

Application of Freezing and Thawing to Carrot (*Daucus carota* L.) Juice Extraction

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Abstract This paper presents a study of the effects of freezing and thawing carrot pulp and pomace on the efficiency of the pressing process and the quality of juice. In this study, various combinations of pretreatment strategies were used based on freezing and thawing the carrot pulp and pomace before pressing. The pressing process for pulp and pomace was carried out using a laboratory press with a perforated base. The juice obtained as a result of freezing and thawing the carrot pulp and pomace was characterized by a higher sugar content (°Brix) and a slightly lower dynamic viscosity. Furthermore, the study showed the impact of pretreatment on the chemical composition of the juice produced. On the basis of energy use and quality indicators of the resultant carrot juice (viscosity, pH, selected minerals, sugars, total carotenoid content, and vitamin C), a recommended solution is to press the pulp directly after grinding the carrots and then to press the pomace again after freezing and thawing. The proposed method for juice production using freezing and thawing allows a reduction in pomace quantity and the use of its valuable nutrients.

Keywords Carrot · Juice · Freezing · Pressing · Efficiency · Quality

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Introduction

Fruit and vegetables are an important ingredient of a balanced diet (Wootton-Beard and Ryan 2011). The carrot (*Daucus carota* L.) is a source of a number of compounds that have documented antioxidant, antimicrobial, antiviral, anti-inflammatory, anti-allergenic, and even anti-cancer properties (Abbey et al. 1995; Cortés et al. 2005; Sharma et al. 2012). The short growing time caused by the conditions of a moderate climate leads to an unequal availability of carrot juice during the year. Carrots can be processed into many ready-made products, such as juices, concentrates, infant foods, powdered soups, tinned foods, and frozen foods (Klaiber et al. 2005; Sharma et al. 2012). The main nutritional advantages of products made from carrots are related to their low energy value, high content of carotenoids, vitamins (C, B₁, B₂, B₆, B₇, E, K, and PP), the presence of easily assimilated sugars (sucrose, fructose, and glucose), minerals (calcium, potassium, magnesium, and iron), and other biologically active ingredients (Yen et al. 2007; Quitao-Teixeira et al. 2009; Barański et al. 2010).

Industrial methods for processing fruit and vegetables may significantly change their nutritional properties (Anese et al. 1999; Marx et al. 2003; Rosenthal and Jansky 2008; Rababah et al. 2011) through losing several valuable nutrients and their by-products. Approximately 50 % of carotenoids remain in the pomace (residue after pressing) during the industrial production of carrot juice (Sharma et al. 2012); therefore, methods of carrot processing need to be developed that minimize the negative impact of processing on its nutritional properties (Boekel Von and Jongen 1997; Ma et al. 2013). Consumers expect manufacturers not only to maintain the nutritional properties of a product, but also to improve them (Ioannou et al. 2012).

The most common method for obtaining juice from fruit and vegetables is pressing, which consists of creating pressure

on the food that causes the release of liquids that flow through capillaries between the solid parts. The efficiency of pressing is influenced by many factors: the properties of the food being pressed, the degree of grinding, the thickness of the layer being pressed, the porosity of the food, the viscosity of the liquid produced, the pressure of pressing and the dynamics of its changes, and the design of the press (Sharma et al. 2006; Nadulski 2010). Currently, the fruit pressing industry commonly uses basket presses but rarely uses screw, roll, and belt presses, which are intended for continuous work owing to their lower efficiency (Brennan et al. 1990). For basket presses, two designs are used: presses with a perforated basket or a solid basket, where the juice flows out through drainage hoses. Under laboratory conditions for research into the pressing process, basket presses with perforated elements (Pearson and Rath 2009) and layer presses (Gerard and Roberts 2004) are most often used.

During the preparation of foods for pressing, a commonly used technique is enzymatic processing, which aims to increase the efficiency of the process (Mutlu et al. 1999; Chadha et al. 2003; Mieszczakowska-Frąc et al. 2012). However, the current trend is to eliminate any chemical methods and procedures from the production process that lead to an excessive increase in temperature, which may affect the functional properties of the food. Research interest has focused on the use of physical methods for the initial processing of pulp and juice, such as pulsed electric field (PEF) (Lebovka et al. 2003; Grimi et al. 2007; Abenoza et al. 2013; Parniakov et al. 2014), ohmic heating (OH) (Lima and Sastry 1999; Wang and Sastry 2002; Praporscic et al. 2006), radiation (Mitchel et al. 1991; Patterson et al. 2012), high pressure processing (Patterson et al. 2012), sonification (Costa et al. 2013; Jabbar et al. 2014), and microwave heating (Gerard and Roberts 2004; Cendres et al. 2012). The use of all these forms of processing aims to maintain the organoleptic and nutritional features of juice at the highest possible level, while, at the same time, ensuring an acceptable level of efficiency. One process with no documented significant influence on the nutritional properties of food is freezing (Sun 2011). Generally, freezing is used to preserve foods, but for some, freezing can be used as a pretreatment to enhance the efficiency of the main processing procedures (Chung et al. 2013).

Taking into account the fact that during freezing and thawing some destruction of the structures of plant materials and the release of cell juices take place, this form of processing may be used for initial processing before pressing to produce juice with a high nutritional quality.

The extraction of carrot juice has been investigated with juice yields reported to be only 60–70 % (Sharma et al. 2006, 2012; Singh et al. 2006; Nadulski 2010). Because of the low yields associated with carrot juice production, industry is using new technologies for extracting juice such as depolymerizing enzymes, mash heating, and decanter technology. With

enzymatic maceration pretreatment (Vora et al. 1999; Demir et al. 2004; Sun et al. 2006; Liao et al. 2007), the yield can be improved up to 65 %. Giacomo and Taglieri (2009) reported that carrot juice can be produced with a yield higher than 80 % without using any extraneous substances.

The aim of the present study was therefore to determine the influence of initial processing using freezing and thawing techniques on the efficiency, energy consumption, and quality of juice yielded by pressing. Energy consumption will be determined only for the pressing process, without taking into account the energy input for grinding and freezing the carrots. Pressing the pulp and pomace will be carried out using a laboratory press with a perforated base. The scope of the study will include determining the efficiency and energy consumption of pressing and the quantitative parameters of the juice obtained: the sugar content; acidity (pH); dynamic viscosity; density; and the contents of calcium, potassium, magnesium, sugars, carotenoids, and vitamin C.

