LWT - Food Science and Technology 85 (2017) 427–433

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

The combined effect of ultrasound and enzymatic treatment on the nanostructure, carotenoid retention and sensory properties of ready-to-eat carrot chips

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A R T I C L E I N F O

Article history:
Received 30 June 2016
Received in revised form
29 November 2016
Accepted 30 November 2016
Available online 3 December 2016

Keywords:
Drying
Vegetable snacks
Quality
Sonication
AFM

A B S T R A C T

Fat-free crispy carrot snacks, could be an interesting proposal for consumers eager to increase their vegetable consumption, if the carotenoids naturally occurring in carrots could be retained during the drying processes used in their production. In an attempt to enhance carotenoid retention during the snacks production, ultrasound (US) and enzymatic treatment (EN) were applied as pre-treatment operations. Carrot slices were first sonicated for 20 min (25 kHz, 0.4 W/cm^2), and then soaked in a light sucrose solution (110 g/L) with or without pectin lyase enzyme (2 g/L), and finally were conventionally dried to a crispy state. Final product quality was assessed, paying attention to the carotenoid content, and changes in molecular pectin structure. Both the applied pre-treatments caused transformations of diluted alkali soluble pectin fraction in the form of shortening the skeleton length. Moreover, a decrease in the diameter of pectin polymers was noticed for samples treated with ultrasound, whereas enzyme action resulted opposite alteration. The US turned out to be a less effective factor in enhancing carotenoid retention of dried carrot chips than the EN; however, their simultaneous application not only had a positive effect on carotenoid retention, but also led to a higher sensory appreciation of the product colour.

1. Introduction

Ready-to-eat dried fruit and vegetable chips have roused the interest of food technologists for many years, as the conjunction of attractive sensory properties with a high concentration of phytonutrients in a dried tissue matrix, provided a unique opportunity to offer a product with functional properties in an appealing form (Vinson, Zubik, Bose, Samman, & Proch, 2005; Konopacka et al., 2010b; Dueik, Marzullo, & Bouchon, 2013). Among different vegetable species, carrots are considered to be one of the most promising raw materials to exploit in the production of crispy chips (Skrede et al., 1997; Sulaeman et al., 2001; Albertos et al., 2016). Due to their naturally high carotenoid and dietary fibre content, carrot snacks could be an interesting proposal for consumers eager to increase their vegetable consumption. Generally two kinds of technology can be used to transform carrot slices into crunchy snacks: frying in oil in a reduced pressure environment (Sulaeman et al., 2001; Albertos et al., 2016) and drying, either by means of a hot air drying method (Plocharski & Konopacka, 2002; Dueik et al., 2013) or a microwave-vacuum technique (Cui, Xu, & Sun, 2004; Lin, Durance, & Scaman, 1998 .).

In all the above cases the carrot slices are subjected to thermal processes, leading to a strong dehydration of the tissue matrix, which may cause major carotenoid degradation, mainly due to β-carotene isomerization and oxidation reactions that can substantially decrease biological activity in the final products (Hiranvarachat, Devahastin, & Chiewchan, 2011; Dueik et al., 2013). The current trend for a healthy diet, eliminating any fried salty snacks, induced the efforts of researchers towards developing and improving the technology of dried vegetable snack production (Konopacka et al., 2010b; Hiranvarachat et al., 2011). The hot air drying method, relatively cheap and widely available without excessive cost investments, easily leads to carrot quality

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http://dx.doi.org/10.1016/j.lwt.2016.11.085
0023-6438/

degradation, including colour, aroma, as well as flavour losses (Dueik et al., 2013). These alterations are not accepted by consumers, who are not willing to sacrifice the sensory attributes in their quest for a healthy diet (Sijtsema, Jesionkowska, Symoneaux, Konopacka, & Snoek, 2012), thus many technological proposals have been put forward, to enable the production of dried carrot chips with visually pleasing attributes, whilst retaining the required high carotenoid content (Cui et al., 2004). Among the different solutions, the most popular are blanching and different variants of osmotic treatment, all which lead to an enhancement of taste and an increase in texture crispness (Górnicki & Kaleta, 2007; Hiranvarachat et al., 2011; Konopacka et al., 2010b). One of the possible methods to enhance both the required aspects was described by Konopacka, Dyki, and Seroczyńska (2010a), where a short treatment of raw carrot in an enzyme preparation of pectolytic activity substantially diminished carotenoid losses, not only during hot air drying, but also during subsequent storage. The same research team suggested that an enzymatic pre-treatment with a preparation of pectin lyase activity can be recommended for other carotene-rich vegetables, and especially for winter squash (Konopacka et al., 2010b). Recent literature describing the possible positive effect of ultrasound energy on carotenoid retention during plant material drying, could also point to a new technological option for the production of dried carrot snacks with substantially improved bioactivity (Rawson, Tiwari, Tuohy, O'Donnell, & Brunton, 2011). It was proven that optimized ultrasound treatment of carrot slices (25 °C, 3–10 min, 20 kHz, 0.39–0.95 W/ml) could be used instead of traditional blanching (85 °C, 3 min) (Gamboa-Santos et al., 2013). By using the mentioned conditions, the authors were able to produce dried carrot of higher carotenoid retention (including falcarinol of anticancerogenic properties) than in the case of those subjected to regular blanching. Moreover, the ultrasound treatment did not influence the sensory profile of the final product.

