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Chemical composition and properties of spray-dried sugar beet concentrate obtained after ultrafiltration of diffusion juice

Piotr Regiec*, Agnieszka Kita, Hanna Boruczkowska, Wioletta Drożdż

Wroclaw University of Environmental and Life Sciences, The Faculty of Food Science and Technology
Corresponding author: e-mail: piotr.regiec@wnoz.up.wroc.pl

Ultrafiltration of diffusion juice is a method that can reduce environmental pollution during the production of sugar. A by-product (concentrate) of ultrafiltration contains a large amount of sucrose, but due to its properties, it is difficult to manage. The aim of this study was to determine the effects of the temperature used during drying of diffusion juice concentrates on the content of certain components and characteristics of resultant preparations. Diffusion juice obtained from one of the Polish sugar plants was subjected to ultrafiltration and the obtained concentrates were dried in a spray dryer. In the dried samples, the following parameters were analyzed: dry mass, sucrose, total ash, protein, crude fiber and color. It has been declared that the degree of concentration and drying temperature influenced the chemical composition and the properties of the dehydrated diffusion juice concentrates. An increase in drying temperature was accompanied by the increased content of dry mass, protein, ash and fiber content in the preparations. The greater the degree of juice concentration, the greater was the content of dry mass, ash, and fiber. Inversely, the greater the degree of juice concentration, the lower the content of sucrose. The brightest color of the dehydrated product was observed at the drying temperature of 200°C. Spray-drying may be used for waste management after the diffusion juice membrane filtration, and the resultant preparations might be used in the production of feedstuff or food industry in general e.g. as sucrose source, in fermentation processes or in microorganisms propagation.

Keywords: ceramic membrane, ultrafiltration, diffusion juice, concentrate, spray drying.

INTRODUCTION

The sugar industry is one of the most energy-intensive food industries. Thickening of the purified juice requires vast amounts of energy, and purification of the diffusion juice, i.e. defecation and carbonation, are also burdensome to the environment.

During limestone burning, the resultant flue dust is partly removed during the purification of kiln gas, while the excess CO_2 and other gases pass to the atmosphere during flue gas carbonation. Membrane filtration is an alternative to this technology.

In 1971, Madsen[1] first described the results of diffusion juice ultrafiltration using cellulose nitrate membranes. Ultrafiltration of diffusion juice with a purity of 88.9% resulted in achieving a purity of 91.5%, and after the standard purification process (defecation and carbonation) – 92%. Schrevel[2] found that in order to achieve a sufficiently high purity of juice after filtration, a membrane with a cutoff from 10 kDa to 0.1 mm was needed. Similarly, Bubnik[3] and Hinkova et al.[4] obtained good results using a ceramic membrane with a pore size of 20 nm. Sarka et al.[5] studied juice ultrafiltration using various membranes, including a ceramic membrane with a 20 nm cutoff, with good results too.

As it is clear from these studies, juice purification using membrane techniques can have an effect comparable to that of traditional methods, concerning thin juice purity and purification effect. An extensive review of literature, related to the use of membrane technology in the sugar industry, is presented in Lipnitzki et al.[6].

The use of membrane techniques for the purification of diffusion juice does however involve the problem of developing the by-product, i.e. concentrate remaining after filtration, which contains all the high molecular weight substances separated by the membrane, in addition to small amounts of sucrose. Due to fouling of membranes and other issues, the most commonly achievable volume concentration factor (VCF) is a maximum of 5[7] or even 6[8]. Unfortunately, the greater the VCF, the faster the membrane fouling which reduces the efficiency of the process. In a sugar plant converting 10. 000 tons of sugar beet per day, about 2.000 m^3 of concentrate may be produced. As this has a valuable chemical composition, it should not be treated solely as waste, but may have some potential use, especially after drying.

EXPERIMENTAL

The aim of this study was to determine the effects of the temperature used during drying of diffusion juice concentrates on the content of certain components and characteristics of resultant preparations. The research was performed on diffusion juice obtained from one of the Polish sugar plants. The ultrafiltration was performed using a test rig with a Fairey ceramic tubular membrane: pore diameter – 0.2 μm, type – asymmetrical, filtration area – 0.24 m^2 ; pH range 1–14. Process was performed using an ultrafiltration unit (produced by Euro-Sep, Warsaw, Poland) which is shown on Figure 1.

