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Effect of ultrasound treatment on microstructure, colour and carotenoid content in fresh and dried carrot tissue

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ABSTRACT

The aim of the study was to investigate the influence of ultrasound treatment on the carrot tissue microstructure, colour and carotenoids content. To avoid adverse effects of rinsing out substances contained in the raw material, carrot slices were vacuum-packed and treated with ultrasounds in an ultrasonic bath using 21 and 35 kHz frequency for 10, 20 and 30 min. Images of the carrot tissue made by scanning electron microscope were analysed by calculating the cross-section area for each cell. The colour was measured using CIE $L^*a^*b^*$ method. To determine total carotenoid content spectrophotometric method was used. Obtained results indicate that the structural properties of carrots treated with ultrasound were significantly different from the samples without any treatment and it was clearly noticed during analysing images of scanning electron microscope. There was observed the influence of ultrasound treatment on colour L^*, a^* and b^* parameters, especially for carrot treated with ultrasound for 30 min, independent of the applied frequency of the ultrasonic waves. Similarly, sonic treatment resulted in substantial increase of carotenoid in comparison to raw carrot, especially in the case of 35 kHz frequency ultrasounds. Probably, such significant increase is caused by the destruction of the original structure and thus higher extraction ability of these compounds.

1. Introduction

Carrot is a root vegetable known and grown throughout the world. It is an important source of dietary fiber, carotenoids, vitamin K and magnesium, as well as many other important nutrients. Carrot root contains approximately 86–89% water, 0.7–0.9% protein, 0.2–0.5% fat, 6–10.6% carbohydrates, 1.2–3.6% dietary fiber and 1.2% ash [1–4]. After harvest, carrot quality is gradually lowered by reducing their sweetness, content of the carotenoids and also by forming a bitter taste and unpleasant smell due to oxidation processes. During storage, carrot also loses firmness, changes its colour and covers with a white coating. The result of these changes is lower acceptability of the product by the consumers. To reduce qualitative changes carrot should be stored at 0 °C and 93–98% humidity [5,6].

The relatively high content of the water in carrot root places this vegetable in the group of really perishable food products. Drying is one of the most common method of food preservation [7–9]. Water activity reduction inhibits microbiological and physicochemical changes. Dried carrot may be a component of many products, including instant soups, healthy snacks, stews, baby food, cakes, halva, curry spice desserts and many others. Products based on carrot powder are good source of protein, fiber, iron, calcium and β-carotene [10].

The most popular method of drying is convective one, which uses hot air to remove water from plant tissue [11]. However, the cost linked to high energy expenditures on foodstuff drying caused growing interest in new technologies, which can be applied to intensify drying process [12]. Ultrasound technology is one of the non-thermal techniques, which can be used to accelerate mass transfer processes [13–18].

Ultrasound is a form of energy generated by acoustic waves of frequencies higher than those, which can be heard by human ears, above 18 kHz and propagated in gases, liquid or solid medium. According to the range of frequency, ultrasound can be divided into two groups: low intensity with low energy and high frequency

Abbreviations: US, ultrasound pre-treatment; US 21_10, treated sample with ultrasound at frequency 21 kHz for 10 min; US 21_20, treated sample with ultrasound at frequency 21 kHz for 20 min; US 21_30, treated sample with ultrasound at frequency 21 kHz for 30 min; US 35_10, treated sample with ultrasound at frequency 35 kHz for 10 min; US 35_20, treated sample with ultrasound at frequency 35 kHz for 20 min; US 35_30, treated sample with ultrasound at frequency 35 kHz for 30 min.

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(higher than 100 kHz), and high intensity with high energy and low frequency between 20 and 100 kHz [19–23]. Low intensity ultrasound is used to control the quality of food as non-destructive method, analyse physicochemical properties of food and to monitor the changes during food production process. High intensity ultrasound is used for breaking cellular structures also in order to activate and inhibit chemical or physical alterations in food, what finally leads to the intensification of heat and mass transfer based processes. In the scientific literature there can be found a lot of examples of the use of high ultrasound power in such food processes as drying, osmotic dehydration, freezing, thawing, extraction, filtration, crystallization or emulsification [18,20,24–27].

The phenomenon of ultrasound is based on so called "sponge effect". Ultrasonic waves cause rapid compressions and expansions of the plant cells, what leads to the bubbles formation in both surrounding and sonicated sample. Thousands of fast-moving microbubbles generated during operation of ultrasounds violently collapse. These effects cause rapid and very short pressure and temperature changes in the point, what leads to changes of viscosity, surface tension, destroying cell walls, causes formation of the microscopic channels and free radicals as well as to the production of sonochemicals. The phenomenon of cavitation is responsible for a reduction of the diffusion boundary layer, what results in an increase of the water transfer from the foodstuff during drying and causes alterations in food properties [13,17–19,20,25,26,28]. The changes in food properties are dependent on the parameters used during pre-treatment process. However, the ultrasonic treatment can be regarded as an alternative to conventional blanching treatment [29,30].

