Zeszyty Problemowe Postępów Nauk Rolniczych
nr 600, 2020, 3–11
DOI 10.22630/ZPPNR.2020.600.1

ULTRAFILTRATION AS A METHOD TO OBTAIN SUGAR REDUCED CLOUDY JUICES – A RESEARCH ON JUICE'S PROPERTIES

Alicja Barańska✉, Anna Kot, Katarzyna Samborska
WULS-SGGW, Institute of Food Sciences

Summary. The effect of ultrafiltration (UF) on the properties of cloudy apple and apple-beetroot juice was investigated. The final product considered by the current study was UF retentate in contrast to the traditional juice production process. Ultrafiltration was applied in order to partially remove sugars, with simultaneous retention of fiber and other macromolecular components with health beneficial properties present in the cloudy fraction. After UF in apple cloudy juice, the total soluble solids and sugars content decreased from the initial values 11.0 and 10.4% to 9.2 and 8.8%, respectively, while in apple-beetroot cloudy juice from 11.4 and 8.2% to 8.7 and 5.8%, respectively. In addition, the cloudy fraction was retained and concentrated. The retention of soluble solids and sugars after UF of apple juice was 66 and 67% respectively, i.e. 34% of soluble solids and 33% of the sugars were removed to the permeate. In apple-beetroot juice 68 and 71% of soluble solids and sugars was retained, respectively.

Key words: cloudy juice, ultrafiltration, recovery, reference intake

INTRODUCTION

In the literature there are several examples of health beneficial properties of fruit juices, especially in cloudy form, as a result of their high content of vitamins, polyphenols, minerals and other valuable nutrients [Oszmianski et al. 2007, Markowski et al. 2015]. Generally speaking, fruit juices, regardless their form, have a similar energy density and sugar content to sugar sweetened beverages: 250 mL of apple juice typically contains 110 kcal and 26 g of sugar; 250 mL of cola typically contains 105 kcal and 26.5 g of sugar

Alicja Barańska https://orcid.org/0000-0003-2711-6073; Anna Kot https://orcid.org/0000-0003-3850-1743; Katarzyna Samborska https://orcid.org/0000-0002-1221-7261

✉ alicja_baranska@sggw.edu.pl

[Gill and Sattar 2014]. According to the Regulation (EU) 1169/2011 of the European Parliament and of the Council, the reference intake of energy and sugars are 2,000 kcal and 90 g per day, respectively. It is worth underlining that sugars intake of juices' consumption compared with reference intake, is considerably high – for apple juice reaches even 28.8%. However, the energy intake connected with the consumption of fruit juice portion is relatively low (for apple juice 5.25% of the reference intake). Furthermore, following the recommendations of the World Health Organization, a person with a healthy body weight, consuming approximately 2,000 kcal per day, should cover less than 10% of total energy intake from free sugars, which is equivalent to 50 g. Reduction of free sugars to less than 5% of total energy intake would provide in consequence additional health benefits (glass of juice would cover the total daily recommended portion of 25 g of free sugars) [WHO 2015]. The World Health Organization highlights that the limitation of products such as sugary snacks, candies and sugar-sweetened beverages (i.e. all types of beverages containing free sugars – these include carbonated or non-carbonated soft drinks, fruit or vegetable juices and drinks, liquid and powder concentrates, flavored water, energy and sports drinks, ready-to-drink tea, ready-to-drink coffee and flavored milk drinks) may reduce total sugars intake [WHO 2014, 2018].

Recent evidence shows that in the last decade consumer's requirements regarding food production have been changed considerably, switching to alternatives food with health beneficial properties [Bigliardi and Galati 2013], while it has become apparent, that fruit juices with their high sugars content, are less popular. Gill and Sattar [2014] affirmed that the accepted guidelines recommending the consumption of 5 portions of fruit and vegetables per day should not include fruit juices. Indeed, in the currently published recommendations this list contains only "fruits and vegetables", excluding potatoes, sweet potatoes, cassava and other starchy roots, not mentioning juices [WHO 2015]. It has now been demonstrated that although consuming a significant amount of whole fruit lowers the risk of diabetes, drinking considerable amount of fruit juices may increase a risk of type 2 diabetes [Muraki et al. 2013]. Thus, it seems necessary to reduce sugar content of fruit juices in order to positively change consumers perception on juices.

