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Peeling of tomatoes using novel infrared radiation heating technology

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ABSTRACT

The effectiveness of using infrared (IR) dry-peeling as an alternative process for peeling tomatoes without lye and water was studied. Compared to conventional lye peeling, IR dry-peeling using 30 s to 75 s heating time resulted in lower peeling loss (8.3%–13.2% vs. 12.9%–15.8%), thinner thickness of peeled-off skin (0.39–0.91 mm vs. 0.38–1.06 mm), and slightly firmer texture of peeled products (10.30–19.72 N vs. 9.42–13.73 N) while achieving a similar ease of peeling. IR heating increased the Young's Modulus of tomato peels and reduced the peel adhesiveness, indicating the tomato peels to loosen, become brittle, and crack more easily. Also, IR heating resulted in melting of cuticular membrane, collapse of several cellular layers, and severe degradation of cell wall structures, which in turn caused peel separation. These findings demonstrated the effectiveness of the novel IR dry-peeling process for tomatoes.

Industrial relevance: Development of a sustainable and non-chemical peeling technique for food processing industry is urgent. Currently, industrialized peeling methods such as hot lye or steam peeling are water- and energy-intensive operation and result in a large amount of waste effluent. Disposal of these wastewater containing high salinity and organic solids poses negative environmental footprints. Tomato processors have long been interested in pursuing a sustainable and non7 chemical peeling alternative in order to minimize waste effluent containing high salinity and organic loads and reduce the negative environmental impacts associated with conventional hot lye peeling. The emerging infrared dry-peeling technique offers a novel approach to eliminate the usage of chemicals and water in the peeling process while maintaining high quality peeled products. The study explored several crucial and fundamental aspects of developing infrared radiation heating technology as a sustainable tomato peeling method. The findings of this research provide scientific evidence of the benefits of infrared dry-peeling in comparison to the conventional hot lye peeling and have been used for the development of a pilot scale tomato infrared dry-peeling system.

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1. Introduction

Peeling is widely used in the food processing industry to produce premium quality canned fruits and vegetables. The conventional peeling process applies hot lye or steam for peel removal and is an energy- and water-intensive operation. Particularly, the hot lye peeling using sodium hydroxide or potassium hydroxide solution results in a significant amount of peeling effluent discharges containing high salinity and organic solids. Disposal of the wastewater and threat to long-term water supply associated with lye peeling have become serious concerns to the tomato processors. To minimize the chemical contamination and negative environmental impacts, steam peeling has been adopted by food processors as an alternative peeling technique. However, steam peeling produces inferior products with deteriorated peeling appearance, high loss in firmness, and reduced peeling yields compared to conventional hot lye peeling. Therefore, there is an urgent need to develop sustainable and cost-effective peeling alternatives which can reduce water usage and wastewater generation while producing high quality peeled products without using lye and steam (Li et al., 2014; Pan, Li, Bingol, McHugh, & Atungulu, 2009; Rock, Yang, Goodrich-Schneider, & Feng, 2011).

To address the critical challenges, different alternative peeling technologies have been considered and studied, such as enzymatic peeling, ohmic peeling, and ultrasonic peeling (Baker & Wicker, 1996; Li, 2012; Rock et al., 2011; Wongsa-Ngasri, 2004). However, industrialization of these technologies has been limited due to the high cost and low throughputs. Infrared (IR) radiation heating has a rapid surface heating characteristic and allows heating only a shallow layer of tomato surface while maintaining the edible flesh portion intact. The feasibility of IR radiation heating as an effective non-chemical method for tomato peel removal has been investigated through different peeling approaches,

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including IR peeling, combined lye-IR peeling, enzyme peeling, and enzymatic pretreated IR peeling (Li et al., 2009). Among all approaches investigated, IR peeling yielded the best peeling results. The peeling performance and quality of IR peeled tomatoes were comparable to those from conventional hot lye peeling (Li et al., 2009; Pan et al., 2009). Because neither chemicals nor water was required during IR heating, it was named as IR dry-peeling (Li, 2012; Pan et al., 2009).

In general, a sustainable peeling method should be to minimize product loss, quality change, water and energy consumption, and pollution loads (Setty, Vijayalakshimi, & Devi, 1993). Accordingly, different criteria have been developed to evaluate the peeling process for different purposes (Barrett, 2000; Garcia & Barrett, 2006a; Li et al., 2014; Milczarek, 2009). For example, the United States Food and Drug Administration (FDA) launched a specific regulation of tomato peelability, requiring that the amount of non-removed peel must be less than 0.015 cm^2/g (FDA standard, 21CFR 155.190). Other commonly used criteria to evaluate peeling performance in literatures are peeling yield and peeling loss calculated based on the weight changes of tomatoes before and after peeling (Das & Barringer, 2005; Garcia & Barrett, 2006b; Schlimme, Corey, & Frey, 1984). It is worth mentioning that applying individual criteria in peeling evaluation has certain limitations. For instance, when only peelability is adopted to compare the efficacy of different peeling conditions, details about the ease of peel and peeling loss are not reflected in the index of peelability. In practice, commercial tomato processors are interested not only in the peelability and peeling yield, but also in the quality of the peeled fruit, particularly the firmness (Garcia, Watnik, & Barrett, 2006; Milczarek & McCarthy, 2011). Hence, a metric that can facilitate characterizations of different peeling performance and product quality is vital to precisely evaluate a peeling process.

