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Ultra-high-pressure homogenization in chicory root juice production

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Abstract:
The demand for freshly squeezed natural fruit juices has increased in recent years, however their shelf life is quite short. Thermal processes applied to extend the shelf life of such products and increase their storage stability cause significant losses in color and other sensory properties, depending on the temperature applied. Therefore, the preference for high-pressure homogenization as an alternative to thermal processes is on the rise. We aimed to determine effects of ultra-high-pressure homogenization and production stages on some quality properties of chicory root juice.
Ultra-high-pressure homogenization was applied at the pressure levels of 0 (control), 50, 100, 150, and 200 MPA. The samples also included juice after homogenization with an ULTRA-TURRAX disperser and after a water bath.
Ultra-high-pressure homogenization affected such quality characteristics of chicory root juice as total soluble solids ($p < 0.01$), pH ($p < 0.01$), L^* ($p < 0.01$), a^* ($p < 0.01$), b^* ($p < 0.01$), a^*/b^* ($p < 0.01$), chroma ($p < 0.01$), hue angle ($p < 0.01$), and total color difference ΔE ($p < 0.01$). Higher levels of ultra-high-pressure homogenization pressure increased pH ($p < 0.05$), a^* values ($p < 0.05$), and the a/b^* ratio ($p < 0.05$) but reduced L^* ($p < 0.05$), b^* ($p < 0.05$), chroma ($p < 0.05$), and hue angle ($p < 0.05$) values of the juice samples. Thus, the use of ultra-high-pressure homogenization (100 and 200 MPa) contributed to improving the total soluble solids and redness values of chicory root juice.
Our study showed that the ultra-high-pressure homogenization process improved the quality of chicory root juice.

Keywords: Chicory root juice, ultra-high pressure, homogenization, color characteristics, pH, total soluble solids

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INTRODUCTION

Chicory is a tuberous taproot with rosette leaves that grows widely under cool conditions. Although increasingly cultivated for different purposes around the world, chicory is not grown in Turkey. The genus Chicory (*Asteraceae*) contains six species, two of which are of economic importance, namely *Cichorium intybus* and *Cichorium endivia*. These two species are morphologically similar. However, *C. intybus* can be distinguished from *C. endivia* by its short pappus (extension at the end of the fruit), as well as other perennial and self-sustainable characteristics. *C. intybus* is the most prevalent and varied species of the genus Chicory in the world [1].

Chicory roots are one of the most important plant resources used in the production of inulin [2, 3]. Inulin contains less energy compared to other carbohydrates. It stimulates the growth of bifidobacteria in the intestines, reducing the risk of developing heart disease, diabetes, osteoporosis, and cancer [4]. European countries are increasing the consumption of inulin as a dietary lithium and producing up to one million metric tons of indigenous Chicory for the food industry [5]. Inulin is resistant to digestion and passes directly into the colon without being absorbed in the small intestine. Chicory sticks contain another sugar group, oligofructose (5–10), which has similar effects to inulin. It is found in glucose and sucrose, which are sugar groups [6]. The content of raw protein and raw fiber in Chicory shoot and root after industrialized extraction are higher than that in corn grain. It is therefore regarded as a valuable industrial plant in terms of its economic yield and quality [7]. Furthermore, spruce-type chicory varieties are also used as coffee additives after processing [8].

Chicory is rich in water, low in calories, and contains a significant amount of dietary fiber, particularly inulin, which is a prebiotic. It also has a modest amount of proteins, low level of fats, and is a good source of several minerals like potassium, calcium, magnesium, and iron, as well as vitamins such as vitamin C and some B vitamins [9, 10]. Chicory is known for its high content of bioactive compounds including inulin, sesquiterpene lactones (such as lactucin and lactucopicrin), caffeic acid derivatives, and various phenolic compounds [11]. These compounds are associated with various health benefits, including antioxidant, anti-inflammatory, and hepatoprotective effects [12]. Chicory and its extracts are generally considered safe for consumption, with inulin from chicory recognized for its prebiotic properties that support gut health. The potential health benefits of chicory include its role in reducing post-prandial glycemic responses and promoting bowel function, as well as its antioxidant and anti-inflammatory properties. These health benefits make chicory an attractive ingredient and a source of inulin for functional foods aimed at improving health and preventing disease [13]. Chicory is used in various food products, including salads, and as a coffee substitute. Food scientists are trying to optimize the extraction of chicory's bioactive compounds for their application in food products on an industrial scale [14]. Chicory presents a promising potential as a functional food ingredient due to its rich nutritional profile, bioactive compounds, and associated health benefits for humans and animals [15, 16]. Its application in the food industry could contribute to the development of health-promoting functional foods, aligning with the consumer demand for natural and beneficial food ingredients [17].

