwave oven (Butane MR-1, Iran, with a maximum output of 900 W at 2,450 MHz) was changed for microwave evaporation and used in intermittently mode. A hermetic glass container (V=1,000 mL) containing 600 mL of juice sample was positioned at the middle of the microwave, which was linked to a vacuum pump (Robinair, USA), and microwave energy was used. Some undesirable results such as charring and foaming were detected at power > 300 W, therefore the study was conducted at 300 W (Figure 1). As shown in Figure 1, a digital thermometer with a very thin probe (thermometer: EBRO TFI 500, 60 °C to 760 °C, the probe: TESTO 0602–0593 NiCrNi, d=1.5 mm, L=300 mm) was located in the heating system. The probe of thermometer was immerging in the solution at the middle of the container which was totally closed. While sampling, pump 5 was on, valve 9 was open, and valve 10 were closed. When the pump was on, the sample flows to the sampling point. To return the sample to the container, the vacuum caused the sample suction into the evaporation container. So, the pump was off and the regulators (9 and 10) were opened carefully. The vacuum controller kept the pressure applied by the pump constant (Vacuu brand, CVC 2111, England).

Temperature was recorded periodically and microwave power and pressure were controlled by computer. For necessary measurements, samples (3 ml) have been taken periodically. Microwave heating method was conducted at two different effective pressures: 11 kPa and 38 kPa, and their effects were examined.

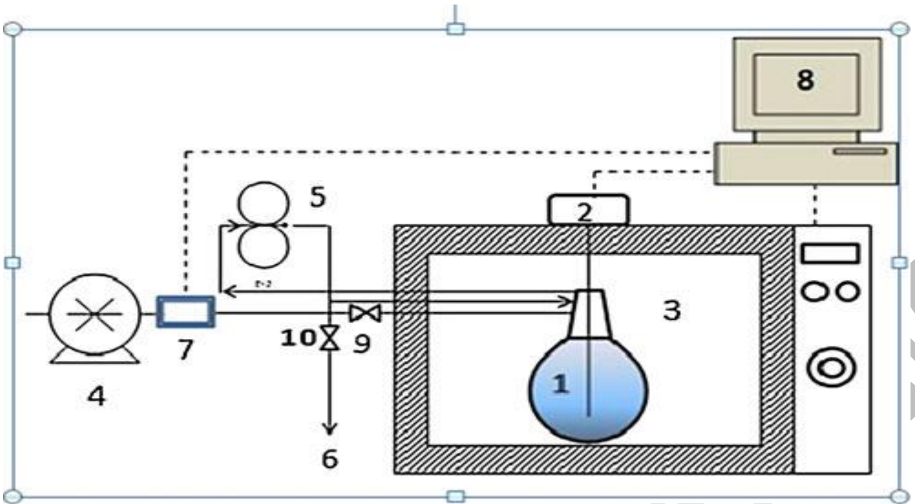

Figure 1. A schematic diagram of microwave evaporator unit. 1 airtight jar, 2 thermometer, 3 microwave heating chamber, 4 vacuum pump, 5 recirculation pump, 6 sampling point, 7 pressure controller, 8 PC with data acquisition card, 9 and 10 sampling valves [18].

Concentration using evaporator

Concentration was done at two pressures of 11 kPa and 38 kPa. The evaporator (NIBF, Iran) was set to 65°C (Table 1) [20].

Concentration using conventional heating

Concentration was done using a stove at a pressure of 25 kPa and a temperature of 120 °C. The concentrated samples were kept at -18 °C till analysis. The concentration time in each method was calculated (Table 1) [20].

Experiments

pH measurement

The pH value was measured by a digital pH meter (Trohem 744, Germany) according to the national standard No. 12949 [21].

Dissolved solids measurement

First, a clean and dry porcelain or platinum crucible was brought to a constant weight in an electric furnace (U30, Iran) at 525°C. It was placed in a desiccator to cool and 2 to 5 g of the concentrate were weighed by a sensitive laboratory balance. Then, an appropriate amount of the sample was transferred to the crucible and calculated according to the national standard No. 2685 using Equation [22].

