Influence of three different concentration techniques on evaporation rate, color and phenolics content of blueberry juice

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Abstract The present study was undertaken to assess the effects of three different concentration processes open-pan, rotary vacuum evaporator and microwave heating on evaporation rate, the color and phenolics content of blueberry juice. Kinetics model study for changes in soluble solids content (°Brix), color parameters and phenolics content during evaporation was also performed. The final juice concentration of 65° Brix was achieved in 12, 15, 45 and 77 min, for microwave at 250 and 200 W, rotary vacuum and open-pan evaporation processes, respectively. Color changes associated with heat treatment were monitored using Hunter colorimeter (L*, a* and b*). All Hunter color parameters decreased with time and dependently studied concentration techniques caused color degradation. It was observed that the severity of color loss was higher in open-pan technique than the others. Evaporation also affected total phenolics content in blueberry juice. Total phenolics loss during concentration was highest in open-pan technique (36.54 %) and lowest in microwave heating at 200 W (34.20 %). So, the use of microwave technique could be advantageous in food industry because of production of blueberry juice concentrate with a better quality and short time of operation. A first-order kinetics model was applied to modeling changes in soluble solids content. A zero-order kinetics model was used to modeling changes in color parameters and phenolics content.

Keywords Blueberry juice · Color · Evaporation rate · Microwave · Phenolics content

Introduction

Blueberries (*Vaccinium corymbosum*, Bluecrop variety) are considered to be one of the richest source of phenolic compounds. They have high biological activity and may provide health benefits (Xu et al. 2014; Liu et al. 2015). The phenolic substances with high antioxidant capacity play important roles in prevention of many degenerative diseases such as cancer, cardiovascular and Alzheimer by providing neutralization of unstable free radicals (Mohideen et al. 2015). Consumption of blueberries has increased recently due to raised health awareness (Ścibisz et al. 2012).

Concentration of fruit juice is one of the most common preservation methods because it provides a number of benefits such as reduced volume or weight, reduced packaging, easier handling, transportation and longer shelf life (Maskan 2006). Despite many advantages of concentration process, there are some adverse effects leading to quality and nutritional changes and degradation of phenolic compounds that have health benefits (Yousefi et al. 2012). Color of food products is an important quality characteristic that influences consumer acceptability. Anthocyanins are responsible for brilliant red color of blueberry juice. These compounds are not stable and highly sensitive to degradation during fruit juice processing (Barba et al. 2012). The prevention of anthocyanin degradation is of significant concern due to affecting color and nutritional value of fruit juices (Patras et al. 2010).

Concentrating fruit juice using conventional methods results in huge losses of quality parameters and requires long time. Therefore, innovative techniques for concentration process have been investigated (Cassano et al. 2004). Microwave application for juice concentration could be an alternative to traditional methods. Fruit juice concentration using microwave irradiation has a lot of benefits when compared to conventional means such as shorter process time and better

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organoleptic properties. However, there is lack of studies concerning use of microwave in fruit juice concentration process.

Therefore, the objectives of the present work were 1) to investigate the rate of evaporation of water during concentration processes, 2) to compare color degradation and phenolics content of blueberry juice during concentration processes such as open-pan technique, rotary vacuum evaporator and microwave heating at two different irradiation power levels (200 and 250 W).

Materials and methods

Preparation of fresh blueberry juice

Fresh blueberry fruits (*Vaccinium corymbosum*, Bluecrop variety) were purchased from a farm in Trabzon in Turkey and stored in refrigerator at 4 ± 1 °C until processing. Fresh berries were crushed using the Waring blender (HGB150, USA). Pectinase (0.045 g/l) was then added, as it is most active at 27 °C. Depectinization was complete as indicated by a negative alcohol precipitation test after 2 h. After depectinization, rice hulls (1 %) were added to aid in juice pressing. Then the depectinized crushed berries pressed by a lab scale press and juice obtained was filtered. The clear juice was immediately used for concentration experiments.

Juice concentration

Clarified juice was concentrated by three different concentration techniques from an initial concentration of 10 to a final concentration of 65°Brix by the following processes.

