Journal of Food Engineering 122 (2014) 84–91

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Kinetics of carrot texture degradation under pasteurization conditions

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ARTICLE INFO

Article history:
Received 11 April 2013
Received in revised form 12 July 2013
Accepted 2 September 2013
Available online 8 September 2013

Keywords:
Carrot texture
Preheating
Isotonic concentration
Calcium
Microbial curve

ABSTRACT

Texture degradation of carrot dices in different solutions (distilled water, 0.1% and 1.4% $CaCl_2$ solutions) under temperatures ranging from 80 to 110 °C was investigated. The effects of preheating (60 °C for 20 min) before high temperature treatment on carrot texture were studied and kinetic parameters were estimated. Preheating enhanced the texture of the final products, and the improvement in texture became more apparent when $CaCl_2$ was added. High temperature increased the texture degradation rate. The isotonic solution of carrot tissue was evaluated to avoid possible ion leakage of carrot tissue during heating, but no significant differences were found between the texture of carrots immersed in isotonic solution and distilled water after thermal treatments. The texture degradation of preheated carrot dices under the investigated pasteurization conditions follows a 2nd order reaction. Kinetic results obtained were used to recommend processing conditions for carrot products that could control food pathogens and inactivate enzymes.

1. Introduction

Carrots are one of the most commonly consumed vegetables in the United States, with one-fourth of all carrots consumed in processed form, largely canned and frozen (Lucier and Lin, 2007). In processed vegetables, texture is a primary marketable characteristic for the customer. The texture of processed products is mainly controlled by the chemical composition, physical structure and amount of cell wall and middle lamella (Bourne, 1989). The various mechanisms of texture loss during heating of vegetables include breakdown of cellular membranes, and cell wall degradation and disassembly resulting from enzymatic and non-enzymatic transformations in pectin structure and composition (Anthon et al., 2005; Greve et al., 1994a,b; Sila et al., 2008). Pectinmethylesterase (PME) and polygalacturonase (PG) are the two principle enzymes related to the enzymatic degradation of cell wall pectin. PME catalyzes the de-esterification of pectins, creating binding sites for divalent cations (primarily Ca^{2+}, naturally present in the tissue or added during processing) on the polygalacturonic acid backbone of the pectin to form cross-links between pectin chains which improves the texture. Pectin may undergo non-enzymatic degradation through β-elimination, a chemical reaction that takes place at higher pH levels (>4.5) and at temperatures higher than 80 °C (Keijbets and Pilnik, 1974; Sila et al., 2008).

Texture degradation of carrots during thermal processing has previously been investigated in several studies. Huang and Bourne (1983) and Bourne (1989) observed a rapid initial softening followed by a much slower rate of softening during the retort process of diced carrots. The authors proposed that carrot texture degradation consisted of two simultaneous first order reactions at different reaction rates during the thermal softening process. Rizvi and Tong (1997) re-determined the kinetic parameters using the fractional conversion technique based on the published data supporting two substrate mechanisms of tissue softening. They suggested fractional conversion as an alternate technique which was more accurate and reliable to describe the overall trends for texture degradation of vegetables. Vu et al. (2004) investigated the kinetic degradation of sliced carrots in distilled and demineralized water in a temperature range from 80 to 110 °C, and estimated the kinetic parameters using a fractional conversion model. Later, Smout et al. (2005) studied the thermal texture degradation of carrot cylinders in a 0.5% $CaCl_2$ solution using different preheating conditions followed by treatments at two heating temperatures (90 and 100 °C) and also applied a fractional conversion model. In the current study, the concepts of "equilibrium texture" and the fraction of texture changes were used to evaluate the kinetic data of texture degradation of diced carrots. Kinetic models with different reaction order were evaluated and the best-fit one was selected to estimate the related kinetic parameters.

When heating cut vegetables in aqueous solutions, differences in osmotic pressures within and outside the cells may result in ion leakage of the higher salt concentration within the cell leading

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0260-8774/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jfoodeng.2013.09.004

to loss of cell integrity, which may influence mechanical properties (e.g. texture) (De EscaladaPla et al., 2006; Gonzalez et al., 2010). Thus, an isotonic solution may be helpful in reducing the additional stress that a hypotonic bathing solution places on the already perturbed vegetable membranes. Gonzalez et al. (2010) found that isotonic solutions help maintain membrane integrity in fresh onion tissues, and reported that the onion cell membranes ruptured between 50 and 60 °C. However, no published literature reported the rupture temperature of carrot cell membranes, nor the impact of osmotic solutions on carrot texture. In the current study, the isotonic concentration of carrot tissue was determined and the effects of immersing carrot slices in the isotonic solution on the texture of the tissue at elevated temperatures were studied.

