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A novel two-step ultrasound post-assisted lye peeling regime for tomatoes: Reducing pollution while improving product yield and quality

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ABSTRACT

In this paper, the effects and mechanisms of a novel two-step tomato peeling method, hot lye with a post-assistance of ultrasound, were investigated. The present work aims to improve the environmental friendliness of the conventional hot lye tomato peeling method (10% w/v, 97 °C, 45 s). The results showed that 4% (w/v) lye treatment at 97 °C for 30 s with a post-assistance of a 31.97 W/L ultrasound treatment at 70 °C for 50 s achieved a 100% peelability. In this scenario, the peeling yield and lycopene content in the peeled product were significantly higher than the peeling yield and lycopene content with the conventional hot lye peeling method. The present two-step peeling method was concluded with a mechanism of chemico-mechanical synergism, in which the hot lye functions mainly in a chemical way while the ultrasound is a mechanical process. Especially from the lye side, this work first demonstrated that the lye penetrated across the tomato skin via a pitting model rather than evenly. The findings reported in this paper not only provide a novel tomato peeling method with significant environmental benefits but also discover new clues to the peeling mechanism using hot lye.

1. Introduction

Peeling is an essential operating unit in tomato processing industry, especially in producing canned tomatoes. In addition to removing the skin from tomatoes, peeling also affects the sensory and nutritive qualities of the final products [1]. To date, hot lye and hot water or steam have been successfully used to peel tomatoes, while hot lye was the most commonly adopted method by tomato processing enterprises due to its higher peelability and better protection of product quality than a hot water or steam method [2]. Usually, the lye peeling was performed by immersing fresh tomatoes in hot (60–100 °C) NaOH solution at concentrations ranging from 8 to 25% for 15–75 s [2–4]. Although the peelability of this method is dependent on its operating parameters such as temperature, lye concentration and processing time, the treatment with 10% lye at 97 °C for 45 s was demonstrated by several studies, showing satisfactory peelability [5–7]. Apparently, in contrast to hot water or steam peeling, hot lye peeling has its drawbacks. The most severe drawbacks lie in the environmental pollution problem caused by its effluent of lye at a high concentration [8,9] as well as the health risk to employees. Therefore, it is worthwhile investigating methods to reduce the lye concentration or eliminating lye usage while retaining or even improving the quality of the peeled tomatoes.

In response to the ever-increasing environmental concerns regarding chemical peeling, alternative methods of tomato peeling have also been explored in recent years. These novel tomato peeling techniques include infrared heating [1,10–16], ohmic heating [9,17,18], and ultrasound treatment [5]. As an innovative technique, power ultrasound has been widely used in the food industry to lower the operating cost, decrease energy consumption and improve environmental friendliness of traditional food processing techniques [19–23]. However, literature reports the utilization of power ultrasound in tomato peeling are quite scarce. Only one article was available for this topic where Rock et al. [5] compared the peeling efficiencies of power ultrasound-assisted lye (2%, w/v) and conventional lye (10%, w/v). In the power ultrasound-assisted lye treatment, power ultrasound was directly applied in the lye solution in which the tomatoes were immersed. To achieve a satisfactory peelability, after the power ultrasound-assisted lye treatment, the skin should be manually split with paring knives. Obviously, this operation is difficult to achieve in large-scale production. In view of the environmental concerns associated with concentrated lye (usually 10% w/v) used in conventional lye peeling and the working mechanism of the power ultrasound, we propose that mild lye treatment (far below than 10%, w/v) followed with a

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further ultrasonic treatment could possibly generate peelability comparable to the concentrated lye (usually 10% w/v). However, this hypothesis has not been verified until now. In the present work, a two-step tomato peeling method, lye treatment followed by ultrasonic treatment, has been developed. The operating parameters have been optimized, and the underlying working mechanisms were clarified. This novel method is an environmentally benign alternative to the conventional lye method.

2. Materials and methods

2.1. Materials and reagents

Fresh tomatoes (cultivar Tunhe 8) grown on Changji of Xinjiang Uygur Autonomous Region were used for this study. Selected tomatoes were hand-harvested at red-ripening stage according to the USDA standard [11], and where only defect-free tomatoes were collected. Harvested tomatoes were stored at 9–10 °C [14], and all tomatoes were processed within 5 days after harvested. Food grade sodium hydroxide was obtained from Befar Group Co., Ltd (Binzhou, China). Brilliant green was obtained from Meryer Technologies Co., Ltd (Shanghai, China). Acetone, ethanol, chloroform, sulfuric acid was obtained from Chuangdong Chemical Group Co., Ltd (Chongqing, China). Hexane, methanol was obtained from Kelong Chemical Reagent Co., Ltd (Chengdu, China). All chemicals are of analytical grade and used as received.

