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EFFECT OF THE ULTRASOUND ON THE CARROT JUICES FREEZING PROCESS

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Abstract. Ultrasound is a relatively new method that has been used in the food industry for enhancing unit operations such as drying, extraction and freezing. Sonication, despite a small invasiveness, has an effect on various physical, chemical and biochemical changes in the treated materials. Freezing is a widely used process in the food industry for extending the shelf-life of the products due to decreasing the food temperature. The aim of this study was to investigate a 30-minute ultrasound treatment on the freezing process of carrot juices (9, 12 and 21°Bx) from two producers. Freezing was conducted by immersion and air chilling method at -30°C medium temperature. The study examined how ultrasound effects the extract, density of juices, the specific freezing time, freezing point, Moreover, the freezing curves were evaluated. It was observed that 30-minute ultrasonic treatment did not affect physical properties of tested juices, only in the case of higher concentrated juices, the increase of tested parameters was seen. There was no difference in the shape of freezing curves, regardless of the freezing method, concentration of the juice and its producer and the application of sonication either. Regardless the concentration or the US pre-treatment, it has been observed that the specific time required to freeze the product in the immersion method was shorter than in the shock freezing. Along with the increase of concentrations of carrot juice the freezing point decreased, regardless of the producer. The freezing point of carrot juices, after the application of the US, slightly decreased. Research in this study confirms the reports of the reduced freezing time after the application of ultrasound in case of carrot juices.

Key words: sonication, carrot juice, freezing, freezing point

Introduction

Carrot juices are one of the most commonly produced vegetable juices in the Polish market. The most valuable components of carrot juice are carotenoids and polyphenols. Carotenoids and foods rich in these pigments, are considered to be beneficial in preventing diseases such as enhanced immune response, eye diseases, cardiovascular diseases and cancer but they are also sensitive to thermal or physical degradation because of long conjugated chain of C–C double bonds which is an unfavourable situation for both consumers and producers (Sun et al., 2010). Usually carrot juice used in the food industry has extract form 9-15 or, if it is a concentrated carrot puree, 29%. Because of this high concentration and presence of particles in the juice the rheological and thermal properties are useful in the designing of such processes as pumping, mixing, pasteurization or freezing. Also beta-carotene and colour of carrot juice may be considered as a factor for the product quality assessment. Moreover, the quality of a product can be improved by application of new methods like for example sonication (Vandresen et al., 2009).

Ultrasounds (US) are one of the most commonly used emerging technologies that can minimize processing, maximize quality and guarantee the safety of food products, nowadays (Nowacka et al., 2013; Šimunek et al., 2013). This properties of US has been commercialized in the petrochemical, pharmaceutical, cosmetics and food industries. In food products such as fruit juices, mayonnaise and tomato ketchup, sonication is used for creation of viscosity because of the emulsification process (Seshadri et al., 2003), inactivation of microorganisms (Rawson et al., 2011) or as a pre-step before freezing, drying and extraction processes (Knorr et al., 2004; Nowacka et al., 2013).

Similarly, the freezing process can be used for preserving quality of carrot juices. The freezing process reduces the temperature of foods below their freezing point, preserving them by a combination of biochemical, enzymatic and microbial activity inhibition. It was also stated that during freezing water activity is reduced to the 0.8, while sensory qualities and nutritional value are minimally changed (Singh and Heldman, 2001; Fellows, 2009).

Some researches indicate no or minimal effect of ultrasound on the physical properties of fruit juices (Tiwari et al., 2008, 2009 and 2010; Costa et al., 2013). However, Wong et al. (2010) and Gómez-Lopez et al. (2010) in case of orange juice, have found some significant changes in the tested parameters. The most popular vegetable which was treated by US was tomato juice and its concentrated form (Vercet et al., 2002).

In all studies, authors have mentioned longer period of juice storage after US treatment and freezing. That was the reason why these two methods freezing and ultrasound treatment were combined in juices processing. There were two methods of combining. The first includes the use of US before the freezing process and the second includes the use of US during the freezing process (Ultrasounds Assisted Freezing – UAF) (Kiani et al., 2011).

There is limited information about freezing carrot juices processes and no information about freezing of carrot juices treated with ultrasounds before freezing. Therefore, the aim of this study was to investigate the effect of sonication on the carrot juices freezing process. Two different refrigerators and three concentrations of two different carrot juices producers were used.