Ultrafiltration parameters: T = 35°C; p = 0.13 MPa; closed circuit (filtrate turn back to feed tank). Concen-

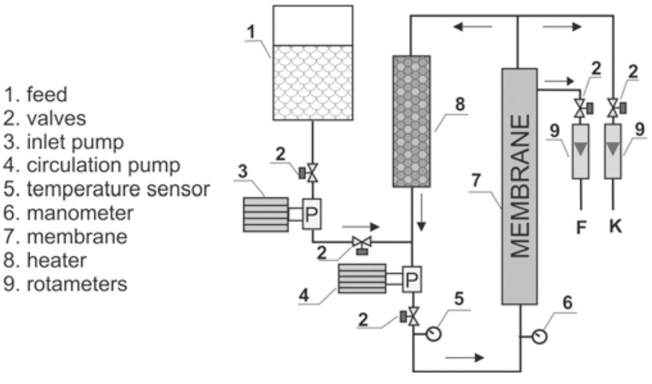

Figure 1. The scheme of ultrafiltration unit

trate samples were collected after separating 1/3, 1/2 and 2/3 of the filtrate volume. Drying was carried out in a spray drier (Lab. 1). Technical data: temperature range: 300/90°C inlet/outlet; max water evaporate: 7.5 kg/h. Drying temperatures were: 150°C, 200°C, 250°C, and 300°C. In the dried samples of concentrates, the following parameters were analyzed: dry mass (thermo-gravimetric method)[9], sucrose (polarimetric method)[9], total ash (gravimetric method)[9], protein (Kjeldahl method)[9], crude fiber (Henneberg and Stohman method)[10] (all in mass percentage) and color, examined using a Chroma Meter CR-200b Minolta camera (L*, a*, b*)[11]. The results were statistically analyzed in STATISTICA 7.0. One-way multivariate analysis of variance at a confidence level $\alpha = 0.95$ were performed. Homogeneous groups were determined using Duncan's multiple comparison test.

RESULTS AND DISCUSSION

The study used diffusion juice obtained from a sugar plant, and immediately after collection, juice ultrafiltration was performed. The chemical composition of the diffusion juice is shown in Table 1.

Table 1. The chemical composition of the diffusion juice

Dry matter [%]	Sucrose [%]	Protein [%]	Fiber [%]	Ash [%]
16.47	15.12	0.72	0.09	0.38

As is apparent from the data, the juice had moderate levels (in Polish conditions) of dry matter and sucrose, as well as protein and ash. Fiber content is not usually determined in sugar analytics, as only pectins may cause problems in the later stages of the production process. The collected concentrate samples were spray-dried at 150°C, 200°C, 250°C and *300°C. The temperature 300°C proved to be impossible to use in the experiment, as the dryer jets became instantly clogged. Most likely, this was due to a number of chemical reactions induced by excessive temperature.

An increase in drying temperature caused an increase in dry matter content in the preparations. Similarly, the more filtrate that was isolated, the greater the dry weight level recorded in the dried preparations. The highest content of dry matter was found in preparations obtained after drying at 250°C, obtained from concentrate at 2/3 volume.

The resulting preparations were characterized by a very high content of sucrose: 78.98%–83.04%. This is due to the pore size in the membrane (0.2 μm), which halted the pulp and macromolecular chemicals that are harmful in the later stages of the production process. However, sucrose (Table 3) and substances with smaller particles were present in both the filtrate and concentrate. Separation of substances with a molecular weight lower than sucrose is possible by nanofiltration, which can be used for the thickening of the purified juice[6]. Such a high sucrose content in the dehydrated by-products creates opportunities for their use as a high-energy feed additive for fermentation and other industries.

Protein content (Table 4) in the formulations was greater the higher the drying temperature. However, there was no difference in protein content between preparations obtained after separation of the 1/2 and 2/3 of filtrate. The natural tendency is a higher protein content (high molecular weight substances) where the concentrate thickening was seen only in preparations dried at a temperature of 150°C. Higher drying temperatures may have caused chemical reactions between different substances (such as sugars) and the partial breakdown of proteins, resulting in irregular changes in protein content.

Data presented in Table 5 indicate that the ash content in the preparations increased with the degree of concentration and temperature increase. Cations present in

Table 2. The dry matter content in the preparations obtain by spray-dried concentrates after ultrafiltration of the diffusion juice

Preparation	Temperature of drying [°C]			Mean	NIR
	150	200	250		
Concentrate (1/3)	93.14	95.02	96.72	94.96	0.47
Concentrate (1/2)	93.73	96.34	96.88	95.65	
Concentrate (2/3)	94.46	96.72	97.54	96.24	
Mean	93.78	96.03	97.05		
NIR	0.41				

Table 3. The sucrose content in the preparations obtain by spray-dried concentrates after ultrafiltration of the diffusion juice

Preparation	Temperature of drying [°C]			Mean	NIR
	150	200	250		
Concentrate (1/3)	82.73	84.10	82.57	83.13	0.08
Concentrate (1/2)	80.72	84.16	84.24	83.04	
Concentrate (2/3)	78.98	83.05	83.04	81.69	
Mean	80.81	83.77	83.28		
NIR	0.07				

Table 4. The protein content in the preparations obtain by spray-dried concentrates after ultrafiltration of the diffusion juice