2.2. Peeling procedure

Prior to peeling, tomatoes were equilibrated at room temperature (22 ± 1 °C) for at least 2 h. The tomatoes were washed with tap water, and water drops on their surfaces were drained off. Then, twenty-seven tomatoes were randomly divided into three groups with nine tomatoes in each group. To perform peeling, three groups were processed individually and a basket with nine compartments, constructed with stainless steel wire, was applied. For one group, nine tomatoes were loaded separately in nine compartments and processed as one batch. For lye treatment, the tomato-loaded basket was totally immersed in lye (4–12%, w/v) solution maintained at 97 ± 3 °C for a period of 10–30 s with slight agitation. After that, it was transferred into the processing tank of a MJ-3028 ultrasonic cleaner (Meijie, Chongqing, China) containing 36 L hot water (70 °C). The tank is rectangular with internal dimensions of 500 × 400 × 350 mm. The equipment was operated at a constant frequency of 25 kHz with varying output ultrasound power (1500–3000 W) and processing time (30–50 s). As already known, the output power stated by the equipment manufacture is not consistent with the actual acoustic power in sonochemical process, and thus the volumetric power is recommended [24]. For the present study, the volumetric powers corresponding to the output powers of 1500, 1800, 2100, 2400, 2700 and 3000 W were determined as 19.13, 25.08, 31.97, 38.73, 45.38 and 51.92 W/L, respectively, according to the method reported by Margulis et al. [25]. To preserve the product quality and prevent any possibly adverse effects of the residual heat, the processed tomatoes were immediately cooled to room temperature (22 ± 1 °C) with tap water for 30 s after the ultrasonic treatment. At the same time, the loosened skins were removed with the aid of a slight hand rubbing. The operating temperature of lye treatment was adopted from the reference, while that of ultrasonic treatment was settled according to the instructions of the equipment. The upper limits of other parameters applied in lye and ultrasound treatments were settled by preliminary experiments, giving equal considerations for peelability and product quality.

2.3. Evaluation of peeling performance

To comparatively evaluate the efficiency of various peeling procedures, peelability and peeling yield were determined. Peelability was used to quantify the degree of peel removal [15] and was defined as the area ratio of the removed skins to the predicated overall surface area of the tomato. Illuminated by the imageJ method in measuring the cell area at the cross-section of a bread in our previous [26], a similar method was developed to determine the total area of removed tomato skins. To calculate their total area, the removed skin pieces were spread on a sheet of paper, and the image of the removed skin pieces was obtained by an HP LaserJet M1136 MFP scanner and saved as a JPG file. Subsequently, the cropped colour image was converted into a binary image using the automated fuzzy measure thresholding method with the aid of software ImageJ (version 1.46r, National Institutes of Health, Maryland, USA) (Supplementary Data 1). In the resulting binary image, the total area of the peeled skins was accurately measured (cm^2). Although not detailed here, a mass-based overall surface area predicting model was developed for the tomatoes by ourselves. In this model, the predicted overall surface area (A, cm^2) of a tomato could be estimated accurately based on its mass (m, g) via the equation of $A = 0.810m + 11.5$, $R^2 = 0.965$ (Supplementary Data 2). Peeling yield was used to weigh the product recovery or loss respective to varying peeling procedures and defined as the mass percentage of peeled product to the initial material applied. Both for peelability and peeling yield, an average of 27 tomatoes was reported for the peeling procedure.

2.4. Evaluation of the quality of the peeled products

2.4.1. Firmness

The firmness of peeled tomatoes was determined according to the method of Pinheiro et al. [27] with slight modifications. In brief, the firmness (N) was measured through a puncture test on a CT 3 Texture Analyser (Brookfield, Middleborough, MA) equipped with a TA 10 probe (a 12.7-mm diameter probe with flat surface). The tomatoes were penetrated at their equators with a depth of 10 mm. The texture analyser was operated under a texture profile analysis model with the following parameters: pre-test speed 1.0 mm/s, test speed 1.0 mm/s, post-test speed 1.0 mm/s, and a trigger force of 0.1 N. The maximum peak force (N) measured during the puncture test will be referred to as the firmness. The average maximum peak force of 27 tomatoes was reported as the firmness for each treatment.

2.4.2. Colour

The colour parameters, lightness (L^*), redness (a^*) and yellowness (b^*), were recorded with an UltrasScan PRO colorimeter (Hunter, Virginia, USA). According to Pan et al. [10], Hue^o is considered to be the most appropriate value to measure tomato colour rather than the individual chromatic components. Hue^o was calculated according the equation of $Hue^o = \tan^{-1}(b^*/a^*)$, and a value closer to zero indicates a redder tomato. The colour parameters of tomatoes were measured at three different locations along their equators and the average of 27 tomatoes was reported for each treatment.

2.4.3. Lycopene content

The whole juices of fresh and peeled tomatoes were obtained using a WBL25B36 laboratory scale juice homogenizer (Midea, China) which could remove seeds and peels. The juices obtained were stored at -18 °C prior to the measurements. The lycopene was quantified according to the method of Salvia-Trujillo et al. [28] with slight modifications. Tomato juice (0.5 g) was accurately weighted into a 50-mL flask, and 20 mL of hexane-acetone-ethanol solution (2:1:1, v/v/v) was added. The mixture was continuously stirred for 30 min in the dark. Then, 5 mL of distilled water was added, and the resulting mixture was further stirred for 10 min. Then, the upper hexane phase (supernatant) containing lycopene was collected, and its absorbance at 503 nm was recorded with an L6 UV–Vis spectrophotometer (Inesa, China) using hexane as a blank.