There has been a recent increase in the demand for freshly squeezed fruit juices as natural products. However, the shelf life of such products is quite limited due to microbiological and enzymatic spoilage. In order to reduce these negative effects, thermal processes (60–90°C, < 1 min) are frequently used. However, these temperature applications may cause a significant loss in color and other sensory properties, depending on the temperature and duration [18]. Therefore, in recent years, alternative non-thermal techniques have been widely used in food technology to overcome these disadvantages and enhance the product's quality [19–22]. One of such techniques is high-pressure homogenization applied as an alternative to thermal processing in the fruit juice and beverage technology.

High-pressure homogenization can improve the rheological properties of foods and their emulsion capacity, as well as reduce their particle size. This technology can also inactivate microbial growth and extend the shelf life of the products. Most importantly, it provides a better protection of nutrients and bioactive components whose structures are damaged by thermal processes. In this context, high-pressure homogenization can be used in the fruit juice technology to reduce pulp precipitation, increase physical stability, and improve product's physical properties [22, 23].

Ultra-high-pressure homogenization is used in different areas of food processing, e.g., to improve the rheological properties of citrus fiber or the functional properties of gelatin, as well as to develop functional foods and produce juice [24–28]. A previous study, which applied ultra-high-pressure homogenization (60, 80, 100, 120, 140, and 160 MPa) to native rice starches, found that the viscosity of starch increased between 60 and 120 MPa, while higher pressure applications produced the opposite effect [29].

In summary, ultra-high-pressure homogenization is a method that has been widely applied and studied in recent years to improve the techno-functional properties of fluid foods. Many of its effects have been proven, such as microbial inactivation, changing the physical properties of liquid foods and viscous properties of liquids, homogenization, and enzyme inactivation [23, 30]. Previous studies have generally used fruits as raw materials to determine the effects of ultra-high-pressure homogenization on fruit juice quality. However, we know of no research into the quality of juice produced from the roots of plants. Therefore, we aimed to determine the effects of ultra-high-pressure homogenization at different pressure levels on some quality properties of chicory root juice.

STUDY OBJECTS AND METHODS

Study objects. In our research we tested juice samples after homogenization with an ULTRA-TURRAX disperser, samples after homogenization and keeping in a water bath, and samples treated by ultra-high-pressure homogenization at different pressure levels, namely 0 (control), 50, 100, 150, and 200 MPa.

Preparation of chicory root juice and ultra-high-pressure homogenization. For this research, chicory roots were obtained from the Ertuğrulgazi gardens (Eskişehir, Turkey). They were separated from the soil by washing with tap water and used as material for producing chicory juice (Fig. 1). The chicory juice was passed through an ultra-high-pressure homogenization system (50, 100, 150, and 200 MPa) using a table-top homogenizer (GEA Homogenizer Panda PLUS 2000, Parma, Italy). High-pressure homogenization-untreated chicory juice was considered a control group. The maximum flow rate of the high-pressure homogenization system was 9 L/h. The inlet temperature of the juice was about 4–6°C, while the outlet temperature was in the range of 30.5–36.8°C. For this reason, the chicory juices coming out of the high-pressure homogenization system were immediately cooled and analyzed.

Analysis of chicory juices. ***Determination of total soluble solids.*** Total soluble solids in the control and high-pressure-homogenized samples of chicory juice were determined using a digital refractometer (Hanna HI 96801, USA). A constant temperature of 20°C was used in all the measurements.