Materials and method

Materials for the study were commercial pasteurised carrot juices (12%) of two different companies A and B. The concentration of carrot juice for the study was 9, 12 and 21%. To the obtained juice with lower concentration (9%) the distilled water was added. To the obtained juice with higher concentration (21%) carrot juices were concentrated in pressure evaporator (Bűchi Labortechnik AG, Switzerland) at pressure 0.0055 MPa what ensured that the temperature of carrot juice was at the level of 35ºC.

Sonication

Carrot juices, independently of the concentration were sonicated for 30 minutes at 21 kHz, at power of 300 W, in the of Ultrasonic MKD-3 device (Stary Konik, Poland, internal dimensions 240x135x100mm). The 300 g (accurate to 0.01 g) of juice was placed in glass containers immersed in the 1.5 l of distilled water, which provided the immersion of the whole carrot juice in the baker. Each time before and after US treatment the juice temperature was measured. Experiments were performed in five repetitions. Acoustic intensity applied during sonication process was determined calorimetrically by recording the temperature increase against the US treatment (Nowacka et al., 2013). The acoustic intensity of ultrasounds was 2.2 10^{-2} $W \cdot cm^{-2}$.

Carrot juices analysis

In juices, with and without US treatment extract and density were studied. All tests were performed in five repetitions. Extract was measured in pocket refractometer (Atago, Tokyo, Japan). The density ($kg \cdot m^{-3}$) were determined by pycnometric method and was calculated by the formula presented by Janiszewska et al. (2010).

Freezing

Juices were frozen in an immerse freezer – IF (Kältemaschinenbau Peter Huber GmbH model CC-505) filled with propylene glycol and in air convective shock freezer –SF (Irinox). In both cases the refrigerant temperature (t_e) was -30ºC. The 300 g of juice, placed in an aluminium can was frozen. A thermocouple was placed in the geometric centre of the can with carrot juice.

The freezing point (t_{cr}) and specific time was determined from the data obtained from thermocouple located in ½ of the can diameter. Moreover, frozen water content (ω) was calculated from the following formula:

$$\omega = 1 - \frac{t_{cr}}{t_e} \tag{1}$$

Statistical method

All measurements were repeated five times. Data are presented as mean ± standard deviation. All obtained results were subjected to the analysis of variance (ANOVA) using Statgraphics Plus 5.1 (Stat Point Technologies, Inc., Warrenton, VA). Individual group differences were identified using Tukey multiple range tests with the probability level set at 0.05.

Results and discussion

Analyzing the effect of a 30-minute ultrasonic treatment at a frequency of 21 kHz on the extract of the carrot juice, at lower concentrations no statistically significant difference was observed, regardless of the juice producer (Tab. 1). The same correlations were observed by Adekunte et al. (2010), who have shown that 10 minutes of ultrasound application at a frequency of 20 kHz did not affect the extract value of the tomato juices, and its value remained below 6°Bx. Also Tiwari et al. (2009), studying the orange juice, found no significant effect of US on the soluble components, regardless of the used parameters: amplitude, the process temperature and the time of US exposure.

For fruit juices with 21°Brix concentration a statistically significant increase in the extract after the application of ultrasound was observed (Tab. 1). It could be due to the breakdown of protein-dye complexes, resulting in higher content of dissolved solids in the juice (Costa et al., 2013) or higher water evaporation during sonication (Hu et al., 2006).

Table 1
Selected physical properties of carrot juice

Tested parameter	Juice producer	US (kHz)	Juice extract concentration		
			9	12	21
Measured extract (°Bx)	A	0	9.26±0.05a	12.28±0.04b	20.72±0.13c
		21	9.22±0.04a	12.58±0.20b	21.86±0.05d
	B	0	9.24±0.05a	12.46±0.21b	20.66±0.30c
		21	9.30±0.10a	12.60±0.16b	21.78±0.14e
Density ρ ($kg \cdot m^{-3}$)	A	0	1038±0.2a	1050±0.1b	1086±0.3c
		21	1038±0.2a	1050±0.0b	1092±0.2d
	B	0	1037±0.2a	1051±0.3b	1085±0.5c
		21	1037±0.2a	1051±0.7b	1091±0.9d

means in columns for tested parameter followed by the same letter are not significantly different at P=0.05 according to Tukey test

The density of carrot juice was the lowest in the case of juice originated from B company at 9°Bx concentration and was 1037 $kg \cdot m^{-3}$ (Table 1). The density increased when the extract increased. The same correlation was obtained by Ferreira Bonomo et al. (2009) for cashew juice and by Shamsudin et al. (2005) for the guava juice.