Equations (1):

$$\mathrm{W3} = \frac{\mathrm{W2} - \mathrm{W1} \times 100}{m}$$

where W_1 is the weight of the empty crucible (g)

W_2 is the last weight of the crucible with the dissolved solids (g)

W_3 is the weight of total solids in (g/100g).

m is the weight of the sample (g)

Antioxidants measurement

The radical absorption capacity was measured based on the reaction of the antioxidants of the juice to DPPH radicals according to the method of Rekha *et al*. [23]. Optical absorption was measured using a spectrophotometer (CE2502, England) at a wavelength of 517 nm. The percentage of free radical absorption was calculated using Equation 2.

Equations (2):

$$\text{Scavenging activity (\%)} = \frac{(\mathrm{A} - \mathrm{B})}{\mathrm{A} \times 100}$$

where A is the absorption of DPPH and B is the absorption of barberry concentrate. The DPPH free radical absorption method is commonly used to evaluate the ability to absorb free radicals from different samples. DPPH free radical showed a maximum absorption of 515-528 nm. In this method, DPPH radical antioxidants decreased and their color changed from purple to yellow. The rate of color change depends on the hydrogen donating ability of antioxidants.

Dominant anthocyanin measurement

The pigments in barberry concentrate were extracted and separated by differential method at two pH values, 1 and 4.5, and two wavelengths, max 510 and 700 nm. To do this, first, sodium acetate buffer and potassium chloride buffer solutions were prepared, and then the appropriate dilution factor was determined via diluting the sample with potassium chloride buffer.

Equations (3):

$$\mathrm{DF} = \frac{\text{(Initial volume)}}{\text{(Final volume)}}$$

Two dilutions were made from the sample. One with potassium chloride buffer and the other with sodium acetate buffer, which were diluted by the determined dilution factor. The solutions were left for 15 min to be calibrated. The absorption rate of the diluted sample was calculated using Equation 4.

Equations (4):

$$A = (A\lambda \text{ vis max} - A\,\lambda 700)\ \text{pH} = 1\ \_\ (A\lambda \text{ vis max} - A\,\lambda 700)\ \text{pH} = 4.5$$

The amount of anthocyanin pigments in the original sample was calculated using the following Equation:

Equations (5):

$$\text{Anthocyanin pigment (Mg/ L)} = \frac{A \times \text{ MW} \times \text{ DF} \times 1000}{(\varepsilon \times 1)}$$

For pelargonidin 3 glucoside, the values of ε and MW were as follows:

$$\text{MV} = 22400\ \text{(Molar absorption)}$$

$$\text{MW} = 2.423\ \text{(Molecular weight)}$$

where MW is the molecular weight [423.2] of the dominant anthocyanin (the dominant anthocyanin in barberry juice is petonidin-3-glucoside). DF is the dilution factor and MA is the molar absorption (18900) of the dominant anthocyanin [24].

Total phenols measurement

First, different concentrations of gallic acid solution (mg/100 mL) were prepared and their absorbance was read at a wavelength of 750 nm by an UV-visible spectrophotometer (Cecil, England, model CE2502). Then, the standard curve was drawn based on concentration/absorbance. Using this standard curve, the amount of total phenolic compounds in barberry concentrate was measured and expressed as mg of gallic acid per 100 mL of sample. Next, its absorbance was read at a wavelength of 650 nm by the spectrophotometer and the amount of total phenolic compounds was reported using the gallic acid standard curve [23].

Color measurement

The color of the barberry concentrate samples was measured using a Hunterlab colorimeter (model 45, USA) with two replications for each treatment. L*, a*, b* indexes were determined. The total color difference values were calculated using the following Equations:

Equations (6):

$$x = \frac{(a + 1.75\ L)}{(5.65\ L\ + a - 3.012\ b)}$$

Equations (7):

$$BI = \frac{[100\ (x - 0.31)]}{(0.17)}$$

where L* represents black-white index ranging from 0 (black) to 100 (white), a* represents green-red index ranging from -60 (green) to +60 (red) and b* represents blue-yellow index ranging from -60 (blue) to +60 (red). Three color parameters were measured as the browning index. BI indicates the purity of the brown color and is an important parameter of browning [25].