Preparation	Temperature of drying [°C]			Mean	NIR
	150	200	250		
Concentrate (1/3)	4.11	4.73	5.08	4.64	0.04
Concentrate (1/2)	4.22	4.74	5.12	4.69	
Concentrate (2/3)	4.30	4.69	5.08	4.69	
Mean	4.21	4.72	5.09		
NIR	0.03				

Table 5. The ash content in the preparations obtain by spray-dried concentrates after ultrafiltration of the diffusion juice

Preparation	Temperature of drying [°C]			Mean	NIR
	150	200	250		
Concentrate (1/3)	2.17	2.25	2.45	2.29	0.07
Concentrate (1/2)	2.31	2.44	2.51	2.42	
Concentrate (2/3)	2.49	2.53	2.79	2.60	
Mean	2.32	2.41	2.58		
NIR	0.06				

the diffusion juice ash are mainly potassium, and then in smaller quantities – sodium, magnesium and calcium[12]. These ingredients do not undergo chemical reactions at the drying temperatures used. The increased ash content is mainly due to an increase in dry matter content in the preparations, due to an increase in drying temperature. The high content of potassium in the dehydrated preparation is also important from the point of use of things such as animal feed.

The fiber content (Table 6) in the preparations was particularly influenced by the degree of concentration. The fiber primarily consists of cellulose, hemicellulose and pectin, which generally are not dissolved in the diffusion juice. Such components mainly come from particulate fragments of beet root fragments that are not retained on the pulp catchers. These were separated at the membrane, gradually increasing fiber content in the concentrate. The increased fiber content that accompanies the increasing drying temperature is primarily due to a decrease in the water content in the resulting preparations. The decomposition of pectins may have also been of some significance, as they have relatively little resistance to higher temperatures[12]. The color of the preparations (Table 7) was characterized by an objective measurement of the parameters "L", "a" and "b". The values of "L", indicating the brightness of color, ranged from 37 to 54 (100 – a perfectly white body[11]). The brightest color was observed in preparations dried at 200°C. The probable cause was the duration of drying, which at 150°C (only slightly higher than the boiling point of the concentrated solution[12]) was longer than at 200°C. The 250°C temperature was high enough for a greater number of colored substances to appear, such as melanin, melanoidin and caramel substances[12].

Table 6. The fiber content in the preparations obtain by spray-dried concentrates after ultrafiltration of the diffusion juice

Preparation	Temperature of drying [°C]			Mean	NIR
	150	200	250		
Concentrate (1/3)	0.39	0.43	0.66	0.49	0.03
Concentrate (1/2)	0.81	1.05	1.04	0.97	
Concentrate (2/3)	1.22	1.23	1.43	1.29	
Mean	0.81	0.90	1.04		
NIR	0.03				

The levels of "a" were close to 0, which with the positive levels of "b", indicate a color similar to yellow[11]. A brown or brownish color, characteristic of melanins, melanoidins and caramel, resulted from the low concentrations in the preparations. It is worth noting that the color of the preparation was pale in comparison with other sugar intermediates, which indicates relatively small transformations that lead to the formation of colored substances.

CONCLUSIONS

1. The degree of concentration and drying temperature influenced the chemical composition and ~~the~~ properties of the dehydrated diffusion juice concentrates.
2. An increase in drying temperature was accompanied by the increased content of dry mass, protein, ash and fiber content in the preparations.
3. The greater the degree of juice concentration, the greater was the content of dry mass, ash and fiber. Inversely, the greater the degree of juice concentration, the lower the content of sucrose.
4. The brightest color of the dehydrated product was observed at the drying temperature of 200°C.
5. Spray-drying may be used for waste management after the diffusion juice membrane filtration, and the resultant preparations might be used in the production of feedstuff or the food industry, in general.

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Table 7. The color of the preparations obtain by spray-dried concentrates after ultrafiltration of the diffusion juice

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Preparation	Temperature of drying [°C]			Mean	NIR
	150	200	250		
Concentrate (1/3)	46.11	54.72	46.98	49.27	1.29
Concentrate (1/2)	37.40	48.81	46.16	44.12	
Concentrate (2/3)	46.46	51.72	42.85	47.01	
Mean	43.32	51.75	45.33		
NIR	1.29				
a					
Concentrate (1/3)	0.27	0.11	–0.06	0.11	0.04
Concentrate (1/2)	0.58	0.49	0.26	0.44	
Concentrate (2/3)	0.36	0.23	–0.02	0.19	
Mean	0.40	0.28	0.06		
NIR	0.03				
b					
Concentrate (1/3)	2.32	2.98	5.04	3.45	0.21
Concentrate (1/2)	2.00	2.31	4.17	2.83	
Concentrate (2/3)	1.92	2.67	5.72	3.44	
Mean	2.08	2.65	4.98		
NIR	0.18				

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