There was no statistically significant change in product density after sonication in the case of juices with lower extracts. Similar results with no or minimal US effect on density were obtained in orange juices (Tiwari et al., 2008 and 2009), strawberry juices (Tiwari et al., 2008 and 2010) and pineapple juices (Costa et al., 2013). However, Wong et al. (2010) and Gómez-Lopez et al. (2010) for orange juice, have found some significant changes in the tested parameters.

In juices at concentration of 21°Bx, (originated from both producers), an increase of the density after the sonication process was observed, which could be due to evaporation of water caused by cavitation (Knorr, 2004).

Each of the individual steps proceeded more rapidly with immersion freezing than with shock freezing. There was also a steeper slope of the curve, after finishing specific freezing stage for immersion freezing in case of juice at lower concentration.

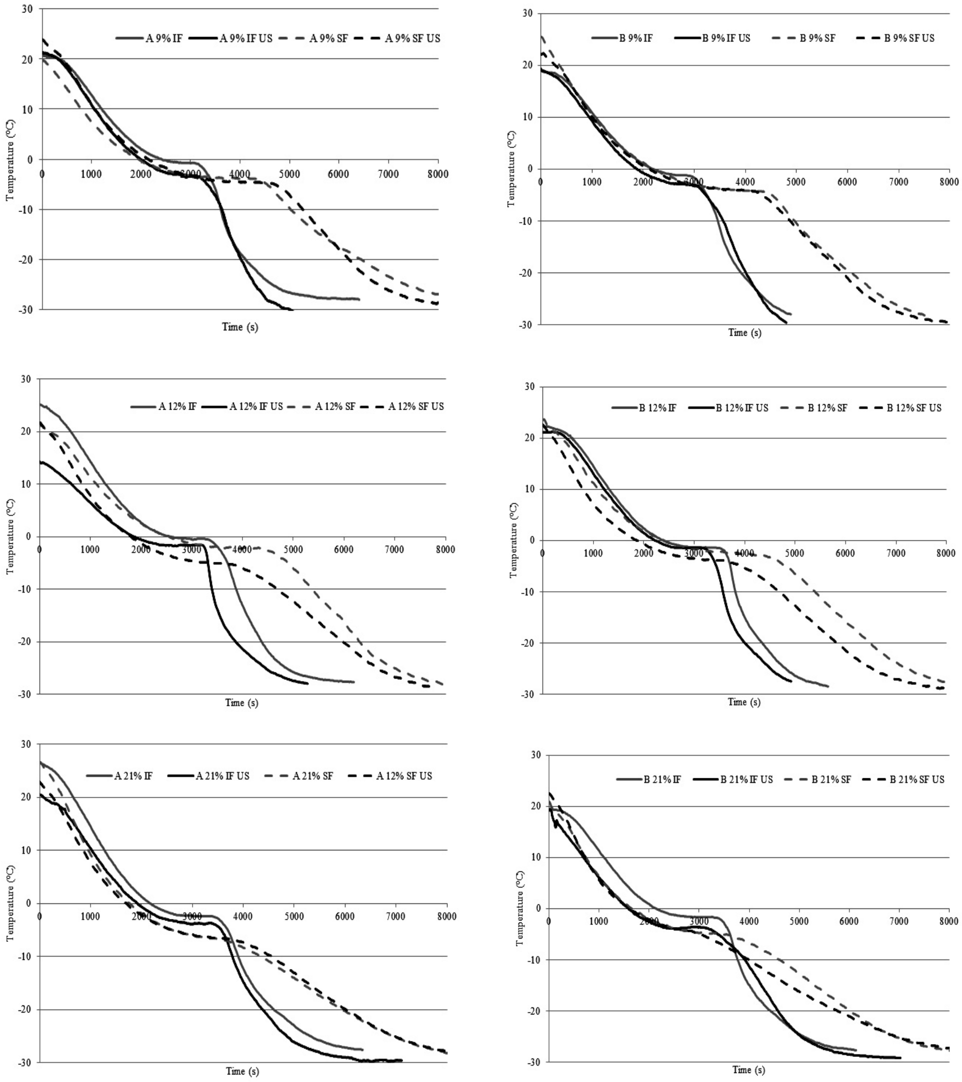

Figure 1. Freezing curves of carrot juices with extract 9, 12 and 21% for both producers A and B

Comparing the carrot juice freezing curves (Fig. 1), it can be concluded that they had a form similar to the theoretical curve shown by Gruda and Postolski (1999) and Fellows (2004). Identical dependence was obtained by Chung et al. (2013) for Prunus mume juice.