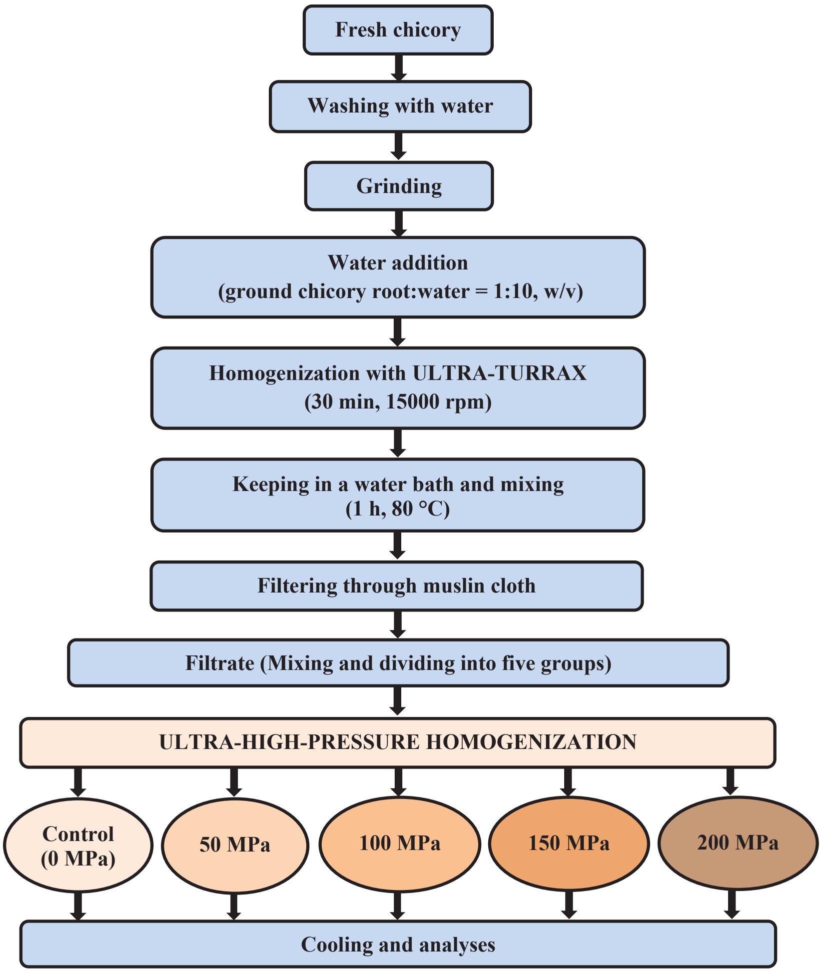

Figure 1 Chicory juice production from fresh chicory root by ultra-high-pressure homogenization

Determination of pH. The pH values of the chicory juice samples were determined using a benchtop pH meter (Hanna Instruments, USA). Measurements were made after the samples were thoroughly homogenized. Before use, a pH meter was calibrated with 3 different buffer solutions with pH of 4.0, 7.0, and 10.0.

Determination of instrumental color values. First, we measured L^* (darkness: $L^* = 0$; lightness: $L^* = 100$), a^* (redness: $+a^*$; greenness: $-a^*$), and b^* (yellowness: $+b^*$; blueness: $-b^*$) values and then, chroma (C*) and hue angle (h°) values [31]. In addition, the total color difference (ΔE) was calculated in the samples treated by ultra-high-pressure homogenization versus the control.

Statistical analysis. The study was carried out according to a completely randomized design with two replications. An analysis of variance was performed using the SPSS package program (SPSS 23.0). The mean values of the main sources of variation were compared with the Duncan Multiple Comparison Test (95% confidence interval, $p < 0.05$).

RESULTS AND DISCUSSION

We found that the chicory root juice samples treated by ultra-high-pressure-homogenization had higher values of total soluble solids compared to the samples after the ULTRA-TURRAX homogenization and keeping in a water bath (Table 1). There was no statistical difference ($p > 0.05$) in total soluble solids between the control and the 50 MPa treatment groups (Fig. 2). However, we observed a statistically significant ($p < 0.05$) increase in the 100 MPa group compared to the 150 and 200 MPa groups (Fig. 2). The amount of total soluble solids mainly refers to soluble sugars in fruit or fruit juices and varies depending on the amount of soluble sugar in the raw material and the applied process [32]. The increase we found in total soluble solids might be due to the

Table 1 Effects of treatments on total soluble solids and pH values of chicory root juices

Treatment	Total soluble solids, °Brix	pH
ULTRA-TURRAX	0.875 ± 0.071	6.82 ± 0.02
Water bath	0.875 ± 0.046	7.47 ± 0.20
Control (0 MPa)	0.925 ± 0.046	7.44 ± 0.01
50 MPa	0.937 ± 0.052	7.54 ± 0.01
100 MPa	1.050 ± 0.053	7.63 ± 0.04
150 MPa	0.975 ± 0.046	7.66 ± 0.03
200 MPa	1.012 ± 0.064	7.75 ± 0.02
SEM	0.020	0.029
p-value	< 0.0001	< 0.0001