Statistical analysis

All experiments were performed in triplicate. The differences were statistically analyzed by one-way analysis of variance (ANOVA) followed by a *Duncan multiple range test (DMRT)* using Minitab 16 software, and graphs were drawn by Excel software.

RESULTS AND DISCUSSION

Effect of different concentration methods on concentration time

The effect of different concentration methods (evaporator, microwave and conventional heating) on the concentration time until reaching Brix 30 is shown in Figure 2. The shortest and the longest times were observed for the microwave treatment at 11 kPa (C) and the evaporator treatment at 38 kPa (B), respectively. The results showed that as the pressure decreased, the concentration rate increased, so that in the microwave method at 11 kPa, the concentration time was 20 min and in the evaporator method at 38 kPa, it was 160 min. Therefore, the reduced pressure and the microwave method resulted in shorter concentration time. A combined use of microwave heating and a vacuum system permits a faster energy and mass transfer at low temperature within a short time. VME system causes more water vapor to separate from the product at appropriate power and vacuum levels due to the fast heating of the product [15].

Alami *et al*. [26] used a rotary evaporator under vacuum (pressures of 38.5 and 7.3 kPa) and a heater equipped with a stirrer under atmospheric pressure to concentrate watermelon juice. The results showed that the time required to reach Brix 40 at atmospheric pressure, 38.5 kPa and 3.7 kPa, was 205, 198 and 150 min, respectively. They stated that in order to reach the same degrees Brix at a lower pressure (7.3 kPa), a shorter time was needed. Other researchers concentrated pomegranate juice using the conventional heating and microwave methods at different pressures (12, 38.5 and 100 kPa). The results revealed that at 100, 38.5 and 12 kPa, the Brix reached 40 by conventional heating running for 140, 127, and 109 min and by microwave heating for 118, 95, and 75 min, respectively [19]. Other researchers evaluated the efficiency of microwave-assisted evaporation (MAE) methods and microwave-assisted vacuum evaporation (MAVE) for concentrating barberry juice and comparison it to the conventional evaporation methods. To do so, the barberry juice was concentrated by two various methods (the microwave evaporation under pressures of 100 and 30 kPa and indirect heating) to reach 60 °Brix. The results exhibited that the rates of evaporation of MAVE and MAE procedures were, respectively, 48.86 and 48.27% higher than those of indirect heating. The conditions reduced the boiling point of the barberry juice from 96 to 77°C. Despite the same evaporation speed of both MAE and MAVE, less time was needed to reach the boiling point in vacuum conditions. In fact, the time required to reach the boiling point in MAE method was 78 min, while under vacuum conditions the time was reduced to 68 min [27].

