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High-pressure-assisted infusion of bioactive compounds in apple slices

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ABSTRACT

High-pressure treatment was explored as a technique for infusion of bioactive compounds (anthocyanin) into solid foods matrix (apple). The rate of mass transfer of moisture, solid, and anthocyanin content with or without the application of high pressure was studied over a wide range of concentration of osmotic solution (0–50% sucrose). The increase in concentration of osmotic solution resulted in reduced infusion of anthocyanin. However, high-pressure treatment resulted in higher moisture and solid mass transfer due to cell permeabilization (as revealed by microstructure analysis). It was revealed that high-pressure treatment resulted in higher infusion of the bioactive compound as compared to infusion at atmospheric pressure. The present study concluded that the high-pressure treatment of solid foods could be a feasible technology for infusion of bioactive compounds without significantly altering its matrix. This work elucidates important aspects of the science of pressure-enhanced infusion.

Industrial relevance: Application of high pressure was shown to be a feasible technique to enhance the infusion of bioactive compound (e.g., anthocyanin) in solid food matrix (apple) without significantly altering its natural solid food matrix. The application of high pressure may open up newer avenues for food industries to develop fresh-like and value-added products with improved nutrition.

1. Introduction

Fruits and vegetables are important dietary components, and consumers today are demanding more minimally processed products that retain the organoleptic characteristics of fresh produce (Garcia & Barrett, 2002). Increased consumer interest in the health benefit of foods has led to significant development of nutraceutical and functional foods (Zhao & Xie, 2004). These compounds can be beneficial antioxidants, natural colorants (e.g., anthocyanin, lycopene, cartenoids), minerals, probiotic bacteria, or vitamins, which are several examples of bioactive compounds that provide added health benefits (Santacruz-Vazquez et al., 2008; Prado, Parada, Pandey, & Saccol, 2008; Shah, 2007; Rico, Martin-Diana, Frias, & Barat, 2007; Anino, Salvatori, & Alzamora, 2006; Lin, Leonard, Lederer, Traber, & Zhao, 2006). For example, a colorant besides being functional health ingredient also enhances marketability, improves sensory attributes, and influences consumer behavior of the product.

Employing osmotic treatment for impregnation of physiologically active compounds such as minerals (Barrera, Betoret, & Fito, 2004; Gras, Vidal, Betoret, Chiralt, & Fito, 2003), phenolic compounds (Rozek, Achaerandio, Guell, Lopez, & Ferrando, 2009; Rozek, Archaerandio, Guell, Lopez, & Ferrando, 2010a, b), curcuminoids (Bellary, Sowbhagya, & Rastogi, 2011; Bellary & Rastogi 2012), anthicyanin (Bellary, Indiramma, Prakash, Baskar, & Rastogi 2015; Adsare, Bellary, Sowbhagya, Baskaran, Prakash, & Rastogi, 2015), probiotics (Alzamora et al., 2005) and vitamins (Hironaka et al., 2011) into solid food tissue was demonstrated by many researchers. Several mechanisms such as osmosis, diffusion, and hydrodynamic mechanisms take part in the mass transfer phenomena (Rastogi, Angersbach, & Knorr, 2000; Rastogi, Raghavarao, Niranjan, & Knorr, 2002).

A number of techniques have been proposed to enhance the inherently low rate of osmotically induced mass transfer that include partial vacuum (Fito et al., 2001; Rastogi & Raghavarao, 1996), high pressure (Rastogi, Nguyen, Jiang, & Balasubramaniam, 2010) or ultrasound (Rastogi et al., 2000; Rastogi, 2011). Pretreatments such as freezing, high-pressure, high-intensity electric field pulses have been reported to enhance mass transfers during osmotic treatments (Ade-Omowaye, Angersbach, Eshtiaghi, & Knorr, 2000; Amami, Vorobiev, & Kechaou, 2006; Mayor, Moreira, & Chenlo, 2006; Tedjo, Taiwo, Eshtiaghi, & Knorr, 2002). Several studies were also carried out on infusion of bioactive compounds (antioxidants, polyphenols, phospholipids, dietary fiber) using conventional and non-conventional methods like osmotic dehydration, vacuum impregnation, pulse electric field, and ultrasonication. Mahadevan, Salvi, and Karwe (2015) demonstrated a comparative study on the high-pressure enhanced infusion of quercetin in fresh and