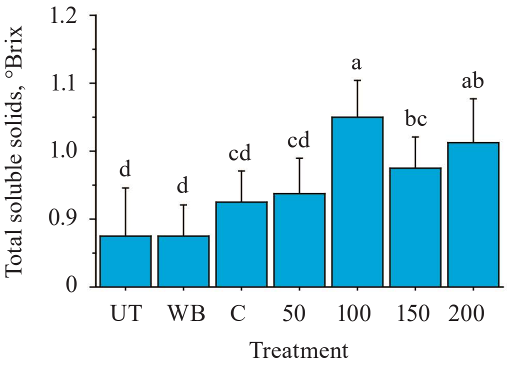

Figure 2 Effects of ultra-high-pressure homogenization on total soluble solids of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

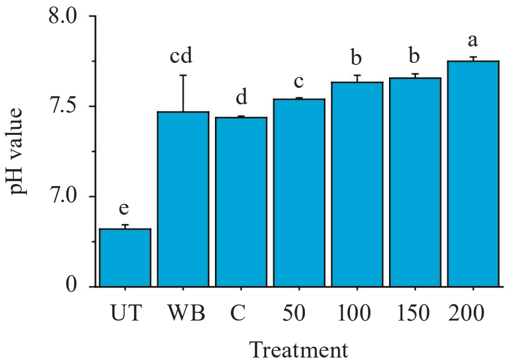

Figure 3 Effects of ultra-high-pressure homogenization on pH value of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

disintegration of macromolecules in chicory root juice under the influence of ultra-high-pressure homogenization. Similarly, Yan *et al.* reported that high-pressure homogenization causes an increase in the amount of water-soluble cell materials and pectin, which might be a cause of the increasing in total soluble solids [33]. A similar change was detected in the study that determined the effects of high-pressure homogenization on the quality of Ottoman strawberry (*Fragaria* × *ananassa*) juice [34]. Contrary to our current findings, we have previously determined that high-pressure homogenization applied to juices produced from different pomegranate genotypes reduced the amount of total soluble solids [35]. This difference could be explained by the difference in the composition and properties of fruit tissue and root properties since plant root parts contain more complex macromolecules than stems and leaves.

Table 1 also shows the effects of the production stages and ultra-high-pressure homogenization treatments at 0, 50, 100, 150, and 200 MPa on the pH values of chicory root juice. As can be seen, the pH values ranged from 6.82 ± 0.02 to 7.75 ± 0.02, with significant ($p < 0.05$) differences between the treatments. We observed that ultra-high-pressure homogenization increased the pH values of the samples, especially at 200 MPa pressure, i.e. the higher the homogenization pressure, the higher the pH values. Lower pH values were determined in the ULTRA-TURRAX stage of the process (Table 1). Among the production stages and high-pressure homogenization processes, the highest pH increase occurred after the ULTRA-TURRAX stage (Fig. 3). This increase could be due to the heat treatment at 80°C for 1 h after the ULTRA-TURRAX process (Fig. 1). The pH probably increased due to an increase in, or a release of, alkaline components by tissue dissolution in the ULTRA-TURRAX process. In line with our current findings, Gul *et al.* and Wellala *et al.* stated that high-pressure homogenization increased pH value, and this was due to breakdown of pectin and proteins into cellular materials [36, 37].

In another study, Liu *et al.* determined the effects of ultra-high-pressure homogenization (50, 100, 150, and 200 MPa) on the pH of pear juice at different temperatures (4, 20, 30, 40, 60, and 80°C) [30]. Contrary to our findings, the researchers reported that different pressures applied at the same temperature did not affect pH. However, the pH value decreased due to the disintegration of cells and the dissolution of organic acids and other substances under the influence of ultra-high-pressure homogenization at high temperatures (especially at 60 and 80°C). These differences among the studies show that the effect of ultra-high-pressure homogenization on pH may vary depending on the matrix of raw material from which the juice is produced, as well as production conditions and the treatment applied.