Materials and Methods

Sample Preparation

The study was conducted using the Finezja carrot variety (type Karotka) supplied by a specialist horticulture farm and harvested in 2013. Healthy carrots of a similar size with no mechanical damage were used for the present study. The moisture content of the carrots was 89.4 %. Initially, the carrots were washed in cold water, dried using blotting paper, and ground using a MKJ250 grinding machine (Spomasz Nakło, Nakło nad Notecią, Poland) with two standard replaceable grinding plates: The first plate works as a grater to produce pulp, and the second plate with 5-mm-diameter perforations produces chips. During grinding, the rotational speed of the plates was 170 rpm. The material obtained was divided into 100-g portions of pulp or chips, which were packed in plastic boxes and placed in a standard air freezer (F6243W, Gorenje Group, Velenje, Slovenia) for 24 h. The material was frozen at -20 ± 1 °C and before pressing was thawed at 20 ± 0.5 °C using an incubator (SUP-4, Wamed, Warsaw, Poland). A standard thawing time of 3 h ensured complete thawing of the carrot chips or pulp. A similar procedure was used for pomace samples obtained at particular stages of the experiment. The effect of the rate and duration of freezing on the efficiency and energy intensity of pressing was not evaluated. The pulp and pomace moisture contents were determined using the oven-drying method.

Juice Pressing Process

The carrots were pressed in a specially designed, laboratory basket press with a working chamber volume of

approximately 300 cm³, which worked in tandem with an Instron 4302 universal testing machine (Instron Ltd, High Wycombe, UK) (Fig. 1). The press consisted of a base with a drainage hole for the juice, a cylinder with a replaceable perforated base with holes of 3-mm diameter, and a piston (Fig. 2). Before loading the pulp onto the base in the press cylinder, a 0.1-mm mesh was introduced. All parts of the press were made of stainless steel. A 100-g sample of ground material was placed into the press cylinder and then pressed down using the piston. The speed of piston displacement was 50 mm min⁻¹ (0.83 mm s⁻¹). After reaching a force of 9.5 kN, the pressing was stopped. This value corresponds to a pressure of 1.7 MPa, a typical value observed in industrial juice pressing. From these measurements, curves were obtained illustrating the relationship between force and piston displacement from which the work of pressing (E_m or E_p) was calculated (Fig. 3) from the area below the curve. Each measurement was performed ten times. The efficiency of pressing the macerated carrot pulp/chips and pomace was calculated using the formulae:

$$W_m = \frac{M_i}{M_j} \quad \text{or} \quad W_p = \frac{M_i}{M_j}, \quad (1)$$

where W_m is the efficiency of pressing macerated carrot pulp or chips, %; W_p is the efficiency of pressing pomace, %; M_j is the mass of juice after pressing, kg; and M_i is the mass of input material (macerated carrot pulp/chip or pomace), kg.

The specific energy while pressing the macerated carrot (pulp/chips) and pomace was calculated using the formulae:

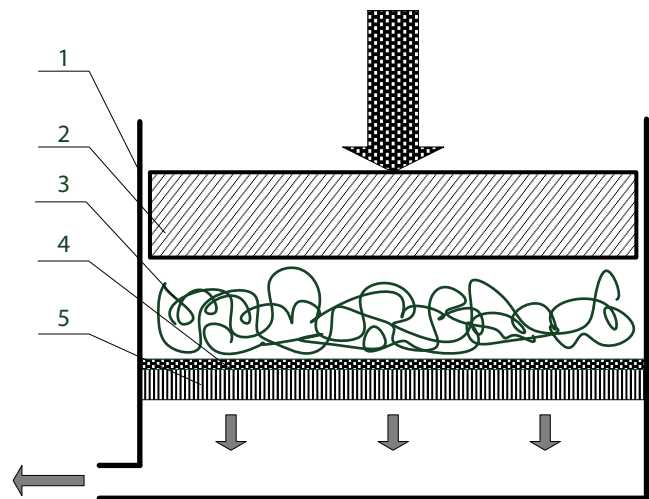


Fig. 2 The construction and principle underlying the operation of the press. 1 cylinder, 2 piston, 3 pulp, 4 mesh, 5 perforated base

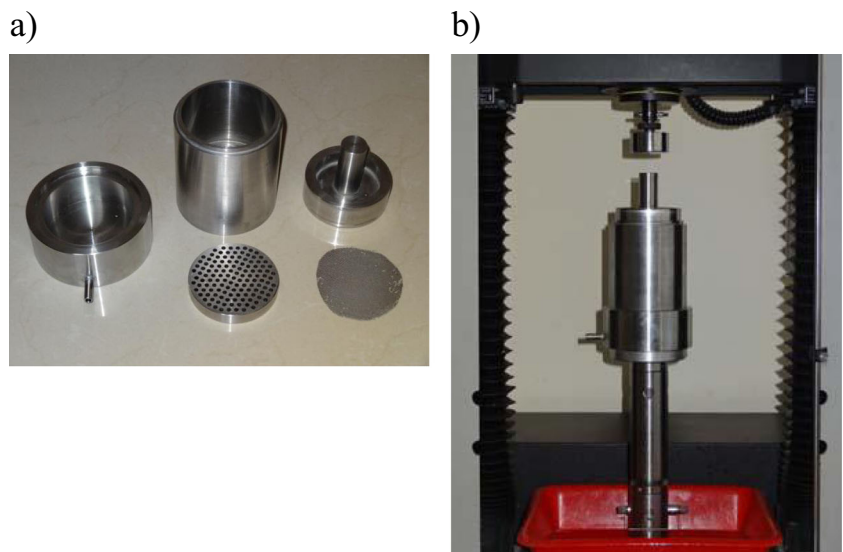
$$E_{jm} = \frac{E_m}{M_j} \quad \text{or} \quad E_{jp} = \frac{E_p}{M_j}, \quad (2)$$

where E_{jm} is the specific energy of pressing macerated carrot (pulp or chips), kJ kg⁻¹; E_m is the pressing work of macerated carrot pulp or chips, kJ; E_{jp} is the specific energy of pressing pomace, kJ kg⁻¹; E_p is the pressing work of pomace, kJ; and M_j is the mass of juice after pressing, kg.