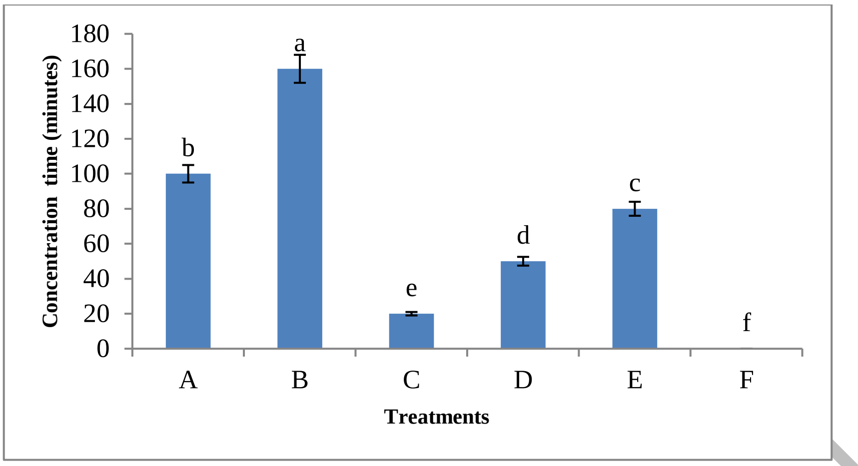

Figure 2. Barberry juice concentration time

A Evaporator (11 kPa), B Evaporator (38 kPa), C Microwave (11 kPa), D Microwave (38 kPa), E Conventional heating (25 kPa), F Unconcentrated control sample

Different letters (a, b, c, d, e, f) represent no statistical difference

Effect of different concentration methods on pH

The results of the investigation of the effect of different concentration procedures (evaporator, microwave and conventional heating) on pH changes are presented in Figure 3. The results revealed that different concentration treatments had different pH values. The lowest (2.59) and the highest (2.69) pH values were found for the evaporator treatment at 11 kPa (A) and the unconcentrated treatment (F), respectively. The pressure reduction led to pH decline. Our results are in agreement with the results obtained by Motamed zadegan *et al.* [28] who investigated the effect of pressure and degree of concentration on the pH of sour pomegranate concentration using atmospheric pressure and vacuum methods (0.1). Their results showed that in both methods, as the Brix increased, the pH value decreased. However, in the vacuum concentration method, the pH decline was more than that in the atmospheric method.

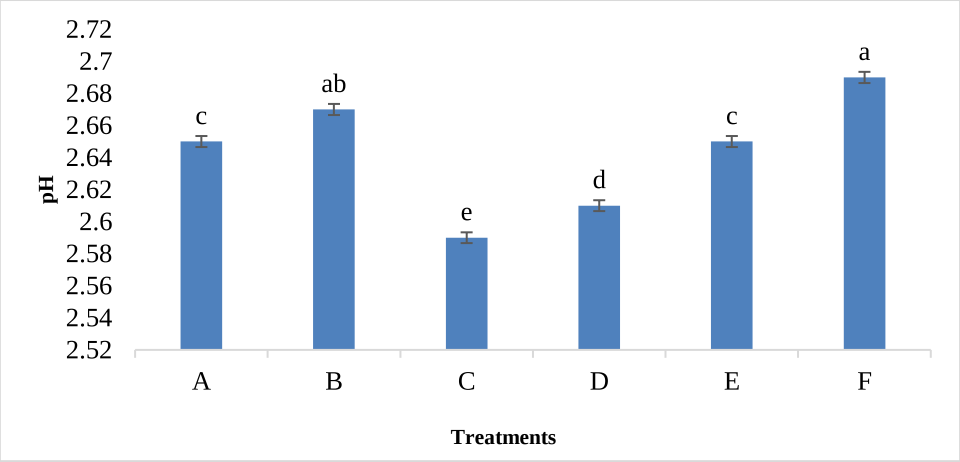

Figure 3. pH values of different treatments

A Evaporator (11 kPa), B Evaporator (38 kPa), C Microwave (11 kPa), D Microwave (38 kPa), E Conventional heating (25 kPa), F Unconcentrated control sample

Different letters (a, b, c, d, e, f) represent no statistical difference

Effect of different concentration methods on total solids content

The results of the investigation of the effect of different concentration methods (evaporator, microwave and conventional heating) on the amount of solids are presented in Figure 4. The brix of all the samples concentrated by the three methods (evaporator, microwave and conventional heating) were not significantly different from each other and the lowest amount of brix or dissolved solids was observed for the unconcentrated sample (F). Basiri and Gheibi [29] studied the effect of concentration of mulberry extract on the amount of total solids up to a concentration of 65 degrees using three methods including solar, conventional heating and vacuum (rotary evaporators). The results showed the highest amount of dissolved solids for the solar treatment followed by the conventional heating method.