Based on each curve, the following parameters have been distinguished: the initial cooling time of the product to the freezing point, specific freezing time, where the phase transition took place and in which the water had been frozen and the last stage: freezing product to the desired temperature. There was no difference in the shape of freezing curves, regardless of the freezing method, concentration of the juice and its producer and also the use of sonication. Comparing the two methods of freezing, it has been observed that in the case of the immersion method the specific time required to freeze the product was shorter than in the case of shock freezing independent of the concentration and whether the US pre-treatment (Table 2).

Table 2
The influence of carrot juice extract, a freezer type and US application on the freezing parameters

Tested parameter	Freezing method	Juice producer	US (kHz)	Juice concentration (%)		
				9	12	21
Specific freezing time (s)	Immersion freezing	A	0	690±42ab	705±190ab	850±64a
			21	600±78a	660±53a	759±99a
		B	0	610±187a	735±215ab	900±21ab
			21	450±42a	552±137a	870±63ab
	Shock convective air freezing	A	0	1375±180d	1470±64d	1503±128d
			21	1290±129cd	1110±167c	1147±11c
		B	0	1162±286cd	1170±43c	1320±103cd
			21	962±250bc	870±149b	1095±212bc
Freezing point (°C)	Immersion freezing	A	0	-0.13±0.06c	-1.00±0.03d	-2.25±0.13c
			21	-0.36±0.18bc	-1.54±0.03c	-2.77±0.15bc
		B	0	-0.77±0.15ab	-1.29±0.18cd	-2.61±0.21c
			21	-0.89±0.05a	-1.36±0.07cd	-2.69±0.10bc
	Shock convective air freezing	A	0	-0.56±0.11abc	-2.52±0.13b	-3.73±0.13a
			21	-0.45±0.70bc	-3.11±0.30a	-3.74±0.54a
		B	0	-0.77±0.18ab	-1.24±0.31cd	-3.37±0.13ab
			21	-0.75±0.23ab	-1.41±0.23cd	-3.88±0.53a
Frozen water content in the product ω (kg/kg)	Immersion freezing	A	0	0.996±0.003c	0.967±0.001d	0.912±0.008bc
			21	0.988±0.007bc	0.949±0.007c	0.944±0.003c
		B	0	0.974±0.005ab	0.957±0.003cd	0.913±0.007bc
			21	0.970±0.002aab	0.956±0.005cd	0.910±0.003bc
	Shock convective air freezing	A	0	0.981±0.004abc	0.916±0.004b	0.877±0.003a
			21	0.985±0.010abc	0.896±0.010a	0.875±0.018a
		B	0	0.974±0.006ab	0.959±0.010cd	0.888±0.003ab
			21	0.975±0.004ab	0.959±0.010cd	0.877±0.003a

Means in columns for the tested parameter followed by the same letter are not significantly different at P=0.05 according to Tukey test

Differences in the length of the specific freezing time at shock air and the immersion method, can be related to the values of heat transfer coefficients from the freezing medium to the wall of the packaging, which were 300 $W\cdot(m^2\cdot K)^{-1}$ to propylene glycol in the immersion method, and 62,8 $W\cdot(m^2\cdot K)^{-1}$ for the air in the air chilling method (Gruda and Postolski, 1999).

It was also found that with both methods of freezing specific freezing time of carrot juice was longer when concentration was higher, but this increase was not statistically significant, regardless of the producer and the use of ultrasonic pre-treatment. Application of US caused a significant decrease in freezing time for shock convective freezing in juices at a concentration of 12 and 21^{o}Bx.