Treatment Procedures

The material for pressing was prepared according to the procedures shown in Fig. 4. For the first procedure (P1), the initial

Fig. 1 The experimental set-up: **a** parts of the press and **b** the press installed in an Instron 4302 universal testing machine



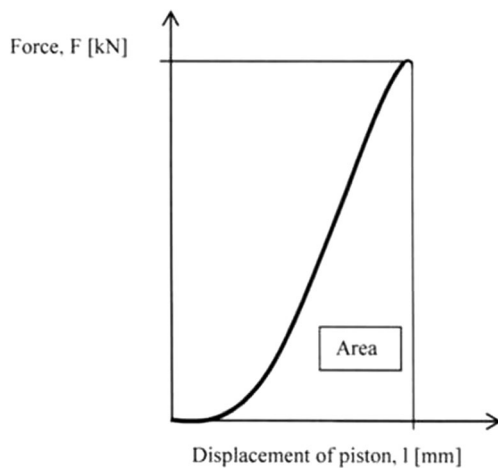


Fig. 3 An example curve of a force/displacement curve when pressing carrot pulp

processing before the first pressing involved grinding the carrot into chips; the second procedure (P2) involved grinding the carrot into pulp; the third procedure (P3) involved grinding the carrot into chips that were frozen at -20 ± 1 °C, then thawed to bring up to ambient temperature; and the fourth procedure (P4) was to grind the carrot into pulp, which was frozen at -20 ± 1 °C, then thawed to bring up to ambient temperature. In each procedure, the material underwent a single pressing. The pomace obtained after pressing by these procedures (P1, P2, P3, and P4) was frozen at -20 ± 1 °C, then

thawed to bring up to ambient temperature. It then underwent a single pressing (P1W, P2W, P3W, and P4W).

Physical Properties of Juice

After each pressing procedure, the amount of juice obtained was measured (mass and volume), as well as its sugar content (°Brix), pH (EN 1132:1994), density, and dynamic viscosity. The physical properties of the juice were evaluated after storage in an incubator at a temperature of 20 ± 0.5 °C (SUP-4). To determine the sugar content of the juice extracted, a PAL-1 refractometer (Atago, Tokyo, Japan) was used; to determine the pH of the juice, a CP-411 pH meter (Elmetron, Zabrze, Poland) was used; and to determine dynamic viscosity, an LVDV-II + PRO machine (Brookfield Engineering Laboratories, Middleboro, MA, USA) was used. The dynamic viscosity of the juice was measured using a ULA spindle at a rotational speed of 50 rpm at 20 ± 0.5 °C, controlled by a thermostat. Rheocalc V3.1 software (Brookfield Engineering Laboratories) was used to record the data and control the viscosity meter.

The Chemical Composition of Juice

The chemical composition of the juice obtained was determined analytically. The contents of the elements K, Ca, and

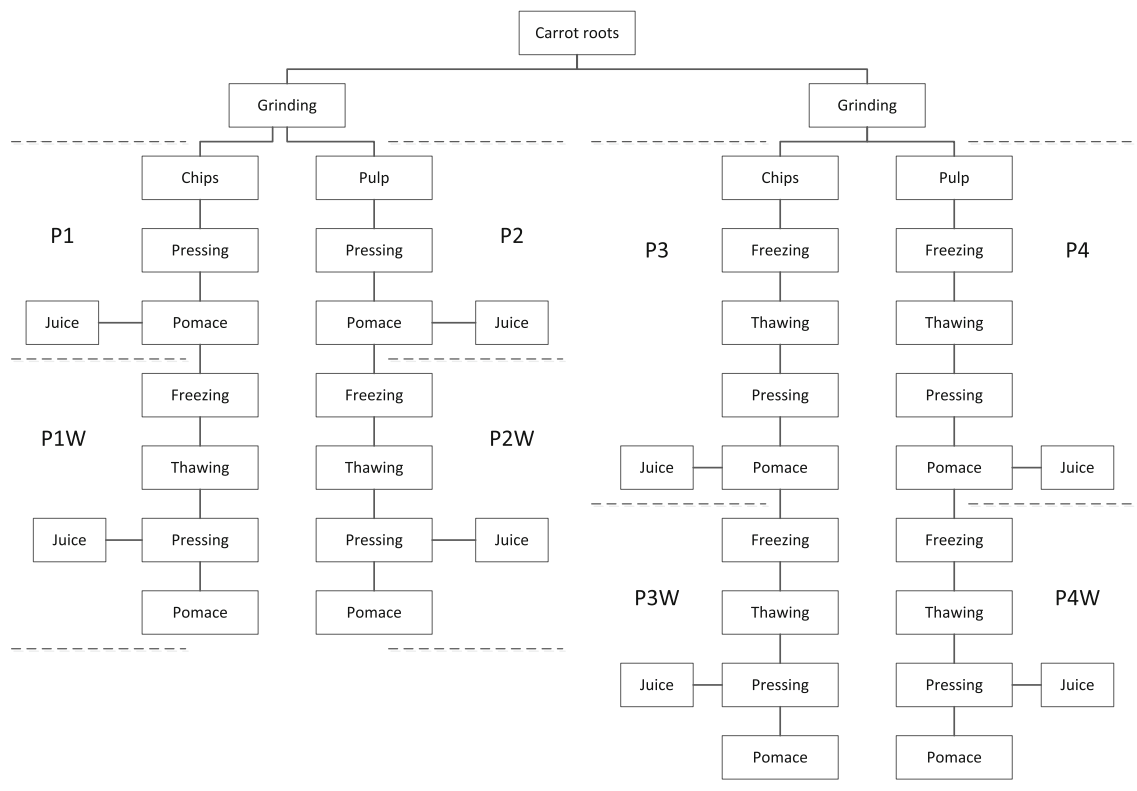


Fig. 4 The experimental procedures used in the study

Mg were determined using atomic absorption spectrometry with excitation in an acetylene-air flame, according to EN 1134:1994. A fast sequential atomic absorption spectrometer was used (Model AA280FS, Varian Inc., Santa Clara, CA, USA). The contents of sucrose, glucose, and fructose were determined according to EN 12630:1999 and for vitamin C content according to EN 14130: 2003 using high-performance liquid chromatography. A liquid chromatograph (Model UFLC, Shimadzu, Kyoto, Japan), equipped with a diode array detector, was used. The total content of carotenoids was determined using the spectrophotometric method in accordance with the EN 12136:1997 standard.

Statistical Analysis

Statistical analysis of the data was performed with Statistica software (Statistica 6.1, StatSoft Inc., Tulsa, OK, USA) using analysis of variance for factorial designs. This also allows the analysis of the interactions for selected quality predictors. The pressing process can be characterized by the two parameters, efficiency and energy consumption. The juice produced can be characterized by the measured quality predictors: sugar content (°Brix); acidity (pH); dynamic viscosity; density; and the contents of calcium, potassium, magnesium, sugars, carotenoids, and vitamin C. The influence of various combinations of the pretreatment strategies on these measured quality predictors was analyzed. The significance of differences between mean values was determined using Fisher's exact test at a level of $p < 0.05$.

