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High humidity hot air impingement blanching (HHAIB) enhances drying rate and softens texture of apricot via cell wall pectin polysaccharides degradation and ultrastructure modification

Li-Zhen Deng[a], A.S. Mujumdar[b], Xu-Hai Yang[c], Jun Wang[a], Qian Zhang[c], Zhi-An Zheng[a], Zhen-Jiang Gao[a], Hong-Wei Xiao[a,*]

[a] College of Engineering, China Agricultural University, P.O. Box 194, 17 Qinghua Donglu, Beijing 100083, China
[b] Department of Bioresource Engineering, MacDonald College, McGill University, Ste. Anne de Bellevue, Quebec, Canada
[c] College of Mechanical and Electrical Engineering, Shihezi University, Shihezi 832001, China

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Sodium borohydride (PubChem CID: 23673181)
Sodium carbonate (PubChem CID: 10340)
Potassium acetate (PubChem CID: 517044)
Trans-1,2-Cyclohexylenedinitrotetraacetic acid hydrate (PubChem CID: 2723844)
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ABSTRACT

The effects of high humidity hot air impingement blanching (HHAIB) over a range of application times (30, 60, 90, and 120 s) on drying characteristics, hardness, cell wall pectin fractions contents and nanostructure, as well ultrastructure of apricot were investigated. Results showed that HHAIB reduced drying time and decreased the hardness of apricot by 20.7%–34.5% and 46.57%–71.89%, respectively. The water-soluble pectin (WSP) contents increased after blanching, while the contents of chelate-soluble pectin (CSP) and sodium-carbonate-soluble pectin (NSP) decreased significantly ($P < 0.05$). The hardness and drying time were found to correlate inversely with the WSP content, but positively with CSP and NSP contents. Atomic force microscopy (AFM) detection showed the decomposition and degradation of pectin fractions during blanching. Additionally, transmission electron microscopy (TEM) observation indicated that the cell wall structure was degraded and middle lamella integrity was destroyed by blanching.

1. Introduction

Apricot (*Prunus armeniaca* L.) is the third most widely grown stone fruit behind peach and plum (Ayour et al., 2016), with a world production of 3.45 million tons in 2014 (FAOSTAT, 2014). Apricot fruits are highly perishable, with a very short storage life under both ambient and refrigerated conditions, which limits commercialization of fresh fruits. Drying is the most frequently used processing method to extend the shelf-life of apricots (Xiao, Zhang, et al., 2010). However, serious enzymatic browning often takes place during the processing of apricots (Yemenicioğlu & Cemeroğlu, 2003). Thermal blanching has been commonly used prior to drying to prevent color deterioration by inactivating enzymes (Deng et al., 2017). However, improper blanching can cause undesirable loss of nutritious components, color and flavor of product (Xin, Zhang, Yang, & Adhikari, 2015). Hot water blanching is the most frequently used blanching method due to its simple equipment, low capital investment and easy operation. However, the soluble nutrient components in materials can dissolve or leach into water, causing a serious deterioration of food quality and generating large quantity of waste water (Deng et al., 2017). Steam blanching can minimize the loss of water-soluble nutrients as compared with water blanching, while, undesirable quality changes often resulted by a long

* Corresponding author.
E-mail address: xhwcaugxy@163.com (H.-W. Xiao).
URL: https://www.researchgate.net/profile/Hong_Wei_Xiao5 (H.-W. Xiao).

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heating time due to the lower heat transfer in steam blanching than hot water blanching, especially when the velocity of the steam is very low. High humidity hot air impingement blanching (HHAIB) is a recently developed thermal treatment technology, which combines the advantages of high humidity hot air blanching and impingement technology (Xiao, Bai, Sun, & Gao, 2014). During HHAIB pretreatment, high humidity hot air impinges on the product surface at high velocity to achieve a high rate of heat transfer, which generates higher transfer heat rate and energy efficiency than traditional superheated steam blanching (Bai, Sun, Xiao, Mujumdar, & Gao, 2013). Meanwhile, it can significantly reduce the loss of water-soluble nutrients during blanching as well (Xiao et al., 2014). HHAIB has been reported to rapidly inactivate polyphenol oxidase (PPO) or peroxidase (POD) enzymes, so as to prevent color and phytochemicals degradation of products during drying and storage (Bai et al., 2013; Wang et al., 2017, 2018).

As a thermal operation, HHAIB brings excessive physicochemical changes in apricots, e.g. loss of texture quality. Textural properties such as hardness are important factors determining consumer acceptability (Ella Missang, Maingonnat, Renard, & Audergon, 2012). The apricot appears to be particularly susceptible to softening problems during thermal processing (Chitarra, Labavitch, & Kader, 1989; Luh & Dastur, 1966). However, little information is available in the literature on texture deterioration of apricots under HHAIB pretreatment. Many investigations report that, the cell wall modification and the changes in the polymer within cell wall are the main causes of tissue softening (Luh & Dastur, 1966; Femenia, Sánchez, Simal, & Rosselló, 1998; Bordoloi, Kaur, & Singh, 2012). Pectin is the primary polysaccharide constituent of primary cell walls and middle lamellae, and it plays an important role in determining the strength, adhesion and porosity of the cell wall (Bordoloi et al., 2012). Several previous studies have demonstrated that thermal processing gives rise to modification of cell wall pectin polysaccharides, e.g. thermosolubilisation, β-elimination depolymerisation and de-esterification reaction, which weaken the adhesion and strength of the cell wall, and thus decrease the tissue firmness (Sila, Smout, Elliot, Loey, & Hendrickx, 2006; Sila et al., 2009; Ella Missang et al., 2012). Besides, pectin structure analysis has provided a new insight to elucidate the relationship between pectin modification and texture evolution during thermal processing (Round, Rigby, Macdougall, Ring, & Morris, 2001; Yang, An, Feng, Li, & Lai, 2005), pectin polysaccharides structure disassembly is largely responsible for tissue softening (Posé, Kirby, Mercado, Morris, & Quesada, 2012; Liu et al., 2017; Yang, Wu, Ng, & Wang, 2017). Despite the aforementioned studies, the relation of texture alteration of apricot to cell wall and pectin modification during HHAIB pretreatment is still not well understood.

