Journal of Food Engineering 126 (2014) 27–34

Contents lists available at ScienceDirect

Journal of Food Engineering

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

A comparison of dynamic mechanical properties of processing-tomato peel as affected by hot lye and infrared radiation heating for peeling

Yong Wang [a,b,1], Xuan Li [a,1], Gang Sun [c], Dong Li [d], Zhongli Pan [a,e,*]

[a] Department of Biological and Agricultural Engineering, University of California at Davis, Davis, CA 95616, USA
[b] COFCO Nutrition & Health Research Institute, COFCO, Beijing 100020, China
[c] Division of Textiles and Clothing, University of California at Davis, Davis, CA 95616, USA
[d] College of Engineering, China Agricultural University, Beijing 100083, China
[e] Western Regional Research Center (WRRC), United States Department of Agriculture (USDA), Agricultural Research Service (ARS), Albany, CA 94710, USA

ARTICLE INFO

Article history:
Received 31 March 2013
Received in revised form 26 July 2013
Accepted 21 October 2013
Available online 29 October 2013

Keywords:
Dynamic mechanical analysis
Frequency sweep
Temperature scan
Creep behavior
Infrared radiation
Tomato peel

ABSTRACT

This study investigated the viscoelastic characteristics of tomato skins subjected to conventional hot lye peeling and emerging infrared-dry peeling by using dynamic mechanical analysis (DMA). Three DMA testing modes, including temperature ramp, frequency sweep, and creep behavior test, were conducted to evaluate the transition temperatures and dynamic moduli of tomato peels heated by infrared radiation and hot lye at four heating durations (30, 45, 60, and 75 s). Fresh tomato peels were used as a control. Results showed that dynamic moduli of tomato peels were sensitive to temperature ramp and frequency sweep tests. Over a temperature range from 20 °C to 100 °C, transition temperatures of infrared treated peels (63–72 °C) and lye treated peels (43–75 °C) were significantly lower than those of fresh control (~88 °C). Values of both storage and loss moduli of infrared heated peels were considerably higher than those of the fresh control, whereas values of the storage and loss moduli from the lye peeled samples were lower than those of fresh peels. DMA tests effectively differentiated the viscoelastic behaviors of tomato peels and indicated mechanistic differences between the lye peeling and infrared dry-peeling.

1. Introduction

Tomatoes are usually peeled prior to further processing into canned products since tomato skins are very tough and undesirable to consumers (Barringer, 2003; Shao et al., 2013). The conventional peeling process applies hot lye to separate skins from tomato flesh and then utilizes a mechanical peeler to remove the loosened skins. The use of lye (sodium hydroxide or potassium hydroxide) for peeling tomatoes results in a significant amount of peeling effluent discharges containing high salinity and organic solids, causing considerable negative environmental impacts (Rock et al., 2011). Sustainable and non-chemical peeling alternatives have long been desired by tomato processors to eliminate the reliance on lye and water. For the first time, we have investigated an infrared (IR) dry-peeling method which can reduce water usage and wastewater while producing high quality peeled products without using lye and water (Pan et al., 2009, 2011; Li, 2012). IR heating is non-ionizing radiation with surface heating characteristics. The IR radiation heats only a shallow layer of tomato surface and leaves the edible inner part of the tomato with minimum changes in texture and nutritional quality (Li and Pan, 2013a,b).

In our efforts in developing this IR dry-peeling method, the dynamic nature of viscoelastic properties of tomato skin is of particular interest and importance because these properties are closely related to several pivotal engineering parameters, such as minimal IR heating time for successful peel removal and critical temperature for peel separation. Thus, in-depth studies are needed to better understand how different peeling methods and conditions affect the dynamic mechanical properties of tomato skins.

Tomato skin, also known as exocarp, consists of a thin cuticle layer, a single layer of epidermal cells, and two to four layers of hypodermal cells (Fig. 1). Epidermal and hypodermal cells are tablet shaped collenchymas which normally feature with unevenly thickened cell walls with the greatest thickness of the cell wall located in the cell corner (Evert, 2006). A hydrophobic cuticle, which mainly consists of solvent-soluble and polymerized lipids (Matas et al., 2005), overlies the epidermal cells as a continuous extracellular membrane (Bargel and Neinhuis, 2005; López-Casado et al., 2007). In addition to physiologically defined skin, mechanically removed skins after peeling also have attached small portions of soft pulp (Garcia and Barret, 2006; Li et al., 2009) consisting of round shaped outer pericarp cells. All these cellular tissues as a unique and complex mix of biopolymers need to be considered

* Corresponding author. Address: Processed Foods Research Unit, USDA-ARS-WRRC, Albany, CA 94710, USA. Tel.: +1 510 559 5861; fax: +1 510 559 5851.
E-mail addresses: zhongli.pan@ars.usda.gov, zlpan@ucdavis.edu (Z. Pan).
[1] These authors contributed equally to this work.

0260-8774/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jfoodeng.2013.10.032

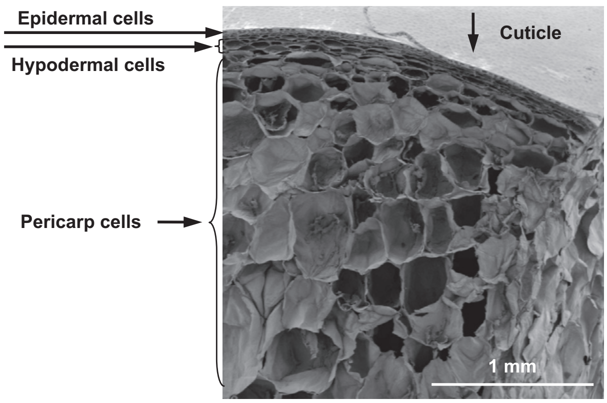

Fig. 1. Anatomical features of outermost pericarp tissue of tomato in the cross section. (The sample in the image of scanning electron microscopy was prepared by chemical fixation and critical-point drying in our preliminary study.)

when investigating the skin viscoelastic characterizes affected by different peeling methods and conditions.

