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Effects of high pressure processing on cocoyam, Peruvian carrot, and sweet potato: Changes in microstructure, physical characteristics, starch, and drying rate

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ABSTRACT

This study investigated the effect of high pressure processing (HPP) at 600 MPa for 5 and 30 min on cocoyam, Peruvian carrot, and sweet potatoes cylinders. The impact of the process was evaluated through syneresis analysis, water activity, polarized optical microscopy, thermal properties, texture profile, and drying rate. The results demonstrated that regardless of the process time, the HPP caused physical damage to the structure of the vegetables, providing greater syneresis (up to 12%), disruption of cell wall, reduction of the maximum force to cut the sample (up to 60%), and increased drying rate (~30%). Starch gelatinization ranged between 30% (in Peruvian carrot) and 70% (in sweet potato). Additionally, this process reduced the gelatinization temperature of the sweet potatoes starch. Therefore, the results suggest that HPP modifies the tubers structure, being an alternative for tubers softening and reduces the time required in its drying process.
Industrial Relevance: The results showed that HPP processing at 600 MPa for 5 or 30 min can be used as an interesting tool for pretreatment of dry tubers, increasing its drying rate and consequently reducing its process time. Additionally, the changes caused by the HPP process promote softening and pre-gelatinization of tubers starch, making them easier to be cooked by the final consumers.

1. Introduction

High pressure processing (HPP) is an emerging technology in food processing (Buzrul & Alpas, 2012; Lopes, Mesquita, Chiaradia, Fernandes, & Fernandes, 2010), and its market share has grown annually worldwide (Bermúdez-Aguirre & Barbosa-Cánovas, 2011; Buzrul & Alpas, 2012; Lopes et al., 2010; Rastogi, Raghavarao, Balasubramaniam, Niranjan, & Knorr, 2007). The gradual cost reduction process between 8 and 23 cents per kg of product produced in 2012 (Buzrul & Alpas, 2012) makes the technology increasingly accessible for processing of various foods.

One of the main appeals of this technology is that it can ensure safe levels of inactivation of pathogenic microorganisms, with lower physicochemical and sensory changes in food when compared with equivalent thermal processes (Rastogi et al., 2007; Oey, Lille, Loey, & Hendrickx, 2008; Bermúdez-Aguirre & Barbosa-Cánovas, 2011; Keenan, Rößle, Gormley, Butler, & Brunton, 2012). From a microbiological point of view, there is not a HPP process condition pre-established for food pasteurization, but FDA recommends the application of 580 MPa and a range of time (at least 3 min) for stabilization of acid food (natural or normal pH equal to 4.6 or below) or low acid food when the process is associated to refrigerated storage (Food & Drug Administration (FDA), 2010). Although several studies had shown that lower process conditions (up to 400 MPa) could be enough to guarantee pathogens inactivation, pressures around 600 MPa is recommended once different food matrix can have different protective effect on microorganisms (due to pH, nutrient content, viscosity for fluids, and other parameters). Therefore, the application of lower pressures does not represent a commercial alternative.

The maintenance of food characteristics after HPP process is based on two characteristics of the isostatic process: first, HPP is not able to break covalently bonded molecules, which is especially important to preserve nutritional (e.g., vitamins) and sensory attributes (colored compounds and aroma of various foods) (Keenan et al., 2012; Laboissière et al., 2007; Oey et al., 2008). This effect can be crucial for thermolabile foods (fluids and solids ones), mainly fruit and vegetable products (Laboissière et al., 2007; Patras, Brunton, Pieve, & Butler, 2009; Keenan et al., 2012; Lopes et al., 2010; Marszałek, Mitek, &

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Skąpska, 2015); second, HPP process follows the isostatic principle, i.e. no pressure gradient is observed (Buzrul & Alpas, 2012; De Roeck et al., 2009) which allows all regions to be equally and instantaneously pressurized, thereby reducing the process time due to the lack of latency time.

The effect of the HPP process on fresh vegetables and fruits structure has been investigated, especially in fruits, which are susceptible to softening of the tissues. This softening has been attributed to changes in cell wall structure and architecture of vegetable tissues, which makes the cells more permeable to salts and sugars, allowing high liquid release (Eshtiaghi & Knorr, 1993; Rastogi & Niranjan, 1998; Sopanangkul, Ledward, & Niranjan, 2002). This effect is dependent on pressure and cell structure of each vegetable (Oey et al., 2008). In general, pressures between 100 and 200 MPa are enough to promote physical changes on pear, apple, pineapple, orange, tomatoes, carrots, celery, and other vegetables (Oey et al., 2008). This effect highlights HPP as an interesting tool for nutrients diffusion in foods (Rastogi, Raghavarao, & Niranjan, 2005; Sopanangkul et al., 2002) and as a pre-drying treatment (Al-Khuseibi, Sablani, & Perera, 2005). Moreover, other authors have shown that HPP favored physical disruption of the cell wall structure of vegetables during pressurization, allowing contact between substrate and hydrolytic enzymes (as pectin methyl esterase, pectinesterase, polygalacturonase, and pectate lyase), which accelerates the enzymatic lysis of the structural wall of the vegetables tissues (Basak & Ramaswamy, 1998; Oey et al., 2008; Sila et al., 2008; Zhang et al., 2012).