Table 2 demonstrates the effects of different treatments on L^*, a^*, b^*, C*, and °h of the chicory root juices under study. As can be seen, pressure application increased the L^* value ($p < 0.01$, Table 2). However, as the pressure level increased, the L^* (lightness) value decreased, so among all the treatments, the highest value was determined in the 50 MPa group, while the lowest value was determined in the 150 MPa group ($p < 0.05$, Fig. 4). In a study on cloudy honey peach juice, the applied pressure of 20–40 MPa significantly increased the L^* value [33]. The researchers stated that this increase was due to the stabilization of the product by decreasing the centrifugation precipitating rates (13.49–24.22%) and the mean particle diameter (from 1853.67 nm to 501.10–665.27 nm) at this pressure compared to the control. Our results clearly show a negative effect of high levels of pressure (over 50 MPa) on the L^* value.

An important color criterion that varies depending on fruit juice characteristics is the $+a^*$ value, which indicates redness. This value is associated with the structure and form of phenolic components in the fruit or its roots. Phenolic components, especially anthocyanins, affect the $+a^*$ value depending on pH [38]. The leaves of *Cichorium intybus* L. are a good source of phenolic compounds of high medicinal importance [39]. High-pressure application, which is a non-thermal technique, also increases the redness value by providing more release of

Table 2 Effects of different treatments on instrumental color values of chicory root juice samples

Treatment	L^*	a^*	b^*	a^*/b^*	Chroma (C^*)	Hue angle (h°)
ULTRA-TURRAX	24.23 ± 0.95	3.99 ± 0.30	9.94 ± 0.67	0.40 ± 0.04	10.76 ± 0.64	68.19 ± 2.24
Water bath	23.94 ± 0.63	3.24 ± 0.11	10.49 ± 0.55	0.31 ± 0.02	10.98 ± 0.53	72.80 ± 0.98
Control (0 MPa)	26.59 ± 1.28	4.51 ± 0.23	14.11 ± 1.09	0.32 ± 0.03	14.84 ± 0.12	72.13 ± 1.58
50 MPa	27.38 ± 0.82	4.38 ± 0.17	15.12 ± 0.79	0.29 ± 0.02	15.75 ± 0.74	73.80 ± 1.13
100 MPa	25.64 ± 0.92	4.86 ± 0.09	13.61 ± 0.98	0.36 ± 0.03	14.46 ± 0.87	70.26 ± 1.38
150 MPa	24.21 ± 0.39	4.48 ± 0.10	11.45 ± 0.51	0.39 ± 0.01	12.29 ± 0.51	68.61 ± 0.52
200 MPa	25.15 ± 0.88	4.99 ± 0.09	12.92 ± 0.94	0.39 ± 0.03	13.86 ± 0.94	68.80 ± 1.26
SEM	0.262	0.057	0.273	0.008	0.253	0.416
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

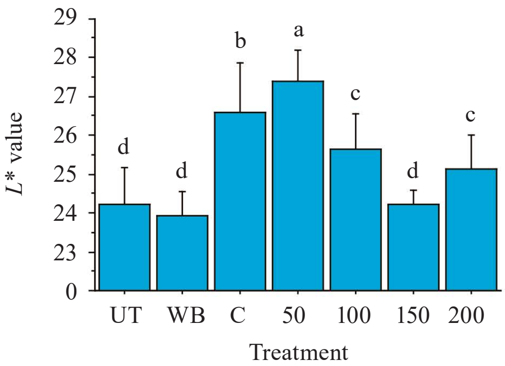

Figure 4 Effects of ultra-high-pressure homogenization on the L^* value of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

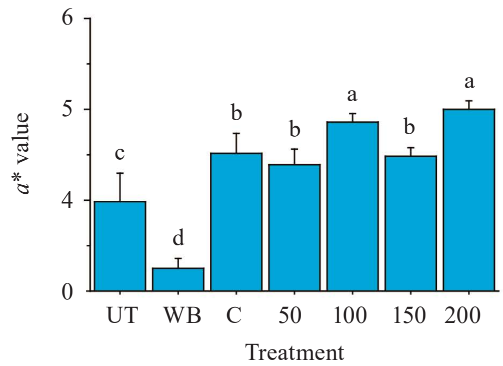

Figure 5 Effects of ultra-high-pressure homogenization on the a^* value of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