Different peeling methods and conditions have substantial effects on the biomechanical and viscoelastic properties of tomato peel, such as skin strength, storage moduli, and loss moduli. However, there is a lack of documented information and fundamental understandings related to characterized viscoelastic response of tomato skins to different peeling methods. The strength of tomato skin primarily comes from the intrinsic strength of primary cell walls, which possess a complicated three dimensional ultrastructure formed by a cellulose–hemicellulose network, pectin matrix, structural proteins, and other non-polysaccharide components such as phenolics (Taiz and Zeiger, 2006). When such an intricate structure is exposed to any dramatic environmental stress, destructive changes in skin tissue occur. For example, diffusion of hot lye solution into tomato skin during the lye peeling process weakens the cellulose–hemicellulose network of cell walls (Barreiro et al., 1995, 2007; Barringer, 2003). As a result, the cuticle melts, pectins in the middle lamella breakdown, and cell wall structures degrade, a sequence leading to skin dissolving (Floros and Chinnan, 1990). Skin separation induced by IR dry-peeling does not involve any chemical diffusion, and thus differs from that of the traditional hot lye peeling. The exact mechanism of skin separation during IR heating still needs to be elucidated. (Pan et al., 2009). When the tomato surface is exposed to a high temperature (>90 °C), thermal effects will dominate the tissue damage and layer separations. Our previous studies have demonstrated that IR heating can substantially affect the microstructure and biomechanical properties of tomato skin (Li, 2012; Li et al., 2013). Characterization of the viscoelastic behavior of tomato skin in response to different processing conditions will add greatly to the understanding of the peeling mechanism of the IR dry-peeling process.

Changes in dynamic mechanical properties of polymeric tomato peels under different processing conditions are extremely difficult to measure, especially when biological uncertainty is considerable and the processing conditions cover a range of temperature or frequencies. A refined analytical method that attempts to better characterize the viscoelastic properties of biopolymer materials is known as dynamic mechanical analysis (DMA). During the DMA measurements, a small oscillatory deformation is applied to a tested sample and allows the sample to be studied in response to the temperature, frequency, stress, strain, or other parameters (Menard, 1998). The resultant dynamic moduli are then used to characterize the viscoelastic properties of tested materials. The DMA technique has been widely employed in polymer science to uniquely identify potential transition points of polymeric materials or changes of viscoelastic behaviors of a material as a function of temperature or frequency (Pothan et al., 2003).

In the present work, a comparison of dynamic viscoelastic behavior of polymeric tomato peels as affected by IR and lye peeling was performed using the DMA technique. Three test modes were implemented to characterize the viscoelastic nature of tomato skin. First, a temperature ramp test was used to characterize the dynamic response of tomato skins to temperature. This test leads to identification of the potential phase transitions occurring in tomato skin when the tomato surface temperature was increased from about 20 °C to 100 °C. Second, to expand the understanding of whether tomato peels exhibit frequency dependent viscoelastic properties, a series of oscillatory forces of different magnitude and frequency were applied to the tomato skin by means of the frequency sweep test. Different frequencies were used to simulate a realistic peeling environment with complex vibration and oscillation. Changes in viscoelastic parameters of tomato skin can be characterized by the power law model over the entire range of tested frequency (Özkan et al., 2002). Finally, creep behavior of tomato skin was studied by applying loading and unloading uniaxial tension. The viscoelastic response of tomato skin over time can be determined using Burger's model. The Burger's model was developed based upon the Maxwell model and the Voigt–Kelvin model and employs four elements to approximate the creep response (Chuang and Yeh, 2006; Menard, 1998). Analyses using the three DMA test modes were expected to give insight into how tomato skin reacts under different peeling conditions and how its viscoelastic properties vary under different heating methods.

Therefore, the main objectives of this study were to (1) characterize the dynamic mechanical properties of tomato peels under three different DMA test modes, and (2) compare the effects of IR and lye peeling methods on the changes in viscoelastic properties of tomato skins.

2. Materials and methods

2.1. Tomatoes

Tomatoes of cultivar AB2 grown on a commercial farm (Campbell's Seeds Co., Woodland, Cal., USA) were used for all the DMA tests. Selected tomatoes were randomly harvested at red-ripening stage (179–183 days after planting) each week over the 2010 peak harvesting season (from August to September). Following industry practice, to ensure homogeneous and consistent ripening of tomatoes, ethylene gas was applied to tomatoes one week before harvest. After harvesting, tomatoes were immediately delivered to the laboratory and stored at 10 °C and 80% relative humidity to avoid chilling injury (Kader, 2002). The DMA tests were completed within four days after each harvest so that the tomatoes were of consistent quality. The tested tomatoes had an average mass of 83 ± 16 g and an average soluble content of 4.9 ± 0.2 °Brix (Li, 2012).

2.2. Peeling procedures

Prior to DMA testing, tomatoes were subjected to IR or lye heating. Tomatoes underwent double-sided IR heating for one of the following durations: 30, 45, 60, or 70 s. The distance between two IR emitters was set at 90 mm. The tomatoes were rotated at a speed of 1 rpm to ensure uniform heating. For lye heating, tomatoes were heated in a 10% (w/v) sodium hydroxide solution at 96 °C for the same four time duration as used for IR heating. The detailed experimental set-up and peeling procedure were previously described by Pan et al. (2009) and Li et al. (2013).