Relatively few works have been dedicated to comprehensive evaluations of the peeling process for fruits and vegetables. To fully develop IR heating into a sustainable dry-peeling method, in the present study we performed an in-depth characterization of tomatoes peeled using IR. Complete evaluation of IR dry-peeling for tomatoes was conducted from five perspectives, including an assessment of physical attributes of tomatoes from different cultivars, peeling performance, peeled product quality, biomechanical properties of skins, and anatomical and morphological features of skin tissue. Such information is critical for better understanding of the IR dry-peeling process and provides guidance for further scale-up towards industrial application.

Our ultimate goal is to develop a new and sustainable peeling technology by using IR heating for tomatoes. The specific objectives of this study were to 1) compare the impact of IR and lye peeling on various metrics of peeling performance and product quality for tomatoes of two cultivars; and 2) characterize the biomechanical and anatomical features within skins and adjacent tissues of tomatoes subjected to IR heating.

2. Materials and methods

2.1. Raw material characteristics

Two processing tomato cultivars, AB2 and Campbell CXD 179, were acquired from local commercial fields (Campbell Seeds Co., Woodland, Cal., and ConAgra Foods Co., Woodland, Cal.) during the peak season of 2009. Random fruits were hand harvested at red maturity stage (i.e., USDA tomato classification 6) with an average total soluble solid content of 5.4 ± 0.2 °Brix and average firmness of 26.3 ± 6.5 N. Harvested tomatoes were sorted to exclude fruits with disease and visual defects, and stored at 10 °C and 80% relative humidity in a cooler according to the method of Kader (2002). Depending on the harvesting date and experimental schedule, different batches of harvested tomatoes were used for different sets of tests. All tomatoes were processed within four days after harvest.

Prior to peeling, tomatoes of each cultivar were randomly selected and evaluated for a number of physical attributes. For each fruit, tomato mass was measured with an electronic balance with 0.1 g sensitivity. Tomato dimensional attributes related to peelability were selected and measured according to Garcia and Barrett (2006a). As illustrated in Fig. 1, fruit height, maximum lateral diameter, height of maximum lateral diameter, shoulder height, and stem scar diameter were measured on whole tomatoes, while pericarp wall thickness and red layer thickness were measured on cut fruits at three locations: equator side, stem end, and blossom end. All dimensional measurements were performed using a Vernier digital caliper with an accuracy of 0.1 mm. During the 2009 season, 197 and 79 fruits were evaluated for cultivars AB2 and CXD179, respectively. Tomatoes with uniform shape and size were selected for peeling evaluations based on measurements of the physical attributes. They weighed between 60 and 110 g and possessed similar size (60 ± 6 mm in height and 49 ± 6 mm in width). The data of physical attributes of raw tomatoes were compared by using student *t*-test at a 0.05 probability level for the two cultivars. Correlations between dimensional attributes and peeling loss or peeled-off thickness were examined with Pearson correlation coefficient.

2.2. Tomato peeling procedure

Prior to peeling, raw fruits were allowed to equilibrate to room temperature (23 °C) for at least 2 h, which ensured that all fruits were of the same initial temperature. For IR peeling, tomatoes were heated using double-sided IR (Fig. 2) with an optimal distance between two emitters of 90 ± 2 mm (Pan et al., 2009). To improve heating uniformity, the tomato was rotated continuously at a speed of 1 rpm by means of a motor driven turntable (Fig. 2). As a comparison, regular lye peeling conducted on a laboratory scale was used as a control. The procedures of lye peeling tomatoes were used as described by Pan et al. (2009). After IR and lye peeling, the loosened skins were manually removed for further evaluations.

2.3. Peeling performance

Comparison of peeling outcomes for IR and lye peeling was based on peeling performance and peeled product quality. Peeling performance which involved determination of peelability, ease of peeling, peeling loss, and peeled-off thickness was comprehensively evaluated using procedures described by Pan et al. (2009). In an attempt to minimize possible subjective bias, randomized double-blind experiments were conducted in scoring the ease of peeling. A higher value of the ease of peeling indicates that the skin is easier to remove. Peeled-off thickness was measured and studied to determine the differences in peeling mechanism between IR and lye peeling methods. Thickness of peeled skin was measured at three locations with a micrometer (model Central Tech 895, Microprecision Calibration Inc., Grass Valley, Cal., USA) with an accuracy of 0.001 mm, and the average value for each fruit was used in further statistical analysis.

2.4. Product quality evaluation

Quality assessment of peeled tomatoes was quantified based on peeled tomato firmness that was determined by a flat-plate compression test (Cantwell, 2006) by using a texture analyzer (model TA-XT2i, Texture Technologies Corp., Scarsdale, N.Y., USA) equipped with a 19.62 N load cell. Tomatoes were placed horizontally on a three-point based stand (ASABE Standards, 2001; Slaughter, Crisosto, Hasey, & Thompson, 2006), and a 50 mm diameter probe with flat surface was used to compress the equator of the whole peeled tomato to a depth of 5 mm at 5 mm/s testing speed (Cantwell, 2006; Li et al., 2009). The average peak force of ten tomatoes is reported for each treatment. In addition to texture, the surface temperature of IR treated tomatoes was determined via a non-contact Infrared Thermometer (Oakton