- i. Evaporation at atmospheric pressure (open-pan): A heater (VELP Scientifica, Milan, Italy) was used to concentrate blueberry juice. A 75 ml of juice sample was put in beaker and a magnetic stirrer was added in it. The beaker was replaced on the heater. The sample was continuously heated and stirred during concentration process without any interruption in the process. It was concentrated until juice was reached to 65 °Brix. Measurements of color and phenolics content were carried out on juice concentrates obtained.
- ii. Rotary vacuum evaporator: A rotary vacuum evaporator (Model VV 2000, Heidolph, Germany) was used to concentrate the juice sample, rotating at 74 rpm and 45 °C. The same sampling method as for open-pan was implemented for measurements of color and phenolics content.
- iii. Microwave heating: the blueberry juices were concentrated in an open system microwave (CEM Corporation, USA, 3100 Smith Farm Road, Matthews, NC 28105–5044). It was studied at 200 and 250 W irradiation powers. Powers above 250 W was caused some

troubles such as foaming, charring of juice. The same sampling method as for open-pan was implemented for measurements of color and phenolics content.

Color measurement

Color measurement was made using a Hunter Lab colorimeter (Model A-60-1010-615 Colorimeter, HunterLab, Reston, VA). The L^* , a^* and b^* color space (also referred to as CIELAB) was used to express the color changes. The L^* shows whiteness or brightness/darkness, a^* (redness/greenness) and b^* (yellowness/blueness). The total color difference (TCD) was also calculated from the CIE L^* , a^* , b^* values from the following equation:

$$TCD = \sqrt{(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2} \quad (1)$$

where L_o^* , a_o^* , b_o^* were initial values of juice; L^* , a^* , b^* were concentrated sample's values.

All measurements were done in triplicate.

Determination of soluble solids content

The soluble solids content of the juice samples was measured at 20 °C using a digital refractometer (Model NR-151, Conecta SA, Barcelona, Spain) and expressed in °Brix. All measurements were done in triplicate.

Determination of moisture content

Moisture content of blueberries was analyzed by drying 8 h in a forced air oven at 105 °C. Values expressed for total phenolic contents are on a dry weight (DW) basis. All measurements were done in triplicate.

Determination of total phenolics content

Total phenolics content of blueberry juice was determined by using Folin Ciocalteu assay with modifications (Singleton and Rossi 1965). The concentration of phenolics was expressed as mg GAE (gallic acid equivalent) in 100 g dry sample. All measurements were done in triplicate.

Kinetics model

Various studies on kinetics have been found in the literature. Zero (Eq.(2)) or first order (Eq.(3)) reactions kinetics have been reported for the degradation.

$$C = C_0 \pm k_0 t \quad (2)$$

$$C = C_0 \exp(\pm k_1 t) \quad (3)$$

where (+) and (−) indicate formation and degradation of any quality parameter, respectively. Kinetics models were applied for changes in soluble solids content, color parameters and phenolics content during evaporation.

Statistical analysis

Effect of concentration method on evaporation time, color parameters and phenolics content of juices was analyzed by one-way analysis of variance (Version 22, 2013, Polr Engineering and Consulting, Nikiski, USA). Significant differences ($p < 0.01$) between means were determined by Duncan's method.

Results and Discussion

Change in concentration

Figure 1 shows the soluble solids concentration (°Brix) of blueberry juice against time of concentration process for three concentration techniques. The time required to obtain the final concentration (from 10 to 65 °Brix) was 12, 15, 45 and 77 min for microwave at 250 and 200 W, rotary vacuum and open-pan processes, respectively. It is obvious that duration of concentration can be reduced depending on evaporation techniques. The statistical analysis showed a significant ($p < 0.01$) difference between durations of evaporation of three different concentration techniques. Durations of concentrations done by microwave techniques were quite shorter than rotary vacuum and open-pan evaporation processes. In microwave technique, the heat is generated within the food

material by reorientation of the dipoles which in turn cause water molecular friction and generate heat (Drouzas et al. 1999). That explains how the concentration process done by microwave heating provided faster heating than other two conventional techniques thereby reduced the time. Similar studies have been reported that microwave energy decreases required times for concentration (Maskan 2006; Assawarachan and Noomhorm 2012; Yousefi et al. 2012). It was also seen that higher microwave irradiation power could reduce required time.