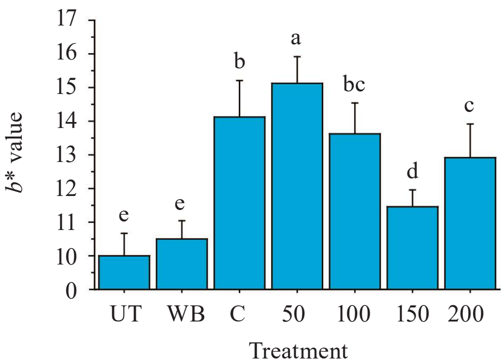

Figure 6 Effects of ultra-high-pressure homogenization on the b^* value of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

anthocyanins from the tissue [34, 40]. In line with this literature, we also found that high-pressure homogenization affected the a^* value ($p < 0.01$, Table 2). Even higher a^* values were determined in the chicory root juices subjected to 100 and 200 MPa pressure treatments compared to the control ($p < 0.05$, Fig. 5). No significant difference was observed between the control, 50 and 150 MPa groups ($p > 0.05$). Another study determined the effects of ultra-high-pressure homogenization and low temperature on the quality of fresh pomegranate juice [40]. The researchers stated that the a^* value increased from 5.31 ± 0.38 in the control to 5.61 ± 0.55 and 6.35 ± 0.23 in the 100 and 150 MPa groups, respectively.

Different levels of high-pressure homogenization of chicory root juices also affected their b^* values ($p < 0.01$, Table 2). The highest b^* values were detected in the 50 MPa group, while lower values were determined in the 100, 150, and 200 MPa groups compared to the control ($p < 0.05$, Fig. 6). As expected, ultra-high-pressure homogenization had very significant effects on the a^*/b^* ratio in the chicory root juices ($p < 0.01$, Table 2). This ratio was significantly higher in the 150 and 200 MPa groups than in the 50 MPa and the control groups ($p < 0.05$, Fig. 7).

Chroma, hue angle (h°), and total color difference (ΔE) parameters are calculated using L^*, a^*, and b^* values. In food science, these parameters are generally used to determine color changes in fresh food and food processed by different methods. In our study, ultra-high-pressure homogenization affected the chroma values of the chicory root juice samples ($p < 0.01$, Table 2), which indicate the degree of intensity or purity of color. We found that the chroma values decreased according to the applied pressure level ($p < 0.05$), with the lowest value recorded in the 150 MPa treatment group (Fig. 8). As

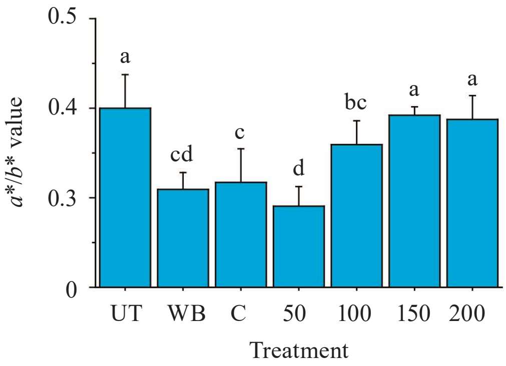

Figure 7 Effects of ultra-high-pressure homogenization on the a^*/b^* ratio of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

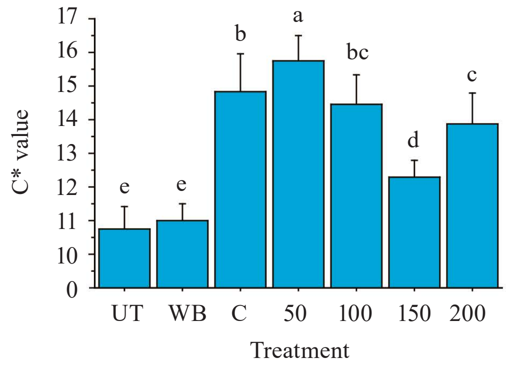

Figure 8 Effects of ultra-high-pressure homogenization on the Chroma (C*) value of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

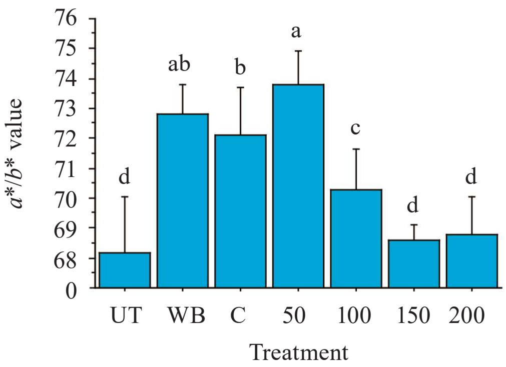

Figure 9 Effects of ultra-high-pressure homogenization on the hue angle (h°) value of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

