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Effect of high-pressure induced ice I/ice III-transition on the texture and microstructure of fresh and pretreated carrots and strawberries

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Abstract

The effect of pressure treatments at −25 °C between 150 and 300 MPa, indicated as high-pressure induced crystallization (HPIC) processes if formation of ice III occurs during pressurization, on the texture and structure of frozen strawberries and carrots were studied. The formation of ice III, which has been proven to inactivate the microbial load of a frozen food, occurred when pressure was increased to 250 MPa or higher. Volume changes related to the formation of ice III affected the cell wall integrity of infused frozen strawberries and caused a 42–46% reduction of the fruit's hardness. These textural and structural changes were not affected by the pressure holding time (30 s versus 10 min), and thus by partial thawing during the pressure holding time, and were absent in frozen fruits treated at pressures lower than 250 MPa. The structure and texture of frozen carrots were respectively not and only slightly altered during high-pressure–low-temperature (HP–LT) treatments at all pressure levels studied. However, if carrots were blanched (30 min at 60 °C, 2 min at 90 °C and a combination of both) prior to freezing, structural damages during pretreatment and freezing made the tissue, in terms of both structural and textural quality, unsuitable for a post-freezing HP–LT treatment. These observations should be taken in mind when analyzing the possibilities of HPIC processes as a tool for post-freezing microbial reduction when applied to tissue based systems.

Keywords: High pressure-low temperature processes; Ice I/ice III transition; Texture; Microstructure; Carrots; Strawberries

1. Introduction

The primary food applications of pressure based on the phase diagram of water are the increased freezing and thawing rates obtained during high-pressure freezing and thawing processes (Knorr, Schlueter, & Heinz, 1998; LeBail, Chevalier, Mussa, & Ghoul, 2002). However, recently, the transient phase change of ice I to ice III during pressurization of frozen systems has also been envisaged as a potential food application. Such solid–solid phase transitions induced by pressure increase are termed high-pressure induced crystallization (HPIC) processes and represent a special case of high-pressure thawing (HPT) processes. Depending on the initial temperature conditions, the crystallization process can be pressure-assisted or pressure-induced (Urrutía Benet, Schluter, & Knorr, 2004).

Subjecting bacterial suspensions to ice I/ice III phase transitions by pressurizing frozen systems above 200 MPa appears to be an effective way to reduce bacterial contamination (Lusher, Balasa, Fröhling, Ananta, & Knorr, 2004; Shen, Urrutia Benet, Brul, & Knorr, 2005). Using this strategy, a treatment at 300 to 400 MPa and −45 °C of *Listeria innocua* in a phosphate-buffered saline solution resulted in an inactivation of about 3 log cycles (Lusher et al., 2004). To inactivate *Bacillus subtilis*, pressure treatments of 250 MPa and higher at −25 °C were most effective (Shen et al., 2005). In this case, a more than 4 log reduction in cell viability was observed. Authors of both studies

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suggested that the configuration change of the ice crystals during pressurization and depressurization was the key factor in mediating a large drop in cell viability at low temperature in combination with pressures higher than 250 MPa.

From the above, it is clear that ice I/ice III phase transitions could provide a unique tool for achieving a reduction in microbial load in the frozen state by applying short time treatment cycles at a rather low pressure level. This could be of large benefit for frozen food applications in which a thermal decontamination step (before freezing) is to be avoided due to quality impairments. However, possible food applications also depend on the effect that solid-solid phase transitions can have on structured matrices. Up to now, the effects of HPIC processes on the structural quality of foods has not been investigated yet. A related study of Schluter (2003) however showed that solid-solid phase transitions during high-pressure assisted freezing (HPAF) and HPT in the domain of ice III have an effect on the quality of potatoes. Moreover, it was clear that the effect depended on the pathway realized in the phase diagram (Schluter, 2003). In case samples were pressurized, cooled at elevated pressure, and phase transition of ice III to ice I was induced by pressure release (HPAF to ice III), thawed samples showed extensive drip loss and textural appearance was extremely soft and deformable. On the other hand, when samples were frozen conventionally, cooled to about −30 °C, pressurized to form ice III, and then thawed at elevated pressure (HPT), samples did not show significant macroscopic changes.