The application of membrane techniques is well known as a method of fractionation of liquid foods [Bhattacharjee et al. 2017]. Depending on the type of the process, it is possible to separate: macromolecules, colloids and microorganisms from the rest of soluble compounds (microfiltration – MF); insoluble solids, macromolecules and proteins from sugars and salts (ultrafiltration – UF); sugars from salts (nanofiltration – NF). Moreover, membrane techniques operate at low temperatures, and offer other important advantages, which make them increasingly popular in food processing: less manpower requirement, greater efficiency and shorter processing time than conventional filtration [Bhattacharjee et al. 2017]. In fruit juice industry, UF is usually a clarification step that enables to reduce production and labor costs and improve the product quality without any chemical additives [Urošević et al. 2017]. As mentioned above, nowadays cloudy juices are attracting widespread interest due to their health beneficial properties. Generally speaking, in the production of this type of juices there is no clarification step, which in consequence enables to retain some valuable ingredients in the final product. More recently a study proposed UF for the preparation of cloudy apple-cranberry juice of reduced sugar content

[Samborska et al. 2018]. During UF done in a batch mode, sugars were separated with the permeate (clarified juice), with the simultaneous rejection of colloids, high molecular weight compounds and fine particles in the retentate. As a consequence, the percentage of the reference intake of sugars connected with the consumption of 250 mL portion of obtained product was successfully reduced from 27.0 to 20.7%. At the same time, the cloudy fraction was concentrated.

This paper investigates the possibility of obtaining cloudy apple and apple-beetroot juices with reduced sugar content and concentrated cloudy fraction. The aim of this work was to further broaden the knowledge of the physicochemical properties of obtained products.

MATERIAL AND METHODS

Materials

Pasteurised apple cloudy juice (AJ) and apple-beetroot cloudy juice (ABJ) were derived from a local producer Sadvit (Poland).

Ultrafiltration

Ceramic membrane 15 kDa MWCO (Tami Industries, France) was used that worked in a cross-flow installation (OBR Pleszew, Poland), at transmembrane pressure of 0.35 MPa. The installation was presented in a previous study by Samborska et al. [2018]. As a result of UF feed juices were divided into permeate (P) and retentate (R), which were weighed, and further sampled for analysis. Retentate was considered as a final product of reduced sugar content and concentrated cloudy phase.

Total soluble solids

Total soluble solids content (TSS) was determined by digital refractometer PAL-3 (ATAGO, Japan).

Color

Color parameters L (lightness), a* (redness/greenness) and b* (yellowness/blueness) were measured by colorimeter CR-5 (Konica Minolta, Japan) in CIE L a*b* system. Total color difference (ΔE) of P and R compared to corresponding juices was calculated.

Density

Density (D) was measured by portable Densito 30 PX device (Mettler Toledo, Japan) with automatic temperature compensation.

Sugar content

Total sugars (TS), glucose (G) and fructose (F) content were determined by high performance liquid chromatography HPLC with refractive detection (Agilent Technologies 1200 series, USA). Non-sugar soluble solids content (NSS) was calculated as a difference between TSS and TS.

Titratable acidity

Titratable acidity (TA) was measured by the titration with 0.1 M NaOH solution, and calculated as mass of malic acid (MA) per 100 g.

Membrane selectivity

Membrane selectivity regarding certain compounds (TSS, G, F, TS, TA and NSS) was expressed as recovery factor – RF [%]: RF = mR / mJ, where mR and mJ are the mass of each compound in R and juice, respectively [Wei et al. 2007].

Statistical methods

The mean values of physicochemical properties of juice before and after UF treatment were compared through one-way analysis of variance (ANOVA) followed by Tukey's test with $\alpha = 0.05$ (Statistica 13 software from Dell Inc., USA).