Blanching is also used as a drying pretreatment to enhance moisture transfer in the tissue; HHAIB shows a profound effect on reducing the drying time of most agro-products (Bai et al., 2013; Wang et al., 2017). Nevertheless, the mechanism of mass transfer accelerated by blanching has not been examined in depth. As stated previously, profound cell structural alterations often take place in tissues after blanching, which influences the mass transfer as well (González-Fésler, Salvatori, Gómez, & Alzamora, 2008; Nieto, Castro, & Alzamora, 2001). Moisture migrates out of the cell preferentially through the cell wall pathway; the increase of the effective moisture diffusivity is partially attributed to decrease of the resistance of cell wall to water flux (Nieto et al., 2001). González-Fésler et al. (2008) found that a significant damage to cell walls occurs in blanched apple, which exhibited a higher drying rate than that of the unblanched one. It indicated that, cell wall structure degradation may reduce the resistance to moisture movement and thus enhance the drying rate. In addition, cell wall can be disassembled by solubilisation and depolymerization of pectins, especially for ionic and covalently bound pectins changes (Sila et al., 2009; Posé et al., 2012). Therefore, evaluation of the role of cell wall structure and pectin polysaccharides characteristics in thermal blanching processing is important for revealing the mechanism of drying behavior and texture changes induced by blanching.

Microscopic analysis techniques, such as atomic force microscopy (AFM) and transmission electron microscopy (TEM) have been used to study the polysaccharide morphology at the molecular level (Liu et al., 2017, Chong, Lai, & Yang, 2015), and cell wall ultrastructure characteristics of foods, respectively (Bordoloi et al., 2012). In the present work, AFM was applied to visualize and characterize the pectic fractions from apricots cell wall samples, TEM was used to visualize the structure of the cell wall of apricots. The primary objectives of this study were to determine (i) the effect of HHAIB on texture and drying characteristics on apricots, (ii) the impact of pectin polysaccharides modification on cell wall structure, and (iii) the role of pectin polysaccharides on texture and drying characteristics of apricots.

2. Materials and methods

2.1. Materials

Fresh apricots (*Prunus armeniaca* L. cv. Shanhuang) were purchased from local markets (Beijing, China), and stored in a 4 °C refrigerator before use (up to 5 days). Defect-free fruits of similar weight of (32.5 ± 2.5) g and fully-ripened (the fruit skin with almost yellow color) were selected. Prior to the experiments, the samples were washed using tap water, blown with ambient air to remove the excess water on the surface. The samples were then cut into halves and de-pitted. The average initial moisture content of the fruits flesh was 87.53% on wet basis (w.b.), as determined by vacuum drying at 70 °C for 24 h (AOAC, 1990).

2.2. HHAIB pretreatment of apricot samples

The HHAIB equipment installed in the College of Engineering of China Agricultural University, Beijing, China, has been previously described by Wang et al. (2017). A schematic diagram of the HHAIB equipment is shown in Fig. S1. This apparatus consists of an electric heater to heat the drying air, a centrifugal fan, nozzles, and a steam generator to supply steam, a Proportional-Integral-Derivative (PID) controller (Omron, model E5CN, Tokyo, Japan) to control the blanching temperature. The steam generator was turned on for HHAIB pretreatment, and turned off for the impingement drying experiments.

The HHAIB pretreatment of apricots was conducted at a fixed air velocity of (14.0 ± 0.5) m/s, temperature of 110 °C, and hot air relative humidity of 35%–40%, following the results of Wang et al. (2017) and Bai et al. (2013). The apricot halves were spread on stainless steel wire grid in a single layer. After equipment reached steady-state at set points, the trays of apricot samples were inserted in the blanching chamber, and blanched for various durations with intervals of 30 s, until 120 s to completely inactivate the PPO and POD (Xiao, Zhang, et al., 2010). The unblanched samples were taken as the control group.

2.3. Hot air impingement drying

The samples with or without blanching were dried by an air impingement drying equipment, as described by Xiao, Pang, et al. (2010). For all the drying experiments, the air velocity and temperatures were kept constant at 12 m/s and 65 °C, respectively. After the dryer reached steady state conditions, the samples about 750 g were spread in a single layer on the stainless steel wire grid in the drying chamber. Weight loss of sample was measured by removing the tray from the drying chamber and weighing it on an electronic balance (SP402, Ohaus Co., New Jersey, USA). Drying was continued until the product reached the desired final moisture content of 15% (w.b.) (Xiao, Zhang, et al., 2010). All the experiments were performed in triplicate.