Taking into consideration the above mentioned positive effect of ultrasound treatment on the bioactivity of carrot tissue, as well as recent literature reports promoting acoustic energy as a feasible method for accelerating fruit dehydration processes (Siucińska & Konopacka, 2014), an investigation was undertaken to assess the usefulness of ultrasound treatment (US) as a tool for enhancing the quality of dried carrot chips. It was decided that this method be compared with the effectiveness of enzymatic treatment (EN), previously described by Konopacka (2006). The effects of both pretreatment methods (US and EN), taking into account various aspects of the quality characteristics of dried carrot snacks, including nanostructure, carotenoid content, as well as sensory perception of colour attractiveness were considered. Special attention was given to the analysis of possible synergy within the compared technological operations.

2. Materials and methods

2.1. Raw material and processing

The carrot variety 'Belgrado' was obtained in March 2015 from the storage facility of a commercial farm dealing with vegetable production, located in central Poland. Up to the processing date (last week of April), the raw material was stored in experimental cold storage (1 °C, 95% RH). On the day of processing, the carrot roots were warmed up to room temperature, washed, peeled and cut into 2 mm slices. Prior to ultrasound treatment, freshly cut slices were immediately placed in polypropylene bags (15 × 20 cm), and after arranging them in a monolayer, vacuum packed. The bags with carrot slices were placed for 20 min into an ultrasonic water bath (model IS–50S; Intersonic S.C., Olsztyn, Poland) fitted with 25 kHz transducers (0.4 W/cm^2, 5-μm wave amplitude). To ensure homogenous interaction between US and the carrot tissue the bags were fitted to shaking platform (30 rpm). The bath container was filled with water to a depth of 5 cm, and a special cooling system controlled the process temperature at 25 ± 2 °C. When the sonication process was completed, the unpacked slices were subjected to further stages of production of fat-free carrot chips according to the method described by Konopacka (2006). First the slices were treated for 2 min with pectin lyase preparation diluted with water to 2 g/L (20 °C) (Rohapect PTE 100 (PF), AB Enzymes GmbH, Darmstadt, Germany). Then they were soaked in a light sucrose solution (110 g/L) mixed with 2.5 g/L of citric acid and 2.5 g/L of ascorbic acid. Finally the slices were subjected to hot air convective drying (85 °C, 120 min, 2.5 m/s), according to parameters which had previously proved to be effective in manufacturing ready-to-eat dietary vegetable chips (Plocharski & Konopacka, 2002). In Table 1 the list of experimental combinations tested is provided. Each sample was produced in two technological repetitions.

Prior to analyses the carrot chips were kept in jars in a dark room. The quality assessment consisted of chemical analyses (carotenoids and cell wall fractions quantification), cell wall structure analyses (cytological studies and atomic force microscopy), as well as a sensory assessment (profiling method).

2.2. Chemicals

For carotenoid determination, HPLC gradient grade chemicals were used (J.T. Baker Chemical Company, Gliwice, Poland). For all other analysis within the experiment the following chemicals of analytical grade were used: ethanol (≥96%, Avantor Performance Materials Poland S.A., Gliwice, Poland), acetone (≥99.5%, Avantor Performance Materials Poland S.A.), cyclohexane-trans-1,2-diamine tetra-acetate (CDTA) (Sigma-Aldrich, St. Louis, MO, USA), sodium carbonate (Sigma-Aldrich), sodium borohydride (Sigma-Aldrich), sulphuric acid (≥95%, Avantor Performance Materials Poland S.A.), di-sodium tetra borate (Sigma-Aldrich), 3-phenyl phenol (Sigma-Aldrich), mono-galacturonic acid (Sigma-Aldrich).

2.3. Carotenoid content

The method described by Bohoyo-Gil, Dominguez-Valhondo, García-Parra, and González-Gómez (2012) with minor modification was applied using a HPLC Agilent 1200 (Agilent, Waldbronn, Germany) system equipped with a DAD detector and Kinetex® C_{18} column (250 × 4.6 mm; 5 μm) (Phenomenex, Torrance, USA). The injection volume was 20 μL. The gradient mobile phase was a mix of three solvents; acetonitrile (A), ethyl acetate (B) and methanol

Table 1
The list of experimental treatments applied to raw carrot slices during snack production.

Combination code	Ultrasound treatment 25 kHz, 20 min	Enzymatic treatment Rohapect PTE, 2 g/L, 2 min	Soaking in sucrose solution 11 g/L, 2 min	Drying 85 °C, 120 min
US + EN + S	+	+	+	+
US + S	+		+	+
EN + S		+		+
Control (C)				+