RESULTS AND DISCUSSION

In this study the UF treatment was performed to retain valuable compounds coming from fruit pulp, with simultaneous partial removal of sugars with permeate stream (clear juice) in a cloudy juice (retentate). The presented approach is in fact opposite to the commonly applied UF treatment that focuses on the juice clarification, in which a clear juice is the final product. Ultrafiltration was carried out until the complete stop of permeate flux, which was the result of membrane fouling. The duration of the process for the apple juice was 120 min, while for apple-beetroot juice it was 80 min. In both processes, 4 L of retentate was obtained from 10 L of feed juice, so the volume reduction factor (VRF), defined as the ratio between the initial feed volume and the volume of resulting retentate was equal to 2.5 [Cassano et al. 2007]. This value was considerably lower than usually noted during UF that leads to juice clarification. Normally, the purpose of clarification is the recovery of possibly the highest amount of juice in the permeate, and the concentration of total dissolved solid in the retentate. He et al. [2007] investigated the clarification of apple cloudy juice by UF (the plate membrane sheets were made of polyethersuphone with MCWO 50 kDa), and high VRF over 20 was noted. On the contrary, Cassano et al. [2007] who ultrafiltrated kiwifruit juice by 15 kDa membranes obtained VRF of 3.75 after 350 min.

Characterization of feed juices, permeates and retentates

Apple cloudy juice (AJ), apple cloudy juice permeate (PAJ), apple cloudy juice retentate (RAJ), apple-beetroot cloudy juice (ABJ), apple-beetroot cloudy juice permeate (PABJ), and apple-beetroot cloudy juice retentate (RABJ) were analyzed. The results of these determinations were summarized in the table.

It was noted that after UF of AJ, the content of soluble solids (TSS) in R was significantly higher than in P, but lower than in the feed juice. For the ABJ, there was no significant difference between TSS content in P and R, however both values were significantly lower than in the juice not subjected to the UF process. The decrease of TSS content in R in comparison to the juice was a consequence of the dilution with water remaining in the installation after washing. Moreover as a result of the membrane's selective properties the lower TSS content was observed in P than in R.

Table. Total soluble solids (TSS), glucose (G), fructose (F), total sugars (TS), non-sugar soluble solids (NSS), density (D), total acidity (TA) of apple cloudy juice (AJ), apple cloudy juice permeate (PAJ), apple cloudy juice retentate (RAJ), apple-beetroot cloudy juice (ABJ), apple-beetroot cloudy juice permeate (PABJ), and apple-beetroot cloudy juice retentate (RABJ)

Tabela. Ekstrakt ogółem (TSS), glukoza (G), fruktoza (F), zawartość cukrów ogółem (TS), zawartość rozpuszczalnych substancji niecukrowych (NSS), gęstość (D), kwasowość ogólna (TA) mętnego soku jabłkowego (AJ), permeatu mętnego soku jabłkowego (PAJ), retentatu mętnego soku jabłkowego (RAJ), mętnego soku jabłkowo-buraczanego (ABJ), permeatu mętnego soku jabłkowo-buraczanego (PABJ), retentatu mętnego soku jabłkowo-buraczanego (RABJ)