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frozen–thawed cranberries. Phoon, Galindo, Vicente, and Dejmeka (2008) demonstrated that a disaccharide trehalose can be impregnated in the spinach leaves using pulsed electric field in combination with vacuum application, thus improving the freezing tolerance of spinach leaves. Jacob and Paliyath (2012) have studied osmotic infusion of soy lecithin and Nutraflora® in fruits such as mango, sweet cherry, and blueberry, resulting in improved quality characteristics. Bellary and Rastogi (2014) demonstrated that extent of infusion can be significantly enhanced by application of combined treatment such as vacuum and ultrasound in case of curcuminoids infusion in raw banana.

The application of high hydrostatic pressure to fruits and vegetables affects cell structure, making the cell more permeable, which in turn can be beneficially used to enhance the uptake of biologically active substances from the surrounding solution (Rastogi et al., 2000). The application of high pressure has been reported to accelerate the diffusion of components into the food (Farr, 1990; Rastogi & Niranjan, 1998). Pressure causes structural transformations in the food, which may alter the diffusion coefficients. The application of high-pressure treatment resulted in increased diffusion during osmotic treatment of pineapples (Rastogi & Niranjan, 1998), potato (Sopanangkul, Ledward, & Niranjan, 2002), glutinous rice (Ahromrit, Ledward, & Niranjan, 2006) and Turkey breast (Villacis, Rastogi, & Balasubramaniam, 2008). Sila, Smout, Vu, and Hendrickx (2004) indicated that the high-pressure treatment of carrots combined with $CaCl_2$ infusion improved texture during thermal processing. Duvetter et al. (2005) and Fraeye et al. (2010) demonstrated that the pressure-assisted infusion of PME and calcium chloride in strawberry was capable of improving the firmness of the strawberries. Rastogi, Nguyen, and Balasubramaniam (2008) and Rastogi et al. (2010) demonstrated that calcium infusion with mild heating and application of high pressure can be used as method for the improvement in the texture of carrot during thermal as well as pressure-assisted thermal processing.

Mahadevan, Nitin, Salvi, and Karwe (2014) have studied the enhanced infusion of natural antioxidant (quercetin) into frozen–thawed cranberries using high hydrostatic pressure processing. The amount that could be infused in 10 min under high pressure needed at least 3 h under atmospheric condition (control), while the amount of quercetin infused into high-pressure processed cranberries was demonstrated to be three times as compared to the control.

The use of natural food colorant (anthocyanin) during impregnation is expected to have dual value by providing exotic color to the food and enhancing its nutritional status, besides being more appealing. During osmotic treatment, the biologically active compounds are diffused along with the solute present in the osmotic solution to the food by a process of diffusion in which naturally occurring cell membrane structure functions as a semi-permeable membrane. The sample immersed in water (0%) containing bioactive compounds results in diffusion of water into the sample due to the higher osmotic pressure inside the cells in comparison to the surrounding medium. Further increase in the concentration of surrounding osmotic solution results in the decrease in the rate and extent of mass transfer as compared to the situation when water (0%) was used as a surrounding solution due to increase in the osmotic pressure because of increase in concentration of sugar solution, which further reduced the concentration gradient (Bellary et al., 2011).