Results and Discussion

Figure 5 shows the influence of the procedures used on the efficiency, W_m , of carrot juice pressing. In all cases, the statistical analysis showed that the applied treatment

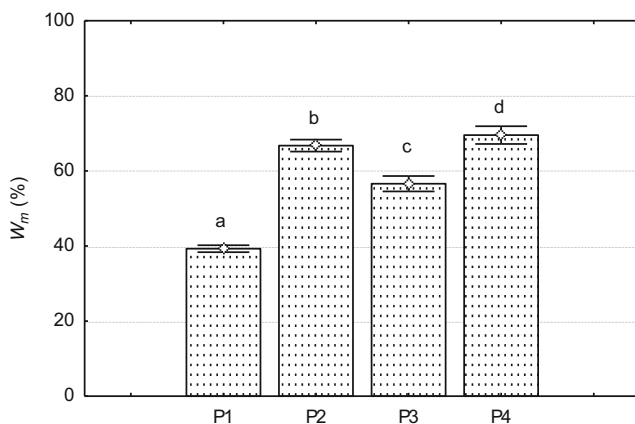


Fig. 5 The relationship between pressing yield, W_m , and the applied treatment procedure

procedures (P1, P2, P3, and P4) had a noticeable influence on the efficiency of the process. The pressing efficiency for fresh carrots in pulp form (P2) was 69.8 % higher than carrots in the form of chips (P1). For carrots subjected to freezing and thawing in the form of chips (P3), a 44.1 % increase in pressing efficiency was achieved compared with fresh carrot chips (P1). In contrast, for carrots subjected to freezing and thawing in the pulp form (P4), the increase in efficiency compared with fresh carrot pulp (P2) was only 4.2 %. The efficiency of pressing carrots subjected to freezing and thawing in the form of chips (P3) was 19.4 % lower compared with those processed in the form of pulp (P4). According to Sharma et al. (2006), the efficiency of carrot juice pressing depends mostly on the initial parameters such as the degree of grinding, pH, temperature, time, and the pressure applied during pressing. An important parameter for juice yield from vegetables is energy consumption. The present study has not accounted for the energy input related to grinding, freezing, or thawing carrots. Figure 6 shows the variation in the specific energy E_{jm} during pressing with the applied treatment procedure. There was a significant difference ($p < 0.05$) between mean values of specific energy for all procedures (P1, P2, P3, and P4). The procedure consuming most energy was pressing fresh carrot chips (P1), and the procedure consuming least energy was pressing carrot pulp subjected to freezing and thawing (P4). For pressing carrot chips subjected to freezing and thawing (P3), there was a 51.3 % decrease in specific energy compared with fresh carrot chips (P1). In contrast, for carrot pulp subjected to freezing and thawing (P4), the decrease in specific energy compared with fresh carrot pulp (P2) was 13.4 %. The specific energy related to pressing carrots subjected to freezing and thawing was 40.1 % higher for chips (P3) than for pulp (P4). After pressing, valuable nutrients still remain in the pomace (Stoll et al. 2003). Therefore, further processing of the pomace could obtain these nutrients. The pressing efficiency, W_p , for pomace using procedures P1W, P2W, P3W, and P4W is shown in Fig. 7, in the range of 19.9–

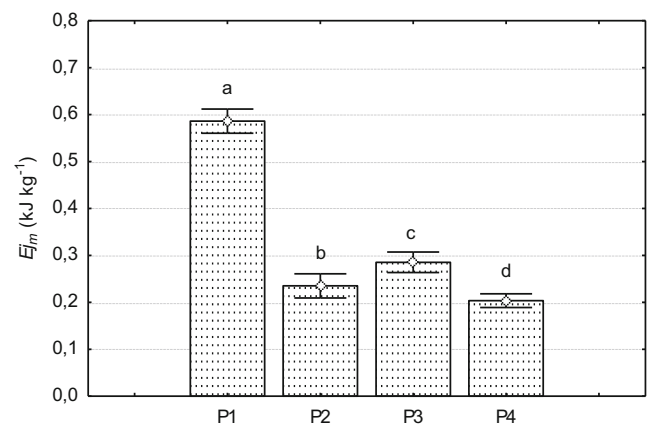


Fig. 6 The relationship between specific energy for pressing, E_{jm} , and the applied treatment procedure

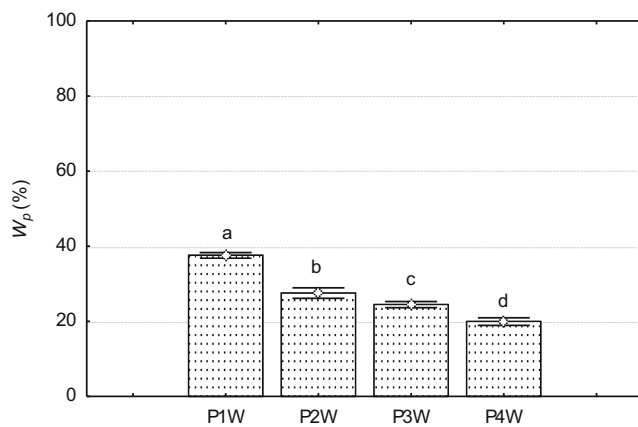


Fig. 7 The relationship between pressing yield of pomace, W_p , and the applied treatment procedure

37.6 %. The differences between the mean values of W_p for the four treatment procedures were significant ($p < 0.05$). The specific energy for pressing juice from pomace after freezing and thawing is shown in Fig. 8. The highest value of E_{jp} was obtained by procedure P4W, 0.63 kJ kg^{-1} , and the lowest for procedure P1W, 0.29 kJ kg^{-1} . There were also statistically significant differences between mean values of specific energy E_{jm} during procedures P1W, P2W, P3W, and P4W ($p < 0.05$). A total assessment of the efficiency of pressing was made, taking into account juice yield from both the pulp and chips (P1, P2, P3, and P4) and from the pomace (P1W, P2W, P3W, and P4W). Figure 9 shows the total pressing efficiency W_c for these treatment procedures. The highest total pressing efficiency of over 75 % was achieved for the two procedures, P2 + P2W and P4 + P4W, but there were no significant differences between these two mean values ($p > 0.05$). The lowest pressing efficiency, 62.3 %, was observed for the procedure P1 + PW. For traditional methods of producing carrot juice, efficiency is 50–65 % depending on the variety of carrot and the initial processing applied (Giacomo and Taglieri 2009). Under laboratory conditions,