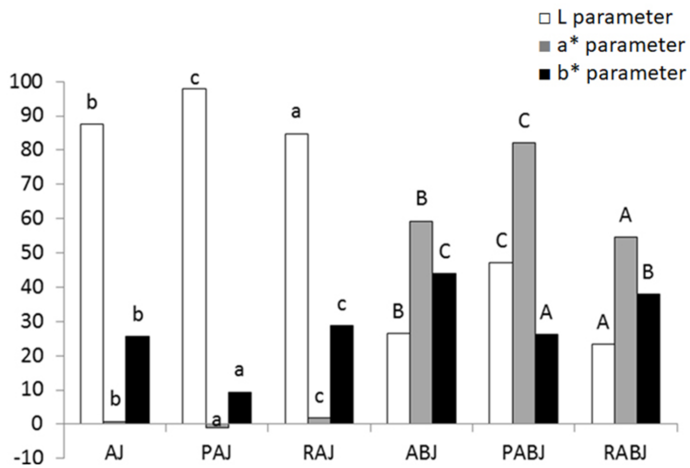
Specification Wyszczególnienie	AJ	PAJ	RAJ	ABJ	PABJ	RABJ
TSS [°Brix]	11.0 ±0.1 c	8.8 ±0.0 a	9.2 ±0.1 b (0.66)*	11.4 ±0.0 b	8.6 ±0.0 a	8.7 ±0.1 a (0.68)*
G [g·100 g^{-1}]	2.1 ±0.1 c	1.6 ±0.0 b	1.8 ±0.1 b (0.68)	1.6 ±0.0 b	0.6 ±0.0 a	0.6 ±0.0 a (0.84)*
F [g·100 g^{-1}]	6.5 ±0.2 d	5.2 ±0.1 c	5.4 ±0.1 c (0.66)*	4.3 ±0.1 b	3.4 ±0.1 a	3.6 ±0.1 a (0.66)*
TS [g·100 g^{-1}]	10.4 ±0.1 c	8.2 ±0.1 b	8.8 ±0.2 b (0.67)*	8.2 ±0.1 b	5.6 ±0.1 a	5.8 ±0.2 a (0.71)*
NSS [%]	0.6 ±0.0 b	0.6 ±0.0 b	0.4 ±0.0 a (0.58)*	3.2 ±0.0 d	3.0 ±0.0 c	2.9 ±0.0 c (0.69)
TA [g·100 g^{-1}]	0.41 ±0.0 c	0.25 ±0.0 a	0.37 ±0.0 b (0.74)*	0.40 ±0.0 b	0.31 ±0.0 a	0.33 ±0.0 a (0.67)*
ΔE	–	19.4	4.2	–	35.5	8.2
D [g·mL^{-1}]	1.041 ±0.000 c	1.034 ±0.000 a	1.035 ±0.000 b	1.044 ±0.000 c	1.034 ±0.000 a	1.036 ±0.000 b

*Recovery factor (RF) of certain compounds in retentates; a–c – the difference between mean values of certain parameters of feed juices and its UF products marked with different letter were statistically significant.

*Współczynnik odzysku (RF) wybranych składników w retentatach; a–c – różnice między statystycznie istotnymi uśrednionymi wartościami określonych parametrów soków i ich produktów ultrafiltracji oznaczone różnymi literami.

As stated in the introduction, the aim of this study was to obtain juices of reduced sugar content, which point to the importance of TSS comparison in juice before and after UF. It was evident that P was characterized by a significantly lower density compared to R as a consequence of the clarification process and the selective rejection of solid components.

Further analysis showed that the color parameters of the tested juices differed depending on the juice type. Furthermore, there was a noticeable and significant color change after UF, which resulted in changes in lightness in juice color in P and in R – P was lighter and P darker (the figure). In regards of ABJ, the value of a* parameter increased significantly in P which indicates that the P was redder in color than juice. Moreover, a significant decrease of b* parameter in P was noted for both juices compared to juice before UF, which points to the shift towards blueish range of color.



a–c – the differences between mean values of color parameters of apple cloudy juice and its UF products marked with different letter were statistically significant; A–C – the differences between mean values of apple-beetroot cloudy juice and its UF products marked with different letter were statistically significant.

a–c – różnice między statystycznie istotnymi uśrednionymi wartościami parametrów barwy mętnego soku jabłkowego i jego produktów ultrafiltracji oznaczone różnymi literami; A–C – różnice między statystycznie istotnymi uśrednionymi wartościami parametrów barwy mętnego soku jabłkowo-buraczanego i jego produktów ultrafiltracji oznaczone różnymi literami.

Fig. Color parameters L, a*, b* of apple cloudy juice (AJ), apple cloudy juice permeate (PAJ), apple cloudy juice retentate (RAJ), apple-beetroot cloudy juice (ABJ), apple-beetroot cloudy juice permeate (PABJ), apple-beetroot cloudy juice retentate (RABJ)

Rys. Parametry barwy L, a*, b* mętnego soku jabłkowego (AJ), permeatu mętnego soku jabłkowego (PAJ), retentatu mętnego soku jabłkowego (RAJ), mętnego soku jabłkowego-buraczanego (ABJ), permeatu mętnego soku jabłkowego-buraczanego (PABJ), retentatu mętnego soku jabłkowego-buraczanego (RABJ)

Total color differences (ΔE) implies the magnitude of the color difference between juices and UF products. For all of the R, ΔE was lower than for P, which was a consequence of the clarification process affecting the great difference in the color of permeates.

The cloudy fraction juices was a reason for the similarity to retentates. Cassano et al. [2007] who clarified the kiwifruit on 15 kDa membrane, confirmed the complete rejection of suspended solids in retentate after cloudy juice UF.