Along with the increase of concentrations of carrot juice, the freezing point decreased, regardless of the producer. This was associated with a lower water content of juice with a higher concentration. The same relation was observed by Auleda et al. (2011) for apple juice, peach and pear juice freezing. The freezing point of carrot juices, after the application of the US, slightly decreased, but only for juice brand A at a concentration of 12Bx the change was statistically significant (Table 2). No major changes in the freezing point values could indicate any change in the proportion of the sugars contained in juices after using US (Auleda et al., 2011). Frozen water content is strictly related to the freezing point of the product. Accordingly, there has been observed the same dependency as in the freezing point. The smallest percentage of the frozen water has been recorded for juices with a concentration at 21% after air shock freezing (Table 2).

The use of a 30-minute sound wave with a frequency of 21 kHz, had significant effect on the process of carrot juices freezing. Also Mortazavi and Tabatabaie (2008) found that during the cream sonication (for 20 min.) the freezing time decreased from 20 to 13 minutes. Similarly Zheng and Sun (2006), found that the power of US at 15.85 W influenced the efficiency of potato freezing time. Zheng and Sun (2006) reported also that the US is a widely accepted method of accelerating food freezing time.

Conclusions

Analyzing the effect of a 30-minute ultrasonic treatment on physical properties of juices only for higher concentration of extract the increase of the tested parameters has been seen.

There was no difference in the shape of freezing curves, regardless of the freezing method, concentration of the juice and its producer and also the use of sonication. Regardless the concentration or the US pre-treatment, it has been observed that the specific time required to freeze the product in the immersion method was shorter than for the shock freezing. Along with the increase of concentrations of carrot juice the freezing point decreased, regardless of the producer. The freezing point of carrot juices, after the application of the US, slightly decreased, but only for brand A juice at a concentration of 12 Bx the change was statistically significant. Accordingly, the same dependence as in the freezing point was observed.

Research in this study confirms the reports of the reduced freezing time after the application of ultrasound in case of carrot juices.

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WPŁYW ULTRADŹWIĘKÓW NA PROCES MROŻENIA SOKU Z MARCHWI

Streszczenie. Ultradźwięki są stosunkowo nową metodą stosowaną w przemyśle spożywczym w celu zwiększenia działań jednostkowych takich jak suszenie, ekstrakcja i zamrażanie. Zastosowanie ultradźwięków, pomimo małej inwazyjności, ma wpływ na różne fizyczne, chemiczne i biochemiczne zmiany surowców. Zamrażanie jest procesem szeroko stosowanym w przemyśle spożywczym w celu przedłużenia okresu ważności produktów poprzez zmniejszenie temperatury produktu. Celem niniejszej pracy było zbadanie 30-minutowego traktowania ultradźwiękami w procesie zamrażania soków z marchwi (9, 12 and 21ºBx) pochodzących od dwóch producentów. Zamrażanie przeprowadzono poprzez zanurzenie i przy użyciu metody schładzania przy średniej temperaturze -30°C. Badanie miało na celu sprawdzenie jak ultradźwięki wpływają na ekstrakt, gęstość soków, określony czas zamarzania, punkt zamarzania. Ponadto, oceniono, krzywe zamarzania. Zaobserwowano, że 30-minutowe traktowanie ultradźwiękami nie wpływa na fizyczne własności badanych soków, tylko w przypadku mocniej zagęszczonych soków, zaobserwowano wzrost badanych parametrów. Nie zaobserwowano żadnych różnic w kształcie krzywych zamarzania, bez względu na metodę mrożenia, zagęszczenie soku i jego producenta oraz zastosowanie ultradźwięków. Bez względu na zagęszczenie czy wcześniejsze zastosowanie ultradźwięków, zaobserwowano, iż określony czas potrzebny do zamrożenia produktu w metodzie immersyjnej był krótszy niż w przypadku zamrażania szokowego. Razem ze wzrostem zagęszczenia soku marchwiowego zmniejszyła się temperatura zamarzania, bez względu na producenta. Punkt zamarzania soków z marchwi delikatnie zmniejszył się po zastosowaniu ultradźwięków. Badania przeprowadzone dla celów niniejszej pracy potwierdzają raporty dotyczące skróconego czasu mrożenia po zastosowaniu ultradźwięków w przypadku soków z marchwi.

Słowa kluczowe: zastosowanie ultradźwięków, sok z marchwi, mrożenie, punkt zamarzania

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