Change in blueberry juice concentration during concentration followed first order reaction kinetics according to non-linear regression analysis (Fig. 1). The fitted parameters of Eq. (3) and corresponding correlation coefficient (R^2) values for the change in the concentration of blueberry juice during concentration process were reported in Table 1. The R^2 values were greater than 0.92 (indicating good fit) in all cases. The evaporation rate constant (k) for microwave heating process at 250 W was 6.2, 3.6, 1.27 times greater than those for open-pan, rotary vacuum concentration and microwave heating at 200 W, respectively. A high evaporation rate constant indicates achieving to final concentration in a shorter time. This is because of the rapid heating effect of microwave and, hence, evaporating water rapidly. The evaporation rate constant (k) for microwave heating process are significantly ($p < 0.01$) greater compared to those obtained for conventional heating. However, evaporation rate constants (k) in microwave irradiation power applied (200 and 250 W) are not significantly ($p > 0.01$) different. Moreover, evaporation rate at atmospheric pressure and rotary vacuum evaporator is not significantly ($p > 0.01$) different to each other.

Fig. 1 Change in blueberry juice concentration (°Brix) produced by various concentration processes (Error bars show $\pm$ SE)

Table 1 Kinetics parameters of first order equation for changes in the concentration (°Brix) of blueberry juice during different concentration processes ($\pm$ shows SE)

Concentration Method	$k_1(\text{min}^{-1})$	C_0	R^2
Open Air	0.025 ± 0.0037^a	10 ± 2.458	0.946
Rotary Vacuum	0.043 ± 0.0071^a	10 ± 2.766	0.925
MW200	0.122 ± 0.0225^b	10 ± 2.910	0.965
MW250	0.155 ± 0.0167^b	10 ± 1.723	0.987

^{ab} Values followed by the same letter within a column are not significantly different ($p > 0.01$)

Change in color parameters

Figures 2, 3, 4 and 5 show changes in L^* , a^* and b^* color parameters and the total color difference (TCD) of juice during evaporation, respectively. The L^* , a^* , b^* values related to the color of blueberry juice were affected regardless of the evaporation method. It has been reported that sugar and sugar degradation products accelerate anthocyanin (blueberry pigment) degradation and progress non-enzymatic browning during concentration process (Maskan 2006; Stojanovic and Silva 2007). Therefore, as soluble solids content of blueberry juice increased, the extent of color degradation also increased. Moreover, it is known that high temperature treatment causes severe color degradation (Patras et al. 2009).

Considerable decrease in L^* values was observed in all samples concentrated up to 65 °Brix with different methods. Decrease in L^* value demonstrates darker color of the blueberry juice concentrate. The decrease in L^* may be attributed to destruction of anthocyanins and occurrence of Maillard reactions during juice concentration and heating, resulting in a color change from a natural red to a more dull brownish color (Skrede 1985). Decrease in L^* value was 64.2, 70.4, 68.9 and 76.8 % for microwave at 200 and 250 W, rotary

Fig. 2 Kinetics of change of the L^* -value color parameter as a function of time during concentration process (Error bars show $\pm$ SE) **Fig. 3** Kinetics of change of the a^* -value color parameter as a function of time during concentration process (Error bars show $\pm$ SE)

vacuum and open-pan concentration processes, respectively. Decrease in L^* value was significantly ($p < 0.01$) lower for microwave heating at 200 W than microwave at 250 W, rotary vacuum and open-pan concentration processes. It was seen that L^* value of juice concentrate was affected by microwave power applied. High microwave power (at 250 W) led to decrease in L^* value more.

Concentration process caused decrease of Hunter a^* value (redness) of blueberry juice as compared to fresh juice sample. Red color of blueberry juice is mainly due to the presence of anthocyanins (Skrede et al. 2000). Decrease in Hunter a^* value was 15.02, 22.99, 19.58 and 25.27 % for microwave at 200 and 250 W, rotary vacuum and open-pan concentration processes, respectively. These results show that more degradation has been observed with the open-pan concentration process. This decrease in a^* values can be attributed to the thermal degradation of color compounds (anthocyanins) for a long time during evaporation (Fischer et al. 2011).