Selectivity of ultrafiltration

Abbreviation RF stands for recovery factor which was expressed as the amount of certain compounds rejected by the membrane, calculated as mass fraction of the initial amount. Recovery factor of certain compounds of AJ varied from 0.66 to 0.74, while in ABJ it ranged from 0.66 to 0.84.

According to Black and Bray [1995], as a result of higher pore size in membrane than the molecular mass of low molecular weight sugars, they are not rejected by UF. Membrane used in this study (MWCO 15 kDa) was not a barrier for low molecular weight sugars. However, membrane permeability for sugars enabled to reduce sugars content in R. Resulting from limited membrane area, the removal of sugars to P depended on membrane fouling which shortened the processing time. As a consequence, only a certain amount of sugars was transported from feed juices to R and residues were rejected by the membrane. Ultrafiltration process was performed until the complete stop of permeate flow as the consequence of membrane blockage – 33 and 29% of sugars (in AJ and ABJ juice respectively) were transported to P, however it was not possible to remove all sugars from R. The limited membrane area and limited possibility for sugars molecules transportation through the pores during the reduced process time were responsible for this result. Recovery factor of total sugars was the most important factor in regards of the production of juices of reduced sugar content – for RAJ it was 0.67 and for RABJ 0.71. These values indicate that 33 and 29% of sugars from AJ and ABJ respectively, were separated with permeate. Recovery factor of non-sugar soluble solids was lower than for sugars (0.58 and 0.69 for RAJ and RABJ respectively). This result was not anticipated, however it has to be emphasized that the retentates contained the cloudy fraction originating from feed juice, concentrated in a reduced volume of final juices/retentates (volume concentration factor was 2.5). In consequence, it increased concentration of cloudy fraction which added value to the obtained products, apart from reduced sugars content.

The recovery of TSS in AJ was 0.67, while in ABJ it was 0.71. These values indicate that 33 and 29% of sugars were transported to permeate in AJ and ABJ juice respectively. Given the results in previous work of Samborska et al. [2018] who noted RF the level of 0.76 of low-sugar apple-cranberry cloudy juice using the same UF membrane, RF depends on the juice type.

Sugars content in obtained juices

Ultrafiltration treatment enabled to lower the sugars contained in a 250 mL glass of AJ from 26.0 to 22.0 g, and in a glass of ABJ from 20.5 to 16.0 g. In regards of the reference intake (RI) of sugars (90 g per day) recommended by the Regulation (EU) 1169/2011 of the European Parliament and of the Council, the consumption of one glass of AJ before UF covered as much as 28.8% of RI, and after UF this value was reduced to 24.2%. This value was successfully lowered from 22.6 to 17.6% for ABJ. In the previous work of Samborska et al. [2018], authors used the same UF membrane for the production of apple-cranberry cloudy juice of reduced sugar content and they observed the reduction of RI from 27.0 to 20.7%.

CONCLUSIONS

Ultrafiltration was applied as an alternative treatment for cloudy juices (apple and apple-beetroot) to the traditional juices processing. Generally, UF is used as the clarification step to remove cloudy fraction during clear juice production. In this research, UF was applied to obtain concentrated cloudy fraction with the simultaneous removal of some amounts of sugars. The obtained results provided further evidence that it was possible to produce new type of juices with reduced sugar content. Taken together, these findings implicate the possibility of considering these juices as value-added products due to potential health benefits of the consumption of cloudy juices in comparison to clear juices.

Acknowledgements

The authors thank Paulina Kamińska for participation in the performance of experiments.

REFERENCES

Bhattacharjee C., Saxena V.K., Dutta S., 2017. Fruit juice processing using membrane technology: A review. Innov. Food Sci. Emerg. Technol. 43, 136–153.

Bigliardi B., Galati F., 2013. Innovation trends in the food industry: The case of functional foods. Trends Food Sci. Technol. 31(2), 118–129.

Black H.F. Jr, Bray R.G., 1995. Sugar separation from juices and product thereof (US5403604A).

Cassano A., Donato L., Drioli E., 2007. Ultrafiltration of kiwifruit juice: Operating parameters, juice quality and membrane fouling. J. Food Eng. 79(2), 613–621.