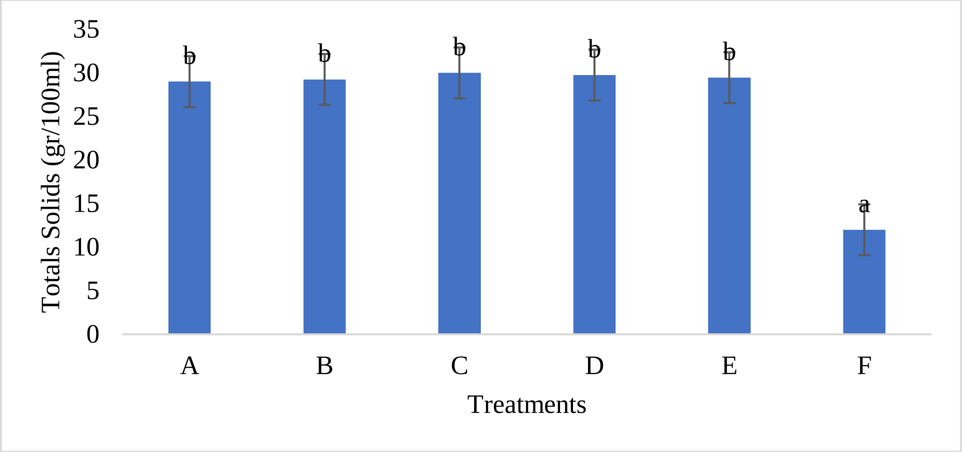

Figure 4. Solids content

A Evaporator (11 kPa), B Evaporator (38 kPa), C Microwave (11 kPa), D Microwave (38 kPa), E Conventional heating (25 kPa), F Unconcentrated control sample

Different letters (a, b, c, d, e, f) represent no statistical difference

Effect of different concentration methods on anthocyanin content

The results of the investigation of the effect of different concentration methods (evaporator, microwave and conventional heating) on the anthocyanin content are presented in Figure 5. The highest (32.18) and the lowest (6.79) amounts of anthocyanin were observed for the unconcentrated treatment (F) and the vacuum evaporator treatment at 38 kPa (B), respectively. In other words, the unconcentrated treatment had the least effect on the anthocyanin content. The highest amount of anthocyanin was found for the microwave treatment at 11 kPa, followed by the unconcentrated treatment. Barberry contains 5 types of anthocyanin with the main one being petonidin-3-glycoside. Cyanidin is also the main anthocyanin present in barberry juice, which is affected by heat [30]. The quality of concentrated fruit juice directly depends on the heating temperature and time. Different concentration methods yielded different results for degradation of the anthocyanins present in barberry juice. The degradation percentage in the microwave method was less than that of the vacuum evaporator. Therefore, there was an obvious difference in the anthocyanin degradation percentage between the heating methods [31]. As a result, in the microwave method, compared to the evaporator method, the loss of anthocyanins was reduced, and also at lower pressure, as the concentration time reduced, the concentration rate increased and a greater amount of anthocyanin was retained. Also in the microwave method, degradation of anthocyanins increased with increasing pressure, so the red color of anthocyanins decreased and the formation of dark compounds increased as a result of increased non-enzymatic browning [32]. Hojjatpanah *et al*. [20] investigated the effect of the concentration methods on anthocyanins of blackberry juice and stated that the microwave method and lower pressure had less effect on anthocyanins compared to conventional heating. Other researchers stated that the anthocyanin content of the sample increased proportionally with increasing juice concentration, however at a constant concentration, the amount of anthocyanin before and after concentration showed no significant changes [32].