Fig. 4 Kinetics of change of the b^* -value color parameter as a function of time during concentration process (Error bars show $\pm$ SE)

Fig. 5 Change in total color difference of blueberries during concentration process (Error bars show $\pm$ SE)

Decrease in b^* value was 13.23, 30.35, 16.34 and 34.24 % for microwave at 200 and 250 W, rotary vacuum and open-pan concentration processes, respectively. This reduction demonstrates that the samples become more bluish in color (Mohideen et al. 2015). It was reported that with heat treatment, reddish anthocyanins are converted to colorless carbinol base, such that the bluish-brown co-pigments dominate the color of the blueberries (Ramaswamy and Nsonzi 1998; Stojanovic and Silva 2007). This reasoning may also explain the significantly ($p < 0.01$) lower b^* values of the concentrated samples.

The total color difference is a combination of the changes of the three components L^* , a^* , and b^* . Development in blueberry juice samples was calculated for all concentration

processes during evaporation. TCD values increased with time during all concentration processes as shown in Fig. 5. TCD values of concentrated blueberry juice at 65 °Brix were 20.41, 22.97, 22.12 and 25.17 for microwave at 200 and 250 W, rotary vacuum and open-pan concentration processes, respectively. The lowest L^* , a^* and b^* values were observed in samples that were concentrated by open-pan method when compared to other treatments (Figs. 2 and 3). TCD, therefore, was greatest in the samples treated with open-pan method and smallest in microwave heating at 200 W. It indicates that open-pan method resulted in a higher color change while microwave heating at 200 W resulted in a lower color change compared to all other concentration processes. Thus, it can be concluded from these results that microwave heating might preserve the color properties of concentrated juice more than other concentration methods. Using microwave in concentration process has the advantage of heating the juice rapidly and uniformly, so provides the final product with a better color than other evaporation processes. In an earlier study, it has been reported that pineapple concentration conducted by using microwave vacuum evaporation preserved color quality more than conventional heating (Assawarachan and Noomhorm 2012). Yousefi et al. (2012) reported similar results regarding the preservative effect of microwave heating on the color properties of foods concentrated.

The most severe color loss was observed in open-pan method for all parameters (L^* , a^* and b^*) compared to other techniques. Results are reasonable as evaporation process at atmospheric pressure was conducted at high temperature (89 °C) and in long time (77 min.). Microwave heating at 200 W preserved the best color quality of concentrate. Even If

Table 2 Nonlinear regression analysis results of color parameters from zero order reaction kinetics ($\pm$ shows SE)

Concentration Method	Parameter	k_0 (min^{-1})	C_0	R^2
Open Air	L^*	-0.3127 ± 0.0552	31 ± 2.536	0.912
	a^*	-0.0751 ± 0.0108	26 ± 0.496	0.943
	b^*	-0.0602 ± 0.0028	13 ± 0.129	0.990
	TCD	0.3301 ± 0.0296^a	0.0 ± 3.338	0.926
Rotary Vacuum	L^*	-0.4848 ± 0.0654	31 ± 1.676	0.942
	a^*	-0.1029 ± 0.0098	26 ± 0.252	0.972
	b^*	-0.0529 ± 0.0042	13 ± 0.107	0.968
	TCD	0.5419 ± 0.0552^a	-1.2 ± 1.414	0.961
MW200	L^*	-1.3069 ± 0.3341	31 ± 3.541	0.793
	a^*	-0.2385 ± 0.0329	26 ± 0.299	0.945
	b^*	-0.1225 ± 0.0121	13 ± 0.110	0.956
	TCD	1.3392 ± 0.2987^b	-3.3 ± 2.713	0.834
MW250	L^*	-1.7150 ± 0.4366	31 ± 3.382	0.843
	a^*	-0.4061 ± 0.1209	26 ± 0.937	0.823
	b^*	-0.2986 ± 0.0451	13 ± 0.349	0.929
	TCD	1.7987 ± 0.2235^b	0.0 ± 4.241	0.853

^{ab} Values followed by the same letter within a column are not significantly different ($p > 0.01$)

Fig. 6 Change in total phenolics contents of blueberries during concentration process to the final Brix value of 65 (Error bars show $\pm$ SE)

microwave application at 250 W compared to 200 W reduced the time considerably, it can lead to adverse effect on quality parameters because of rapid increase in temperature. Therefore, to preserve quality parameters it is crucial to choose the appropriate microwave power.