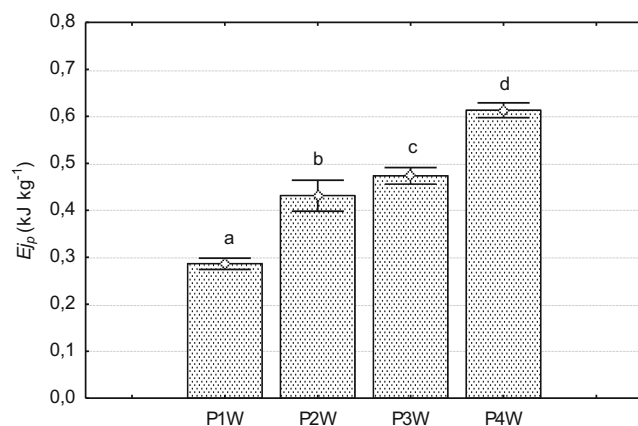


Fig. 8 The relationship between specific energy for pressing pomace, E_{jp} , and the applied treatment procedure

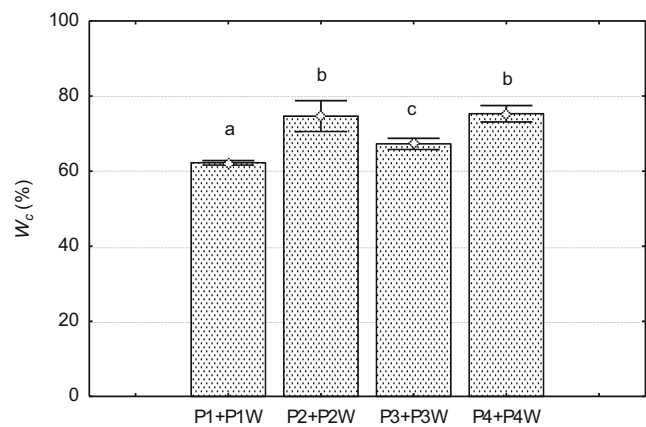


Fig. 9 The relationship between total pressing yield, W_c , and the applied treatment procedure

Sharma et al. (2006) achieved 78.2 % efficiency for pressing carrot juice using a hydraulic press.

The increased pressing capacity through freezing and thawing ground carrots and pomace is related to changes occurring in the structure of the carrot tissue. In cross section, the tissue of a fresh carrot is composed of regular, evenly arranged oval cells. As a result of grinding the carrots, damage can be observed to part of the cells followed by leakage of the vacuolar sap. The ground carrots (chips and pulp) and the pomace were frozen at a temperature of -20°C for 24 h. Slow freezing can increase the size of ice crystals (Chevalier et al. 2000): for carrots, damage to the tissue structure can be clearly observed as a result of this. In vegetable material, empty spaces, one to two cells wide, occur as a result of the movement of vacuolar sap into intercellular spaces, after which growth of ice crystals with a dendritic structure can be observed (Van Buggenhout et al. 2006). These lesions result in the loss of turgor in the cells after thawing and a significant leakage of vacuolar sap. Pressing causes additional damage to tissues and cells and causes the flow of vacuolar sap through the material. The damage to the carrot structure resulting from freezing is intensified during pressing, causing deformation and breaking up of cells, as well as decreasing the resistance to the flow of vacuolar sap through the layer of pressed material. This leads to an increase in process efficiency and a reduction of the energy inputs related to pressing.

Figure 10 shows the variation in total specific energy, E_{jc} , for pressing with the applied treatment procedures. There was no significant difference between total specific energy for procedures P2 + P2W and P3 + P3W ($p > 0.05$). For procedure P1 + P1W, the total specific energy was 73.8 % higher compared with that for procedure P4 + P4W. From the information in Figs. 9 and 10, it can be seen that producing carrot juice according to procedure P4 + P4W is beneficial: It has the highest efficiency of all the procedures analyzed and a low total specific energy related to pressing. The total specific energy for procedure P2 + P2W was 14.3 % higher than for

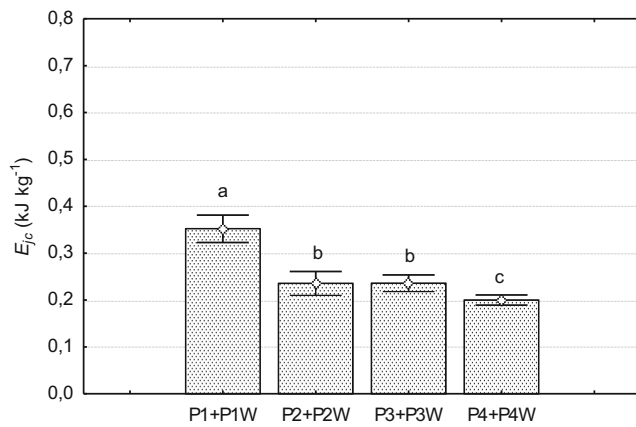


Fig. 10 The relationship between total specific energy of pressing, E_{jc} , and the applied treatment procedure

procedure P4 + P4W, but for procedure P2 + P2W, the pulp was not frozen after grinding, only the pomace obtained after the first pressing. Taking into consideration the technological aspect, a recommended solution would be to press the pulp directly after grinding the carrots and then press the pomace after freezing and thawing (procedure P2 + P2W). The present study has indicated that further research is required on how freezing, as an initial processing step, can facilitate the pressing process, particularly from the point of view of producing carrot juice with better nutritional properties.

The physical properties of carrot juice obtained using different procedures are set out in Table 1. The juice obtained from fresh carrot chips and pulp (P1 and P2) had a few percent lower sugar content (°Brix) compared with juice obtained from carrot chips and pulp subjected to freezing and thawing (P3 and P4). Compared with the present study, Sharma et al. (2006) obtained juice with a higher sugar content but with

similar pH values within the range of 6.35–6.56. Our research showed that the resultant carrot juice behaved as a Newtonian liquid, agreeing with the results of Vandresen et al. (2009). Hence, values of dynamic viscosity at a constant shear rate are shown for comparison in Table 1. The dynamic viscosity of juice from fresh carrots (P1) was a few percent higher than that from carrots subjected to freezing and thawing (P3). There were no statistically significant differences between the mean density values of juice obtained by the different procedures ($p>0.05$).