In contrast to the above high-pressure freezing and thawing processes, HPIC processes that seem to be effective for microbial reduction in frozen foods, are characterized by a solid–solid transition in two directions and freezing and thawing occurs at atmospheric pressure. In the present study, the applicability of such HPIC processes on fruits and vegetables in terms of textural and structural quality was evaluated. Two case studies, strawberries and carrots, were chosen. In case of carrots, blanching was considered as it is required for inactivation of food quality related enzymes and previous studies (Van Buggenhout, Messagie, Van der Plancken, & Hendrickx, 2006a) have shown that HPIC processes do not inactivate these enzymes.

2. Materials and methods

2.1. Raw material

Fresh Belgian strawberries (*Fragaria ananassa*, variety Elsanta) were purchased from a local grocer and stored at 2 °C for maximum 2 days. Strawberries were stemmed and cut into halves. Carrots (*Daucus carota L.*, variety Nanco) were bought from a local auction and stored at 4 °C for maximum five days. The cores of the carrots were cut using a sharp stainless-steel cork borer and chopped into small cylinders (10-mm height and 12-mm dia) using a sharp knife. For a single experiment, a single batch of raw materials (strawberries or carrots) was used, fresh and frozen (without further HP treatment) samples were used as reference and a maximal randomization of samples was established.

2.2. Pretreatment conditions

The strawberry pieces were immersed in a solution containing 100 U/mL Aspergillus aceleatus PME (Novoshape, Novozymes, Bagsvaerd, Denmark) and 0.5% (w/w) $CaCl_2 \cdot 2\,H_2O$ and vacuum (10 hPa) was applied for 5 min at room temperature (Duvetter et al., 2005).

Prior to freezing, carrots were blanched because previous results (Van Buggenhout et al., 2006a, 2006b, 2006c) revealed that high-pressure-low-temperature (HP–LT) treatments following a regular freezing process fail to inactivate most food quality related enzymes. A thermostated water bath (Julabo UC, Merck Belgolabo, Seelbach, Germany) was used to perform different blanching processes. In order to determine the blanching conditions, peroxidase activtity in carrots was measured as described earlier (Van Buggenhout, Messagie, Van Loey, & Hendrickx, 2005). The residual activity of peroxidase after blanching was calculated with respect to the enzyme activity of the fresh carrots. A 2-log reduction in peroxidase activity in carrot cylinders was achieved after 2 min blanching at 90 °C (high-temperature blanching). Low-temperature blanched carrots were soaked in $CaCl_2$ for 30 min and subsequently submitted to a thermal treatment of 30 min at 60 °C. The latter thermal conditions were selected because it has been shown that these conditions affect the pectin demethoxylation degree and contribute to the structural integrity of the plant cell walls (Van Buggenhout et al., 2006b; Van Buggenhout et al., 2006c). However, a treatment of 30 min at 60 °C reduced peroxidase activity only to 62 (±2)%. Therefore, low-temperature blanching conditions were also combined with high-temperature blanching in a two step blanching process.

2.3. Freezing conditions

Freezing conditions were selected based on previous findings indicating that texture loss of frozen, untreated carrots and of frozen, PME/Ca-infused strawberries was minimized for rapid freezing conditions (Van Buggenhout et al., 2006b) and for cryogenic freezing conditions (Van Buggenhout et al., 2006c), respectively.

Carrot cylinders were packed in double film bags and were kept in a pre-cooled cryostat bath at −35 °C (Heto CBN18–50, Heto-Holten, Denmark) for one night. Strawberries, packed in a double polyethylene bag, were placed in a ventilated pre-cooled freezing chamber at −80 °C (Nicool PC Plus, Air Liquide, Paris, France) until the temperature at the center of the strawberry samples reached −25 °C. Then, samples were transferred to cold storage at −25 °C (for one night).

The temperature in the samples was measured using needle-type thermocouples (SSA-12080-G700-TF, Ellab,