The aim of the study was to analyse the effect of ultrasound treatment, carried out at different parameters, on the internal structure of fresh and dried carrot slices. The influence of ultrasound treatment on the colour and carotenoid content were analysed as well.

2. Materials and methods

2.1. Material

Carrot (var. *Nerac*) was selected as a material used in the investigation and it was acquired at the local market. Selection of the appropriate carrot was made taking into account sensory characteristics of the product as colour, size and cylindrical shape of roots.

Before each experiment defect-free roots of carrots were withdrawn from the storage compartment (4 °C), left to equilibrate room temperature and washed with tap water. Afterwards the material was peeled and cut into slices with a thickness of 5 mm. After cutting the slices were subjected to the ultrasound (US) treatment.

2.2. Ultrasound pre-treatment (US)

Ultrasound treatment (US) was performed using two different frequency of ultrasound and three time intervals: 10, 20 and 30 min at room temperature (25 °C). The experiment was conducted in a ultrasonic bath, providing frequencies of 21 kHz (MKD ULTRASONIC, MKD – 3 model, Warsaw, Poland) with calculated ultrasound intensity equalled to 3 W/cm^2 and 35 kHz (InterSonic, IS-3 model, Olsztyn, Poland) with ultrasound intensity equalled to 4 W/cm^2. The ultrasound intensity was calculated according to a following equation [26]:

$$P_i = \frac{P}{A} \tag{1}$$

where P_i – power intensity [W/m^2], P – power of sonotrodes distributed over surface area [W], A – area of sonotrodes [m^2]

An important point of the methodology is that ultrasound was applied to a packed in vacuum. The vacuum-packed sample was used to avoid adverse effects of rinsing out substances contained in the raw material. However vacuum-packaging might reduce the effect of cavitation over the sample and mostly the sponge effect will be the main physical phenomenon affecting the sample [26,31]. Therefore, it can be assumed that packaging will reduce the effect of cavitation over the sample, will refrain mass transfer (which is somewhat important in the pre-treatment) and, moreover, probably the sponge effect will be the main physical phenomena affecting the sample.

In order to prevent direct contact with a liquid medium, the 100 g carrot slices were hermetically packed in BOPA/PE 1540 FF foil, removing the 90% of the air out of the packages by using a vacuum packaging machine (TEPRO, Koszalin, Poland).

Material was weighed with accuracy of ±0.01 g and then it was immersed in 1 L of distilled water, which was used as a medium in both ultrasonic baths. Moreover, the temperature of the water surrounding the immersed sample was measured. To prevent flowing out samples from the bag, packages were locked up in metal net. After pre-treatment the material was weighed with an accuracy of ±0.01 g and the temperature of the medium was measured once again.

2.3. Energy consumption

During the ultrasonic treatment power consumption was measured by an energy consumption meter (Voltcraft Energy Logger 4000F).

2.4. Drying process

Drying was conducted using a laboratory convective dryer (Warsaw, Poland). Process was carried out at 70 °C and air velocity 2 m/s. The air flow was parallel to the net which the samples were placed on. The dryer was previously heated to the set-point temperature and then loaded with 0.2 kg (1 kg/m^2) carrot slices, which were spread on a one shelve in a single layer. Changes of the samples mass during drying were continuously recorded with a balance and by a program "Pomiar" (Radwag, Radom, Poland) with accuracy of ±0.1 g, until constant weight was reached. Drying experiments were carried out in a triplicate.

The effective water diffusion coefficient (D_{eff}) was calculated using TableCurve 2D v5.01 software on the basis of the simplified Fick's diffusion equation [32]:

$$MR = \frac{8}{\pi^2} \cdot \exp\left(\frac{-\pi^2 \cdot D_{eff} \cdot \tau}{4 \cdot L^2}\right) \tag{2}$$

where D_{eff} – diffusion coefficient [m^2/s], τ – drying time [min], L – half-thickness of the sample [m].

The content of dry matter of untreated, ultrasound treated and dried samples was measured according to the Polish Standard PN-90/A-75101/03 by drying at 105 °C to the constant weight [33].

Water activity in raw, pre-treated and dried carrot was examined using hygrometer Aqua Lab CX-2 (Dekagon Device Inc., USA) with the accuracy of ±0.001.

2.5. Microstructure analysis

The microstructure was examined using a scanning electron microscope (HITACHI, model TM-3000, Tokyo, Japan) with a digital image record.