The analysis has shown that the method of grinding carrots (chips or pulp) had no influence on the chemical composition of the juice obtained. Differences in the chemical composition of the juice were caused by the different treatment procedures (Tables 2 and 3). According to data from Sharma et al. (2012), in fresh carrots, the potassium content was 240 mg/100 g, calcium content was 34–80 mg/100 g, and magnesium content was 9 mg/100 g. Under the conditions of the present study, lower levels of these elements were found. No statistically significant differences in potassium content were found in carrot juice obtained by the different procedures ($p>0.05$). Carrot juice from frozen and thawed pulp and chips (P3 and P4) was characterized by lower calcium and magnesium contents than juice from fresh pulp and chips (P1 and P2). Regardless of the pretreatment, lower calcium and magnesium contents were observed in juice obtained from pomace in comparison with juice from pulp and chips. Juice obtained from the pomace using the P1W and P2W procedures was characterized by lower calcium and magnesium contents than juice obtained using the P3W and P4W procedures. The vitamin C content in carrot juice obtained using the different procedures was at a similar level, except for juice obtained from pomace using procedures P1W and P2W, where the

Table 1 The physical properties of carrot juice processed using different procedures

Procedure	Parameter			
	Extract (Brix)	pH	η dynamic viscosity (MPa)	Density d (gcm ⁻³)
P1	8.24±0.049 a	6.53±0.037 a	1.616±0.0258 a	1.063±0.0079 a
P2	8.30±0.063 a	6.49±0.045 a	–	1.061±0.0067 a
P3	8.68±0.098 b	6.56±0.046 a	1.524±0.0242 b	1.069±0.0075 a
P4	8.62±0.040 b	6.52±0.033 a	–	1.067±0.0069 a
P1W	8.44±0.049 c	6.42±0.086 a	1.494±0.0320 b	1.071±0.0080 a
P2W	8.42±0.075 c	6.44±0.069 a	–	1.069±0.0072 a
P3W	8.64±0.049 b	6.35±0.024 a	1.456±0.0102 c	1.069±0.0076 a
P4W	8.62±0.075 b	6.38±0.018 a	–	1.070±0.0066 a
P1 + P1W	8.26±0.049 a	6.48±0.078 a	1.594±0.287 a	1.066±0.0068 a
P2 + P2W	8.42±0.040 c	6.48±0.073 a	–	1.062±0.0077 a
P3 + P3W	8.68±0.075 b	6.53±0.029 a	1.514±0.0242 b	1.069±0.0076 a
P4 + P4W	8.64±0.050 b	6.51±0.041 a	–	1.067±0.0069 a

Average values marked with the same letter are not statistically significantly different ($p>0.05$)

Table 2 The mineral, vitamin C, and total carotenoid content of carrot juice processed using different procedures

Procedure	Parameter				
	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Vitamin C (mg/100 g)	Total carotenoids content (mg/100 g)
P1	988±366 a	281±74 a	32±5 a	7.20±0.86 a	7.93±0.34 a
P2					
P3	1,188±440 a	201±53 b	20±3 b	7.21±0.86 a	8.04±0.43 a
P4					
P1W	1,024±379 a	155±41 c	11±2 c	7.96±0.95 b	7.98±0.38 a
P2W					
P3W	1,049±389 a	194±51 b	15±3 c	7.15±0.85 a	7.98±0.39 a
P4W					
P1 + P1W	997±383 a	251±63 a	27±4 a	7.38±0.90 ab	8.03±0.42 a
P2 + P2W					
P3 + P3W	1,171±423 a	199±52 b	19±3 b	7.20±0.86 a	7.98±0.37 a
P4 + P4W					

Average values marked with the same letter are not statistically significantly different ($p>0.05$)

content was approximately 10 % higher. According to Wronowska and Zadernowski (2012), the vitamin C content in fresh carrot is 5–6 mg/100 g, whereas Sharma et al. (2012) found a content of approximately 4 mg/100 g. The total carotenoid content of juices in the present study was at a similar level, with a range of 7.93–8.04 mg/100 g. According to Simon and Wolf (1987), the total content of carotenoids in carrots had a range of 6–54.8 mg/100 g, depending on the variety (Sharma et al. 2012).

The total sugar content in fresh carrots according to Sharma et al. (2012) was 5.6 %. Under our experimental conditions, a higher sugar content was found. The sucrose content of the carrot juice obtained with the different procedures was at a similar level, but lower values were found for juice obtained

using procedures P1, P2, P1 + P1W, and P2 + P2W. The lowest glucose content was found in juice obtained using procedures P1W and P2W. In the present study, the fructose contents were at a similar level using the various procedures with differences not exceeding 2.3 g/L.

The method suggested for producing juice using freezing and thawing techniques enables both a reduction in the amount of pomace created and better use of the nutrients that it contains. During the production of carrot juice, pomace constitutes 30–50 % of the starting material, and its disposal can also pose a problem to the environment (Bao and Chang 1994). Alkint (2003) has indicated the need to develop new technologies to enable a solution to this problem. The present study suggests a marginally invasive method for the production of carrot juice, which allows the production of juice with the required physical and chemical properties while, at the same time, recovering valuable nutrients contained in the pomace.

Table 3 The sugar content of carrot juice processed using different procedures

Procedure	Parameter		
	Sucrose (g/L)	Glucose (g/L)	Fructose (g/L)
P1	36.0±1.0 a	25.2±0.7 a	19.1±0.5 a
P2			
P3	38.5±1.0 b	22.7±0.7 b	16.8±0.4 b
P4			
P1W	37.3±1.0 ab	15.0±0.7 c	18.3±0.4 c
P2W			
P3W	38.9±1.0 b	23.7±0.7 b	17.7±0.4 c
P4W			
P1 + P1W	36.3±1.0 a	22.8±0.7 b	18.9±0.4 ac
P2 + P2W			
P3 + P3W	38.5±1.0 b	22.7±0.7 b	16.9±0.4 b
P4 + P4W			

Average values marked with the same letter are not statistically significantly different ($p>0.05$)

Conclusions

The present study has demonstrated the clear impact of different procedures on the efficiency and energy intensity of the pressing process as well as on the quality of the resulting juice. Technologically, the recommended solution is to press pulp directly after grinding the fresh carrots and then to press the pomace after freezing and thawing (P2 + P2W). The juice obtained from fresh carrot chips and pulp (P1 and P2) had a few percent lower sugar content (°Brix) compared with juice obtained from carrot chips and pulp subjected to freezing and thawing (P3 and P4). It can be suggested that the method of grinding carrots has no influence on the chemical composition of the juice obtained. Differences in chemical composition of

the juice were caused by the different treatment procedures. The proposed method for obtaining juice using freezing and thawing allows a reduction in the quantity of the resulting pomace and the use of its valuable nutrients. The present study indicates the usefulness of further research into the influence of freezing as a pretreatment to facilitate the pressing process, particularly from the point of view of the production of juice with better nutritional properties.