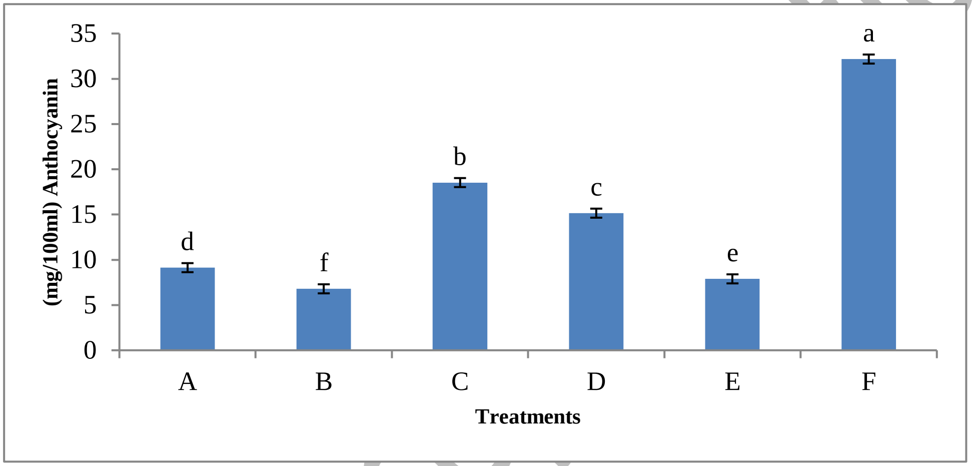

Figure 5. Anthocyanin content

A Evaporator (11 kPa), B Evaporator (38 kPa), C Microwave (11 kPa), D Microwave (38 kPa), E Conventional heating (25 kPa), F Unconcentrated control sample

Different letters (a, b, c, d, e, f) represent no statistical difference

Effect of different concentration methods on phenols content

The results of the investigation of the effect of different concentration methods (evaporator, microwave and conventional heating) on the total phenols content are presented in Figure 6. The highest (1.27) and lowest (0.653) amounts of phenols were observed for the unconcentrated treatment (F) and the conventional heating treatment (E), respectively. As shown in the Figure, the unconcentrated treatment and the vacuum microwave treatment at 11 kPa were significantly different from other treatments. In other words, concentration by microwave method at 11 kPa had the least effect on the phenol content. Increased pressure and heat resulted in phenol degradation. Therefore, the best concentration method to preserve more phenols was microwave treatment at low pressure. Our results are consistent with the findings of the study conducted by Malien-Aubert *et al*. [33] who found that polyphenols were susceptible to heat and were lost during various processing operations. Other researchers compared the phenolics of concentrated blackberry juice with fresh blackberry juice (unconcentrated) using the conventional heating and microwave methods. The results revealed that the concentrated blackberry juice had lower phenol content than fresh blackberry juice (unconcentrated) and the conventional heating method increased the rate of degradation of phenols [20].

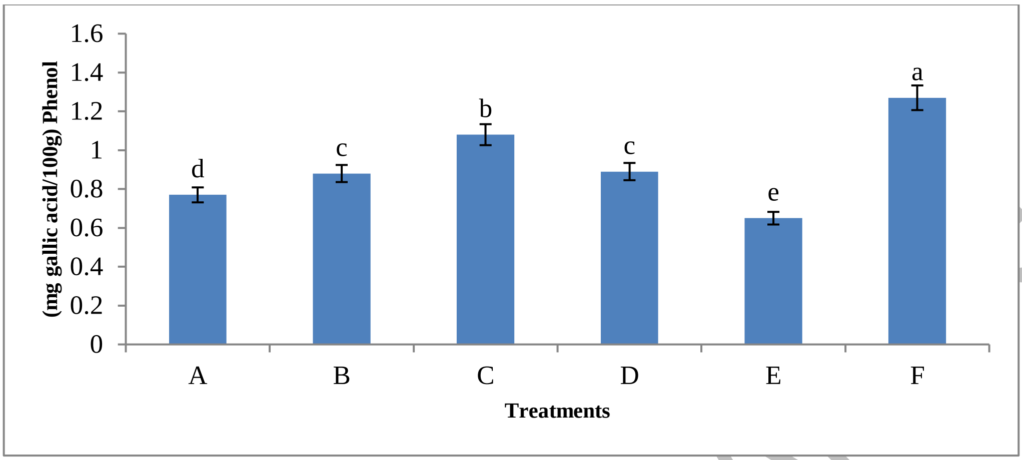

Figure 6. Total phenol content

A Evaporator (11 kPa), B Evaporator (38 kPa), C Microwave (11 kPa), D Microwave (38 kPa), E Conventional heating (25 kPa), F Unconcentrated control sample