Eshtiaghi and Knorr (1993) studied the effect of HPP on potato cubes and found that the process at 400 MPa / 20 ° C / 15 min provided loss of firmness similar to blanching in boiling water. Therefore, HPP is pointed as an interesting tool to soften vegetables, making it ready for consumption. On the other hand, another study under similar conditions found no changes in potatoes texture when compared with fresh samples (Al-Khuseibi et al., 2005), probably due to the formation of calcium bridges between pectins after demethoxilation. Furthermore, although some authors have reported that the HPP process is able to promote gelatinization of various starches in aqueous solution (Katopo, Song, & Jane, 2002; Pei-Ling, Qing, Qun, Xiao-Song, & Ji-Hong, 2012; Rastogi & Niranjan, 1998), there are no published studies on the effect of gelatinization on starchy vegetables.

The main studies on HPP using fresh vegetables have been performed in fruits, whose structure and composition are fundamentally different from tubers. Few studies evaluated the effects of HPP on fresh tubers, especially on starch gelatinization and modification of cell structure. To fill this gap, this study investigated the effect of HPP at 600 MPa (to evaluate the viability of a process to guarantee a safe commercial product) on the physical characteristics of cocoyam, Peruvian carrot, and sweet potato. From the results obtained, it will be possible to compare these tubers and determine the potential application of the HPP technology for softening the vegetables and as a pretreatment for dehydration. These tubers were chosen for this study once they are traditional on the Latin America market and no data have been published on this issue.

2. Materials and methods

2.1. Sample preparation

Sweet potato (*Ipomoea batatas*; 68.4 ± 3.0% moisture), Peruvian carrot (*Arracacia xanthorrhiza*; 77.2 ± 0.2% moisture), and cocoyam (*Colocasia esculenta* (L.) Schott; 74.4 ± 1.7% moisture) were purchased from a local market in Campinas, Brazil. The tubers were selected by shape uniformity and absence of injuries. Each tuber was washed, peeled, and cut into cylindrical form (15 mm in diameter and 15 mm in height; weight of 4.02 ± 0.12 g) and immediately, vacuum-packed in flexible bags (LDPE-Nylon-LDPE, 16 μm thickness—TecMaq, Brazil).

2.2. High pressure processing

High pressure processing was carried out using a high pressure equipment (QFP 2 L-700 Avure Technologies, OH, USA). The temperature of the chamber was measured by two type K thermocouples inserted into the chamber, one located in the top and other in the middle. The pressure was captured by a pressure transducer. The compression time to reach 600 MPa was around 137.7 ± 5.4 seconds and the decompression was practically instantaneous (2.3 ± 0.5 seconds). The temperature of the equipment chamber block was set at 25 °C. The initial temperature of water in the chamber was set at 8–10 °C and the rate of temperature increase in the adiabatic conditions was 3 °C/100 MPa (measured experimentally), reaching 27.4 ± 1.2 °C at the beginning and 25.6 ± 1.3 °C at the end of the process. The processing times were 5 and 30 min at 600 MPa and were selected considering a regular HPP process for pathogens inactivation (5 min), and a process with an extended time (30 min) to confer more expressive changes in tuber structure and starch (Li, Bai, Mousaa, Zhang, & Shen, 2012).

The control (unprocessed) sample was not subjected to pressure. Each tuber was processed in triplicate at each process condition.

2.3. Analysis

2.3.1. Syneresis and water activity

Syneresis was evaluated to assess the amount of water exuded from the sample subjected to the HPP process. For this, 4 tuber cylinders were weighed and subjected to HPP. Then, the samples were drained, superficially dried using a soft paper, and weighted again. The results were expressed as percentage of water exuded from each tuber, according to Eq. (1).

$$\text{Syneresis}\ (\%) = \left[\left(\text{weight}_{\text{initial}} - \text{weight}_{\text{after HPP process}}\right) / \text{weight}_{\text{initial}}\right] * 100 \quad (1)$$

Water activity (Aw) was determined using an Aqualab instrument (Aqualab Series 3TE, Decagon devices Inc., Pullman, WA, USA) at 25 °C (Selani et al., 2014). The analysis was performed for both the control and HPP processed samples. Both syneresis and water activity were determined in triplicate.

2.3.2. Light microscopy analysis

The morphology of tuber cells and birefringence of starch granules of the control and HPP processed samples were visualized using a light microscope (Carl Zeiss Jenaval, Carl Zeiss Micro Imaging GmbH, Germany) connected to a digital camera (EDN2 Microscopy Image Processing System). A thin slice of each sample was placed on a blade and a drop of distilled water was added above the tuber slice. The images were recorded at the magnification of 25× for all samples under common light and polarized light (Pei-Ling et al., 2012).

2.3.3. Differential scanning calorimetry—DSC

The samples (control and processed) were prepared according to the methodology described by Pei-Ling et al. (2012). The samples were weighed (2 μg) in aluminum DSC pans, and 8 μL distilled water was added. The DSC pans were hermetically sealed, and the samples were scanned using a DSC (TA Instruments, 060 WS, Thermal Analyzer, Shimadzu, Tokyo, Japan) from 35 to 95 °C at heating rate of 10 °C/min. The experiment was carried out on dynamic atmosphere using N_2 at the rate of 30 mL/min. An empty pan was used as reference. For each measurement, the overall gelatinization enthalpy (ΔH, expressed as joules per gram of dry sample) and the onset (T_{onset}), peak (T_{peak}), and end temperatures (T_{end}) were determined. T_{onset} is the temperature at which the tangential line from the lower temperature side of the peak intersects with the baseline; T_{peak} is the temperature at the top of the