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Conflict of Interest We declare no conflict of interest.

References

- Abbey, M., Noakes, M., & Nestel, P. J. (1995). Dietary supplementation with orange and carrot juice in cigarette smokers lowers oxidation products in copper-oxidized low-density lipoproteins. *Journal of American Dietetic Association*, 95(6), 671–675.
- Abenoza, M., Benito, M., Saldaña, G., Álvarez, I., Raso, J., & Sánchez-Gimeno, A. C. (2013). Effects of pulsed electric field on yield extraction and quality of olive oil. *Food Bioprocess Technology*, 6, 1367–1373.
- Alklint, C. (2003). *Carrot juice processing—effects on various quality aspects bulletin*. Lund Sweden: Lund Institute of Technology, Lund University.
- Anese, M., Manzocco, A. M., Nicoli, M. C., & Lerici, C. R. (1999). Antioxidant properties of tomato juice as affected by heating. *Journal of the Science of Food and Agriculture*, 79, 750–754.
- Bao, B., & Chang, K. C. (1994). Carrot pulp chemical composition, colour and water-holding capacity as affected by blanching. *Journal of Food Science*, 59, 1159–1161.
- Barański, R., Maksylewicz-Kaul, A., Leja, M., Schulz-Witte, J., Schulz, H., Nothnagel, T., & Carle, R. (2010). Characterisation of carrots of various root colour. *Ecological Chemistry and Engineering*, 17(9), 1053–1060.
- Brennan, J. G., Butters, J. R., Cowell, N. D., & Liiey, A. E. V. (1990). *Food engineering operations*. London and New York: Elsevier Science Publisher Ltd.
- Cendres, A., Chemat, F., Page, D., Le Bourvellec, C., Markowski, J., Zbrzeźniak, M., Renard, C. M. G. C., & Płocharski, W. (2012). Comparison between microwave hydrodiffusion and pressing for plum juice extraction. *LWT-Food Science and Technology*, 49, 229–237.
- Chadha, R., Kumbhar, B. K., & Sarkar, B. C. (2003). Enzymatic hydrolysis of carrot for increased juice recovery. *Journal of Food Science and Technology*, 40, 35–39.
- Chevalier, D., Le Bail, A., & Ghoul, M. (2000). Freezing and ice crystals formed in cylindrical food model: part I. Freezing at atmospheric pressure. *Journal of Food Engineering*, 46, 277–285.
- Chung, H.-S., Kim, D.-S., Kim, H.-S., Lee, Y.-G., & Seong, J.-H. (2013). Effect of freezing pretreatment on the quality of juice extracted from *Prunus mume* fruit by osmosis with sucrose. *LWT-Food Science and Technology*, 54, 30–34.
- Cortés, C., Esteve, J. M., Frigoal, A., & Torregrosa, F. (2005). Changes in carotenoids including geometrical isomers and ascorbic acid content in orange-carrot juice during frozen storage. *European Food Research Technology*, 221(1–2), 125–131.
- Costa, M. G. M., Fonteles, T. V., Tibério de Jesus, A. L., Almeida, F. D. L., Alcântara de Miranda, M. R., Fernandes, F. A. N., & Rodrigues, S. (2013). High-intensity ultrasound processing of pineapple juice. *Food Bioprocess Technology*, 6, 997–1006.
- Demir, N., Acar, J., & Bahçeci, K. S. (2004). Effect of storage on quality of carrot juices produced with lactofermentation and acidification. *European Food Technology*, 208, 465–468.
- EN 1132:1994 Fruit and vegetable juices—determination of the pH-value
- EN 1134:1994 Fruit and vegetable juices—determination of sodium, potassium, calcium and magnesium content by atomic absorption spectrometry (AAS)
- EN 12136:1997 Fruit and vegetable juices—determination of total carotenoid content and individual carotenoid fractions
- EN 12630:1999 Fruit and vegetable juices—determination of glucose, fructose, sorbitol and sucrose contents—method using high performance liquid chromatography
- EN 14130:2003 Foodstuffs—determination of vitamin C by HPLC
- Gerard, K. A., & Roberts, J. S. (2004). Microwave heating of apple mash to improve juice yield and quality. *LWT-Food Science and Technology*, 37, 551–557.
- Giacomo, G. D., & Taglieri, L. (2009). A new high-yield process for the industrial production of carrot juice. *Food Bioprocess Technology*, 2, 441–446.
- Grimi, N., Praporscic, I., Lebovka, N., & Vorobiev, E. (2007). Selective extraction from carrot slices by pressing and washing enhanced by pulsed electric fields. *Separation and Purification Technology*, 58, 267–273.
- Ioannou, I., Hafsa, I., Hamdi, S., Charbonnel, C., & Ghoul, M. (2012). Review of the effects of food processing and formulation on flavonol and anthocyanin behavior. *Journal of Food Engineering*, 111, 208–217.
- Jabbar, S., Abid, M., BingHu, T. W., Hashim, M. M., Lei, S., Zhu, X., & Zeng, X. (2014). Quality of carrot juice as influenced by blanching and sonication treatments. *LWT-Food Science and Technology*, 55, 16–21.
- Klaiber, R. G., Baur, S., Koblo, A., & Carle, R. (2005). Influence of washing treatment and storage atmosphere on phenylalanine ammonia-lyase activity and phenolic acid content of minimally processed carrot sticks. *Journal of Agriculture and Food Chemistry*, 53, 1065–1072.
- Lebovka, N. I., Praporscic, I., & Vorobiev, E. (2003). Enhanced expression of juice from soft vegetable tissues by pulsed electric fields: consolidation stages analysis. *Journal of Food Engineering*, 59, 309–317.
- Liao, H., Sun, Y., Ni, Y., Liao, X., Hu, X., Wu, J., & Chen, F. (2007). The effect of enzymatic mash treatment, pressing, centrifugation, homogenization, deaeration, sterilization and storage on carrot juice. *Journal of Food Process Engineering*, 30(4), 421–435.
- Lima, M., & Sastry, S. (1999). The effects of ohmic heating frequency hot air drying rate and juice yield. *Journal of Food Engineering*, 41(2), 115–119.
- Ma, T., Tian, C., Luo, J., Zhou, R., Sun, X., & Maa, J. (2013). Influence of technical processing units on polyphenols and antioxidant capacity of carrot (*Daucus carrot L.*) juice. *Food Chemistry*, 141, 1637–1644.
- Marx, M., Stuparic, M., Schieber, A., & Carle, R. (2003). Effects of thermal processing on trans-cis-isomerization of β -carotene in carrot juices and carotene-containing preparations. *Food Chemistry*, 83, 609–617.
- Mieszczakowska-Frąć, M., Markowski, J., Zbrzeźniak, M., & Płocharski, W. (2012). Impact of enzyme on quality of blackcurrant and plum juices. *LWT-Food Science and Technology*, 49, 251–256.
- Mitchel, G. E., Isaacs, A. R., Williams, D. J., McLauchlan, R. L., & Nottingham, S. M. (1991). Low dose irradiation influence on yield and quality of fruit juice. *Journal of Food Science*, 56(6), 1628–1631.
- Mutlu, M., Sarioglu, K., Demir, N., Ercan, M. T., & Acar, J. (1999). The use of commercial pectinase in fruit juice industry. Part I:

- viscosimetric determination of enzyme activity. *Journal of Food Engineering*, 41, 147–150.
- Nadulski, R. (2010). Wpływ prędkości tłoka i stopnia rozdrobnienia surowca na wydajność i energochłonność tłoczenia miazg warzywnych (in Polish). *Zeszyty Problemowe Postępów Nauk Rolniczych*, 546, 237–243.
- Parnikov, A., Lebovka, N. I., Van Hecke, E., & Vorobiev, E. (2014). Pulsed electric field assisted pressure extraction and solvent extraction from mushroom (*Agaricus bisporus*). *Food Bioprocess Technology*, 7, 174–183.
- Patterson, M. F., McKay, A. M., Connolly, M., & Linton, M. (2012). The effect of high hydrostatic pressure on the microbiological quality and safety of carrot juice during refrigerated storage. *Food Microbiology*, 30, 205–212.
- Pearson, C. H., & Rath, D. J. (2009). A hydraulic press for extracting fluids from plant tissue samples. *Industrial Crops and Products*, 29, 634–637.
- Praporscic, I., Lebovka, N. I., Ghnimi, S., & Vorobiev, E. (2006). Ohmically heated, enhanced expression of juice from apple and potato tissues. *Biosystems Engineering*, 93(2), 199–204.
- Quitao-Teixeira, L. J., Odriozola-Serrano, I., Soliva-Fortuny, R., Mota-Ramos, A., & Martín-Belloso, O. (2009). Comparative study on antioxidant properties of carrot juice stabilized by high intensity pulsed electric field or heat treatments. *Journal of the Science of Food and Agriculture*, 89, 2636–2642.
- Rababah, T. M., Mahasneh, M. A., Kilani, I., Yang, W., Alhamad, M., Ereifej, K., & Datt, M. A. (2011). Effect of jam processing and storage on total phenolics, antioxidant activity and anthocyanins of different fruits. *Journal of the Science of Food and Agriculture*, 91, 1096–1102.
- Rosenthal, S., & Jansky, S. (2008). Effect of production site storage on antioxidant levels in specialty potato (*Solanum tuberosum* L.) tubers. *Journal of the Science of Food and Agriculture*, 88, 2087–2092.
- Sharma, H. K., Kaur, J., Sarkar, B. C., Singh, C., Singh, B., & Shitandi, A. A. (2006). Optimization of pretreatment conditions of carrots to maximize juice recovery by response surface methodology. *Journal of Engineering Science and Technology*, 1(2), 158–165.
- Sharma, K. D., Karki, S., Thakur, N. S., & Attri, S. (2012). Chemical composition, functional properties and processing of carrot—a review. *Journal of Food Science and Technology*, 49(1), 22–32.
- Simon, P. W., & Wolff, X. Y. (1987). Carotene in typical and dark orange carrots. *Journal of Agricultural Food Chemistry*, 35, 1017–1022.
- Singh, B., Panesar, P. S., & Nanda, V. (2006). Utilization of carrot pomace for the preparation of a value added product. *World Journal of Dairy & Food Sciences*, 1(1), 22–27.
- Stoll, T., Schweiggert, U., Schieber, A., & Carle, R. (2003). Application of hydrolyzed carrot pomace as a functional food ingredient to beverages. *Journal of Food, Agriculture and Environment*, 1, 88–92.
- Sun, D-W. (2011). *Handbook of frozen food processing and packaging* (2nd ed.). CRC Press. ISBN: 978-1-4398-3604-0.
- Sun, Y., Wang, Z., Wu, J., Chen, F., Liao, X., & Hu, X. (2006). Optimizing enzymatic maceration in pretreatment of carrot juice concentrate by response surface methodology. *International Journal of Food Science & Technology*, 41(9), 1082–1089.
- Van Buggenhout, T. S., Lille, M., Messagie, I., Van Loey, A., Autio, K., & Hendrickx, M. (2006). Impact of pretreatment and freezing conditions on microstructure of frozen carrots: quantification and relation to texture loss. *European Food Research and Technology*, 222, 543–553.
- Vandresen, S., Quadri, M. G. N., de Souza, J. A. R., & Hotza, D. (2009). Temperature effect on the rheological behavior of carrot juices. *Journal of Food Engineering*, 92, 269–274.
- Boekel Von, M. A. J. S., & Jongen, W. M. F. (1997). Product quality and food processing: how to quantify healthiness of a product. *Cancer Letters*, 114, 65–69.
- Vora, H. M., Kyle, W. S. A., & Small, D. M. (1999). Effect of enzyme treatment of carrot pulp on juice yield and quality. *Food Australia*, 51, 146–147.
- Wang, W.-C., & Sastry, S. K. (2002). Effects of moderate electrothermal treatments on juice yield from cellular tissue. *Innovative Food Science and Emerging Technologies*, 3, 371–377.
- Wootton-Beard, P. C., & Ryan, L. (2011). Improving public health?: the role of antioxidant-rich fruit and vegetable beverages. *Food Research International*, 44, 3135–3148.
- Wronowska, B. S., & Zadernowski, R. (2012). Skład chemiczny marchwi białej White Satin świeżej i mrożonej (in Polish). *Bromatologia i Chemia Toksykologiczna*, XLV(3), 364–369.
- Yen, Y. H., Shih, C. H., & Chang, C. H. (2007). Effect of adding ascorbic acid and glucose on the antioxidative properties during storage of dried carrot. *Food Chemistry*, 107, 265–272.