It is known that blanching vegetables at low-temperatures (generally 50–70 °C) prior to high-temperature processing may improve the texture of the final products (Anthon and Barrett, 2006; Bartolome and Hoff, 1972; Vu et al., 2004; Wu and Chang, 1990). Preheating at these conditions activates pectin methylesterase (PME), resulting in extensive pectin de-esterification. This increases the chances for formation of ionically cross-linked pectin complexes and reduces the β-elimination reaction. Vu et al. (2004) reported that preheating carrots in distilled and demineralized water at 50–70 °C for 20–40 min prior to high temperature heating could slow texture degradation, increase the final value of hardness and lower the activation energy of texture degradation. In the current study, one preheating condition (60 °C for 20 min) was selected. According to published literature, preheating carrots at 60 °C for 20 min prior to high heat treatment should enhance the vegetable texture (Stanley et al., 1995; Vu et al., 2004). The preheating step also mimics the microwave processing in our further study for pre-packaged carrot dices, where we always preheat the samples to a certain temperature before microwave heating (Tang et al., 2008). Since calcium salt is a commonly used firming agent, the effects of calcium on carrot texture were also investigated in this study. The calcium solution concentration used was chosen based on the FDA regulation for canned carrot products (0.036% Ca in the final products), which is far lower than that used in the published literature (Rastogi et al., 2008; Smout et al., 2005).

In addition to investigating the kinetics of texture degradation of carrot dices in solutions with different calcium levels, the goal of microbial/enzyme inactivation vs. texture retention of carrots during thermal processing predicted by the degradation models was also discussed. This study provides useful information for determining thermal processing parameters for pre-packaged diced carrots, and for predicting quality changes related to texture during processing.

2. Materials and methods

2.1. Sample preparation

Fresh carrots (Bolthouse Farms, Inc., Bakersfield, CA) purchased from a local grocery store were diced into 12.7 × 12.7 × 6 mm pieces. In order to prepare consistent samples, carrots with similar length and diameter were selected (the portion between 4 and 6 cm from the root tip and 4 and 8 cm from the stem), only those dices that contained a core (xylem) size of 4–7 mm diameter and 6 mm height were used in the study. A specially designed cylindrical aluminum test cell with a net inner space of 50 mm in diameter and 8 mm in depth was used to hold meaningful sample sizes for texture analyses while minimizing the come-up time during heating. Eight carrot dices (6.5 ± 0.2 g) were placed in the test cell, then 6 mL solution was added and the test cell was sealed. An o-ring fitting placed in the groove between the base and lid was used to provide a hermetic seal.

2.2. Determination of isotonic concentration of carrot tissue

The concentration of isotonic solution was determined according to the method of Saltveit (2002). Briefly, fresh cut carrot dices were rinsed twice in distilled water for about 1 min each time, blotted dry, and 20 randomly selected pieces were transferred to each tared Petri-dish. The Petri-dishes were placed into a plastic tub lined with wet paper towels and held overnight (ca. 18 h) at room temperature. Twenty-five mL of mannitol solution (0–0.4 M) was added to each dish and shaken at 60 cycles/min for a time period of either 20, 60, 120 or 240 min, and then the solutions were vacuum aspirated off. The weight gain or loss by the carrot pieces bathed in the mannitol solutions was recorded. The concentration of mannitol where there was no net weight gain or loss of the carrot pieces after the initial weight gain was taken to be the isotonic concentration of the carrot tissue. Experiments were done in triplicates.

2.3. Thermal treatment

Carrot dices immersed in different solutions in each test cell were heated in a thermostated oil bath (Model HAAKE DC 30, Thermo Electron Corp., Waltham, MA, USA) at 80, 90, 100 and 110 °C for different time intervals. The temperatures were selected based on the heat-sensitivity of carrot texture and pasteurization conditions. Four solutions were investigated in this study:

(1) Double distilled water.
(2) Isotonic mannitol solution.
(3) 0.1% $CaCl_2$ solution (equivalent to containing 0.035% calcium).
(4) 1.4% $CaCl_2$ solution (equivalent to containing 0.5% calcium).

For the two calcium levels, the former was chosen according to the FDA regulation which allows addition of "up to 0.036% calcium to canned carrots" while the latter was within the range of the most commonly used calcium concentrations (0.5–2.0% $CaCl_2$) added to vegetable products in published reports (Rastogi et al., 2008; Smout et al., 2005). Since the diffusion of calcium into carrot tissues before heating may affect their texture, the time that was sufficient for sample preparation which resulted in little texture change was pre-determined as the equilibration time to keep the consistency of the initial carrot texture. According to our preliminary tests, all samples in the test cells were equilibrated in solutions for 10 min before heating.

To evaluate the effects of preheating on carrot texture, test cells containing carrot dices with different solutions were preheated in a thermostated water bath (Model HAAKE DC 30, Thermo Electron Corp., Waltham, MA, USA) at 60 °C for 20 min, then immediately transferred to an oil bath (Model HAAKE DL 30, Thermo Electron Corp., Waltham, MA, USA) and followed by a high heat treatment with preset temperatures ranging from 80 to 110 °C. After heating, samples were cooled in ice water for 2 min, drained, equilibrated to room temperature and texture analysis was conducted. Unless otherwise stated, the zero-time samples were the samples at the end of the come-up time for the high heat.

2.4. Texture measurement

The firmness of treated carrot dices was determined using a TA.XT2 Texture analyzer (Stable Micro Systems Ltd., Godalming, UK) fitted with a 25 mm diameter aluminum cylinder probe following the methods described by Lemmens et al. (2009). The samples were compressed to 70% strain at a cross head speed of 1 mm/s. For each test, one piece of sample was placed under the probe. The peak force of the first compression cycle of the sample was marked