Since osmotic treatment is a relatively slow process, high-pressure treatment could enhance mass transfer rates due to increase in the permeability of the cell structure (Farr, 1990; Dornenburg & Knorr, 1993; Rastogi et al., 2000; Eshtiaghi et al., 1994). The intercellular spaces present in the natural food matrix decide the extent of infusion of biologically active compounds (Rastogi & Niranjan, 1998). Several mechanisms such as osmosis, diffusion, and hydrodynamic mechanisms take part in the mass transfer phenomena (Rastogi et al., 2000, 2002). Encouraged with this idea of obtaining foods with exotic color and enhanced nutrition, it was thought that the infusion of anthocyanin would enhance the nutritive value of the apple fruit. The application of high pressure leads to rupture of cell membranes resulting in decrease in the resistance to infusion, which in turn would result in higher infusion at high pressure as compared to infusion done at atmospheric pressure. The recommended daily intake of anthocyanin is 25 mg/person to 215 mg/person depending upon gender and age (Delgado-Vargas, Jimenez, & Paredes-Lopez, 2000).

The kokum contains two major types of anthocyanins, namely, cyanidin-3-glucoside and cyanidin-3-sambubioside, and is reported to occur in the ratio of 4:1 (Nayak, Srinivas, & Rastogi, 2010). Besides, it also contains two major active compounds having nutraceutical properties such as garcinol and hydroxycitric acid (Krishnamurthy et al., 1982). Anthocyanins have been shown to possess strong antioxidant, anti-bacterial, anti-carcinogenic and anti-inflammatory activity, anticancer, anti-ulcerogenic, and anti-obesity effect; are cardioprotective; prevent ascorbic acid oxidation; and scavenge free radicals. They have also shown inhibitory effects against oxidative enzymes (Bridle & Timberlake, 1997; Baliga et al., 2011, Mishra et al., 2006).

The objectives of the present work were (a) to develop apple slices infused with anthocyanin from kokum and (b) to investigate the impact of high pressure on the infusion of bioactive compound in solid food matrix.

2. Materials and methods

2.1. Materials

Fuji apples and dehydrated *Garcinia indica* Choisy fruits (popularly known as kokum) were procured from a local supermarket and stored at 4.0 ± 0.5 °C until further use. The anthocyanin was extracted in aqueous solution at ambient conditions as per the procedure provided by Nayak et al. (2010). The dried kokum was grinded with acidified water HCl (0.1%), filtered using a muslin cloth and centrifuged at 10,000 rpm for 10 min. This syrup was used as a source of anthocyanin. The apples were washed, wiped with tissue paper, peeled off, cored, and then sliced uniformly into circular shapes (8 mm diameter and 3 mm thickness). The average moisture content was determined to be 85% on a wet weight basis, by vacuum drying at 60 °C (AOAC, 1998, Procedure number 934.06).

2.2. High-pressure treatment

The apple slices (8 mm diameter and 3 mm thickness) were subjected to high hydrostatic pressure in a cylindrical pressure vessel (Model 7690, Khoday Hydraulics Ltd., Mumbai). The unit had a working volume of 1 L and a maximum recommended working pressure of up to 400 MPa (58,015 lb square inch). The maximum pressure was reached within 10 min, and the decompression time was about 10 s. The samples were suspended in impregnating solution in the ratio of 1:3 in low-density polyethylene (LDPE) pouches. After the exclusion of air, the pouches were heat sealed and the samples were then subjected to a pressure of 50 MPa, 150 MPa, 250 MPa, and 350 MPa for 10 min. The processing conditions were selected based on our earlier work (Rastogi & Niranjan, 1998; Rastogi et al., 2000), which showed that high pressure beyond a certain value (~300 MPa) led to significant changes in the tissue structure.

The maximum temperature experienced by the sample during pressurization was 35 °C and cooling to about 15 °C during decompression. Distilled water was used as the medium for transmitting pressure.

2.3. Impregnation treatments

The infusion medium was made using commercial sucrose (table sugar, 98% minimum purity) and kokum syrup. The concentration of sucrose varied from 0% to 50%. The kokum syrup was prepared by aqueous solvent extraction method (Nayak et al., 2010). The ratio of fruit to infusion medium was 1:3. The samples were withdrawn at regular intervals, rinsed quickly, and blotted gently with tissue paper and then weighed.

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