Different letters (a, b, c, d, e, f) represent no statistical difference

Effect of different concentration methods on color changes

The results of the investigation of the effect of different concentration methods (evaporator, microwave and conventional heating) on the color changes are presented in Figure 7. The highest (348.11) and lowest (167.28) browning index (BI) values were observed for the evaporator treatment at 11 kPa (A) and the unconcentrated treatment (F), respectively. In other words, the unconcentrated sample and the microwave-treated sample at 11 kPa (C) showed the least effect on the color. In this study, the color of barberry juice during concentration by microwave, evaporator and conventional heating methods was examined and it was found that all the color parameters (L*, a*, b*) changed significantly. The results showed that higher temperature increased the browning index of barberry juice. Our results are in agreement with the results obtained by other researchers who studied the color of blackberry during concentration by microwave and evaporator methods. They reported significant changes in all color parameters (L*, a*, b*). Their results showed that BI increased during concentration, indicating a browning reaction like Maillard owing to increasing temperature, and the change was more pronounced in the conventional heating method. The change in the color of the concentrate could be not only due to the browning reaction, but also to the thermal degradation of the pigments in the concentrate. Heating the juice containing anthocyanin caused the color to change to dark red, and the heat treatment resulted in an increase in the brown color. This was the case for barberry juice [20]. Alami *et al.* [27] investigated the effect of concentration on the color of watermelon juice and stated that the use of vacuum reduced the processing time, thereby preserving the quality of the product. They found that reducing the pressure during concentration resulted in lower process temperature, shorter process time as well as improved retention of the lycopene pigment in watermelon.

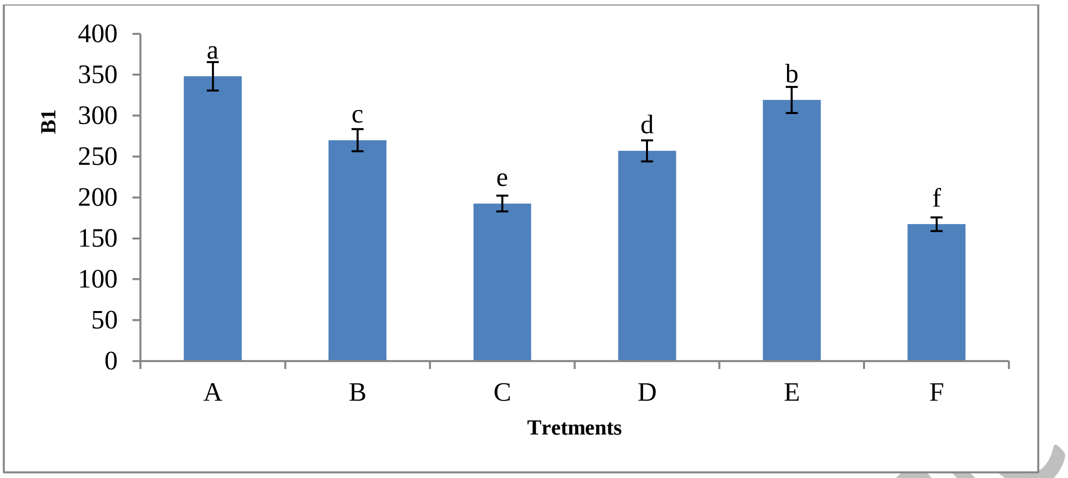

Figure 7. Color of treatments

A Evaporator (11 kPa), B Evaporator (38 kPa), C Microwave (11 kPa), D Microwave (38 kPa), E Conventional heating (25 kPa), F Unconcentrated control sample