Gill J.M.R., Sattar N., 2014. Fruit juice: Just another sugary drink? Lancet Diabetes Endocrinol. 2(6), 444–446.

He Y., Ji Z., Li S., 2007. Effective clarification of apple juice using membrane filtration without enzyme and pasteurization pretreatment. Sep. Purif. Technol. 57(2), 366–373.

Markowski J., Baron A., Le Quéré J.M., Płocharski W., 2015. Composition of clear and cloudy juices from French and Polish apples in relation to processing technology. LWT-Food Sci. Technol. 62(1), 813–820.

Muraki I., Imamura F., Manson J.E., Hu F.B., Willett W.C., Dam R.M. van, Sun Q., 2013. Fruit consumption and risk of type 2 diabetes: results from three prospective longitudinal cohort studies. Bmj 347, f5001. https://doi.org/10.1136/bmj.f5001

Oszmianski J., Wolniak M., Wojdylo A., Wawer I., 2007. Comparative study of polyphenolic content and antiradical activity of cloudy and clear apple juices. J. Sci. Food Agric. 87(4), 573–579.

Regulation (EU) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the provision of food information to consumers, amending Regulations (EC) No 1924/2006 and (EC) No 1925/2006 of the European Parliament and of the Council, and repealing Commission Directive 87/250/EEC, Council Directive 90/496/EEC, Commission Directive 1999/10/EC, Directive 2000/13/EC of the European Parliament and of the Council, Commission Directives 2002/67/EC and 2008/5/EC and Commission Regulation (EC) No 608/2004. OJ L 304 of 22.11.2011.

Samborska K., Kamińska P., Jedlińska A., Matwijczuk A., Kamińska-Dwórznicka A., 2018. Membrane processing in the sustainable production of low-sugar apple-cranberry cloudy juice. Appl. Sci. 8(7), 1082. https://doi.org/10.3390/app8071082

Urošević T., Povrenović D., Vukosavljević P., Urošević I., Stevanović S., 2017. Recent developments in microfiltration and ultrafiltration of fruit juices. Food Bioprod. Proc. 106, 147––161.

Wei D.S., Hossain M., Saleh Z.S., 2007. Separation of Polyphenolics and Sugar by Ultrafiltration: Effects of Operating Conditions on Fouling and Diafiltration. World Acad. Sci. Eng. Technol. 1(10), 115–122.

World Health Organization – WHO, 2014. Guideline: Sugars intake for adults and children. Geneva.

World Health Organization – WHO, 2015. Healthy diet. Fact sheet 394.

World Health Organization – WHO, 2018. Healthy diet. Geneva.

ULTRAFILTRACJA JAKO METODA OTRZYMYWANIA SOKÓW O ZMNIEJSZONEJ ZAWARTOŚCI CUKRU – BADANIE WŁAŚCIWOŚCI SOKÓW

Streszczenie. Zbadano wpływ ultrafiltracji (UF) na właściwości mętnego soku jabłkowego i jabłkowo-buraczanego. W przeciwieństwie do tradycyjnego procesu produkcji soków produktem końcowym był retentat UF. Wpływ ultrafiltracji zastosowano w celu częściowego usunięcia cukrów przy jednoczesnym zatrzymaniu błonnika i innych makroskładników o właściwościach prozdrowotnych występujących w mętnej frakcji. Po procesie UF w mętnym soku jabłkowym całkowita zawartość ekstraktu i cukrów zmniejszyła się z wartości początkowych odpowiednio 11,0 i 10,4% do 9,2 i 8,8%, a w mętnym soku jabłkowo-buraczanym odpowiednio z 11,4 i 8,2% do 8,7 i 5,8%. Ponadto odzyskano i zatężono mętną frakcję. Retencja substancji rozpuszczalnych i cukrów po UF soku jabłkowego wynosiła odpowiednio 66 i 67%, tj. 34% substancji rozpuszczalnych i 33% cukrów zostało usuniętych do permeatu. W soku jabłkowo-buraczanym zachowano odpowiednio 68 i 71% substancji rozpuszczalnych i cukrów.

Słowa kluczowe: sok mętny, ultrafiltracja, odzysk, spożycie referencyjne