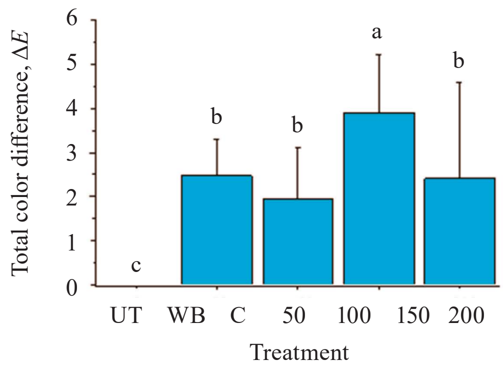

Figure 10 Effects of ultra-high-pressure homogenization on total color difference values of chicory root juice samples. UT – after homogenization with ULTRA-TURRAX; WB – after keeping in a water bath and mixing; C – control (0 MPa). Different letters indicate statistical difference ($p < 0.05$)

Table 3 Effects of ultra-high-pressure homogenization on total color difference values of chicory root juice samples

Treatment	Total color difference (ΔE)
Control (0 MPa)	0
50 MPa	2.47 ± 0.84
100 MPa	1.94 ± 1.19
150 MPa	3.91 ± 1.32
200 MPa	2.41 ± 2.17
SEM	0.252
p-value	< 0.0001

SEM: Standard error of the mean

with the chroma parameter, ultra-high-pressure homogenization also affected the h° value very significantly ($p < 0.01$, Table 2). Generally, a gradual decrease in h° values was determined in the groups according to the levels of pressure ($p < 0.05$), indicating decoloration from red to yellow. However, this decrease was less pronounced in the 50 MPa group, compared to the control, because the 50 MPa group had the highest h° values among all the samples ($p < 0.05$, Fig. 9).

The total color difference (ΔE) between the control group (0 MPa) and the samples homogenized with high pressure is presented in Table 3. This parameter is mostly used to detect color changes in processed foods. Compared to the control sample, higher ΔE values indicate higher color differences [41, 42]. In this study, we found significant differences in ΔE between the control and high-pressure treatment groups ($p < 0.01$, Table 3). The highest value was determined in the 150 MPa group ($p < 0.05$), with no statistical difference between the other treatment groups ($p > 0.05$, Fig. 8).

Another study determined the combined effects of short-wave ultraviolet radiation and ultra-high-pressure homogenization on the properties of cloudy apple juice [43]. The authors reported that the ΔE value increased with the pressure applied to apple juice. Changes in the structure of pigments cause visible color changes during food processing, especially in fruits, vegetables, and beverages. In our study, the increase in the a^* value is an important cause for the change in ΔE. Tiwari *et al.* and Patras *et al.* classified the differences in perceptible color as very distinct ($\Delta E > 3$), distinct ($1.5 < \Delta E < 3$), and minor differences ($1.5 < \Delta E$) [44, 45].

According to our results, there were significant changes in the 150 MPa treatment group and significant changes in the 50, 100, and 200 MPa treatments (Fig. 10). Similarly, Saricaoglu *et al.* found that the Δ*E* value increased depending on the applied pressure and multipass high-pressure homogenization in rosehip (*Rosa canina* L.) nectar [46]. Also, a research on pear juice found that when the total color difference (Δ*E*) was less than 2, there was no visually noticeable color change in the product [30]. These results show that the effect of ultra-high-pressure homogenization on the total color difference (Δ*E*) may vary depending on the raw material, the density of color pigments in the raw material, the temperature applied, and the process conditions.

CONCLUSION

In this research, we determined the effects of ultra-high-pressure homogenization on some quality characteristics of chicory root juice. An important result was the increase in total soluble solids, depending on the pressure level applied, due to the disintegration of macromolecules in chicory juice. Since chicory roots are a good source of inulin, its extraction can be increased by applying ultra-high-pressure homogenization. Based on our results, the quality characteristics of chicory root juice treated with ultra-high-pressure homogenization should be determined in detail with different analyses (total sugar, reducing sugar, particle size, inulin, phenolic components, etc.). In addition, it would be useful to further investigate the color and storage stability of chicory root juice prepared by using ultra-high-pressure homogenization.

CONTRIBUTION

M.I. Aksu and H.I. Erkovan developed the research concept and design, collected and analyzed the material, processed the data statistically, as well as wrote and edited the manuscript. S. Erkovan performed the analysis, and all the authors approved the final version of the article.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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