Different letters (a, b, c, d, e, f) represent no statistical difference

Effect of different concentration methods on antioxidant compounds

The results of the investigation of the effect of different concentration methods (evaporator, microwave and conventional heating) on the antioxidant compounds are presented in Figure 8. The highest and lowest amount of antioxidants were observed for the microwave treatment at 11 kPa (C) and the conventional heating treatment (E), respectively. In other words, the microwave method at a pressure of 11 kPa had the least effect on antioxidant degradation. Given the fact that in the microwave method, the concentration time was shorter and the concentration rate was higher than those in other methods, the microwave method lowered the temperature and reduced the processing time, thereby improving the preservation of antioxidants. Similarly, Wang *et al*. [34] stated that compared to conventional heating, the microwave method at low pressure reduced the processing temperature and time and also improved the preservation of antioxidants. Fazaeli *et al*. [32] reported that different thermal methods yielded different results for antioxidant capacity of blackberry juice. They concluded that the use of microwave energy reduced the thermal degradation and that the antioxidant activity was higher in the microwave method at lower pressure. They also found that the use of higher pressures led to the degradation of antioxidants in blackberry juice in both microwave and evaporator methods. The use of higher pressures decreased the antioxidant capacity in the microwave and evaporator method.

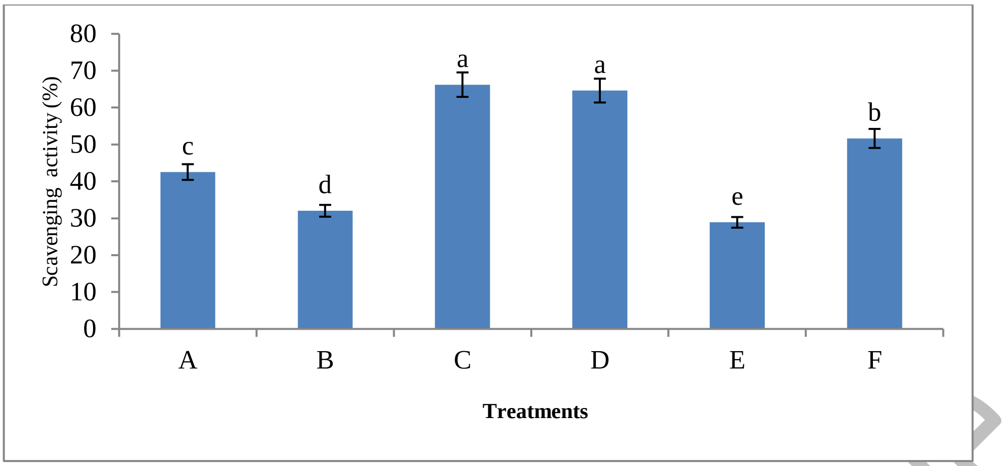

Figure 8. Scavenging activity

A Evaporator (11 kPa), B Evaporator (38 kPa), C Microwave (11 kPa), D Microwave (38 kPa), E Conventional heating (25 kPa), F Unconcentrated control sample

Different letters (a, b, c, d, e, f) represent no statistical difference

CONCLUSIONS

Given the fact that barberry is a product that is rich in antioxidant compounds, the concentration method is very effective in preserving the antioxidants. In this study, the effect of different thermal concentration methods on the physicochemical properties, antioxidants activities and color of the barberry juice was investigated. The results showed that the use of vacuum reduced the processing time, thereby improving the preservation of the quality of the product. Microwave heating provided volumetric heating of food. The concentration was carried out quickly by the combined use of microwave and vacuum, which allowed faster mass and energy transfer within a short time. In the microwave method at low pressure, the degradation of antioxidant compounds, physicochemical properties and color was lower than that in conventional heating and vacuum evaporator. Also, the use of higher pressures in both microwave and evaporator methods led to greater degradation of the compounds. The physicochemical properties of the concentrated barberry juices processed using VME were found to be superior to those of the juices produced using the other conventional methods. The results of the present study can be used for barberry juice concentrate production in industrial concentration processes.

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