Linear regression analysis shows that the variation of color parameters of blueberry juice during evaporation process fitted zero order reaction kinetics. The linear parameters for the variation of color parameters in blueberry juice during concentration are reported in Table 2.

The kinetic rate constants for the color change were observed to have different values for different concentration techniques studied (Table 2). Degradation rate constant (k_0) of microwave heating process at 250 W for L^* value was 5.48, 3.53, 1.31 times greater than those of open-pan, rotary vacuum concentration processes and microwave heating process at 200 W, respectively. The similar results were found for a^* and b^* color parameters. As it could be seen, the application of microwave increased the rate of color deterioration, although the time required to reach the final blueberry juice concentration of 65 °Brix by microwave heating was shorter than those of the other evaporation methods. The degradation rate of color quality in terms of total color difference in a microwave is significantly ($p < 0.01$) faster than those of the conventional heating methods.

Change in total phenolics content

The phenolics content of blueberry juice during evaporation process were plotted as a function of time (Fig. 6). Initial phenolics content of blueberry juice was 837.89 mg GAE/100 g dry sample before concentration process. The losses of total phenolics content in blueberry by the end of

concentration process are 36.54, 34.20, 35.37, 35.44 % for open-pan, rotary vacuum concentration processes as well as microwave heating concentration processes at 200 and 250 W, respectively. Total phenolics content of blueberry is affected by increase in solid content, temperature, process time (Kirca and Cemeroglu 2003). Integral of high temperature and long time leads to a significant degradation of phenolics content (Schmidt et al. 2005; Arancibia-Avila et al. 2012). The lowest phenolics content was observed in samples that were concentrated by open-pan method because of combination of high temperature and long time. It is obvious that higher phenolics content was achieved by using microwave method. However, the results show that there is no significant change ($p > 0.01$) between the concentration techniques with respect to destruction of phenolics of blueberry concentrates.

Linear regression analysis demonstrates that the thermal degradation of blueberry phenolics fitted zero order reaction kinetics. The linear parameters for the thermal degradation of total phenolics content in blueberry juice during concentration are reported in Table 3. Rate constant (k_0) of the total phenolics content for microwave heating process at 250 W was 6.28, 3.74, 1.35 times greater than those of open-pan technique,

Table 3 Nonlinear regression analysis results of total phenolics content from zero order reaction kinetics ($\pm$ shows SE)

Concentration Method	$k_0(\text{min}^{-1})$	C_0	R^2
Open Air	-3.8015 ± 0.226^a	815 ± 10.42	0.987
Rotary Vacuum	-6.3812 ± 0.466^a	815 ± 11.96	0.980
MW200	-17.642 ± 1.671^b	815 ± 15.18	0.971
MW250	-23.901 ± 1.872^b	815 ± 14.52	0.978

^{ab} Values followed by the same letter within a column are not significantly different ($p > 0.01$)

rotary vacuum concentration processes and microwave heating process at 200 W, respectively. It means that the phenolics content losses took place significantly ($p < 0.01$) faster because of the high temperature applied in microwave process.

Conclusion

In this present work, the effect of open-pan technique, rotary vacuum evaporator and microwave heating on concentration rate, color degradation and phenolics content of blueberry juice was investigated. Results showed that the required time for juice concentration was affected by heating method. It was observed that longer time was required for conventional concentration methods such as open-pan and rotary vacuum evaporator. Investigation of color changes of the samples showed that L^* , a^* and b^* values and total phenolics content were affected more severe in conventional concentration processes. This study has also shown various benefits of microwave heating in the concentration of blueberry juice. Microwave heating allowed rapid concentration of juice obtained from blueberry fruit. As a result of short concentration time, microwave heating has preserved phenolics content in blueberry juice more than the other methods. Results, however, showed that high irradiation power (250 W) affected concentration rate, color quality and phenolics content negatively. Therefore, it is crucial to select the appropriate microwave power. In conclusion, microwave heating at a moderate level could be an efficient method to concentrate fruit juices.

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