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Feasibility of jujube peeling using novel infrared radiation heating technology

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A B S T R A C T

Infrared (IR) radiation heating has a promising potential to be used as a sustainable and effective method to eliminate the use of water and chemicals in the jujube-peeling process and enhance the quality of peeled products. The objective of this study was to investigate the feasibility of using IR heating as a dry-peeling method for jujube. The rotating Li jujube fruits were heated using two electric IR emitters. The effects of IR radiation intensity (5.25–6.07 W/cm^2), emitter distance (75–85 mm), and heating time (40–60 s) on the peeling performance of jujube were investigated. Lye-peeled jujubes were used as a control. The operating parameters of the IR peeling system were optimized using response surface methodology (RSM). The heating with an IR intensity of 5.25 W/cm^2 at the emitter distance of 75 mm for 56 s were found as the optimum operating conditions resulting in the peelability of 96%, peeling easiness of 3.8 and moisture loss of 1.29% at jujube surface temperature of 115 °C. The experimental results agreed well with those predicted by the models. The IR peeled jujube had significantly low peeling loss and color change compared to lye peeled ones.

1. Introduction

Jujube is the fruit of *Ziziphus jujuba* Mill, a thorny rhamnaceous plant, mainly grown in the subtropical and tropical regions of Asia and America. Jujube with a high nutritional value and numerous pharmacological effects has been widely used as food, functional food additives, and traditional Chinese medicines for thousands of years. Jujube fruits have the capacity help lower blood pressure, reverse liver disease, treat anemia, and inhibit the growth of tumor cells that can lead to leukemia (Lu, Liu, Yan, & Li, 2010; Wang, Liu, Zheng, Fan, & Cao, 2011). Jujubes have been processed into various food products including canned jujube, paste, puree, syrup, juice and confection (Huang, Yen, Sheu, & Chau, 2008; Liu & Zhao, 2009) usually from the unpeeled whole fruits. Although the high nutritious value, jujube peel is often difficult to chew and swallow. Additionally, if the peel is not perfectly removed, it will affect the taste and product quality. Consequently, the peeling is a key operation before direct consumption or further processing of jujube.

Conventionally, mechanical, chemical and hot soaking peeling methods have been applied for jujube. These peeling methods have adverse effect on product quality. Practically, chemical residues in jujube meat after immersing in an alkaline affect the quality of post-processed products. Moreover, these peeling methods are water and energy intensive, and pose serious salinity and wastewater disposal problems, resulting in considerable negative environmental impact (Pan, Li, Bingol, McHugh, & Atungulu, 2009; Rock, Yang, Goodrich-Schneider, & Feng, 2011; Li, Pan, Atungulu, Wood, & McHugh, 2014a). Therefore, there is an urgent need to develop a sustainable and non-chemical peeling method, which can eliminate or reduce water, energy and chemical usage, meanwhile deliver high quality peeled products. Recently, infrared (IR) technology has been studied as an alternative to food processing technologies with attractive merits such as uniform heating, high

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heat transfer rate, reduced processing time and energy consumption, and improved product quality and safety (Pan & Atungulu, 2011). A sustainable infrared (IR) dry-peeling method was developed by our group and has been successfully used for tomato and peach peeling with a complete elimination of lye and water usage in the peeling process (Li et al., 2014b, 2014c). The IR dry-peeling process uses non-ionizing thermal radiation with surface heating characteristics that allow effective heating of only a shallow layer of the fruit or vegetable surface to achieve peel separation while preserving the nutrients and quality in the edible portion of the products (Li, 2012; Pan et al., 2009, 2011). The tomato peeling is achieved by thermally induced peel loosening by IR heating and subsequent cracking (Li et al., 2014a).

In the IR dry-peeling, the IR radiation intensity, heating time, emitter gap and fruit size are the key processing parameters, which directly affect the peeling performance, including the peelability, peeling yields, and moisture loss (Krishnamurthy, Jun, Irudayaraj, & Demirci, 2008; Li et al. 2014c). The IR radiation intensity affects the heat fluxes that impinge on the fruit surface. High IR intensity generates more heat flux that irradiates onto the fruit surface resulting in more effective peeling. The IR heating time is another important factor which needs to be optimized during peeling to produce high quality peeled product. A longer exposure to IR heating may provide sufficient thermal energy but leads to deterioration of fruit quality and nutritional loss due to overheating. A shorter heating time may not be able to provide sufficient heat to achieve desired peel separation and thus reduces the peelability. When heating is applied on a rotating jujube from both sides (top and bottom) with IR heating emitters, the emitter distance and the fruit size greatly influence the degree of exposure of fruit surface to emitters. In the double sided heating equipment, controlling the distance between the emitters can be an effective way to adjust IR radiation intensity and thus ensure a sufficient radiation heat exchange between the IR emitters and the fruit surface. Varying sizes of fruits cause different gaps between the fruit surface and the IR emitter and absorption of various amounts of thermal energy under the same heating condition, which results in variation of peeling performances and peeled product qualities. In order to ensure a good peeling performance and high quality of peeled end products, the IR heating conditions should be optimized.

Response surface methodology (RSM), a statistical experimental protocol used in mathematical modeling, has emerged as an ideal strategy for standardizing process variables of many food processes. The RSM requires less number of experimental measurements and provides a statistical interpretation of the data and the interaction amongst variables (Myers & Montgomery, 2002). It has been extensively used in the literature for optimizing different processes (Deswal, Deora, & Mishra, 2014; Ko, Changa, Wang, Wang, & Hsieh, 2015). As mentioned earlier, IR radiation heating has a promising potential to be used as an efficient peeling method for jujube. However, no previous reports were found on the feasibility of jujube peeling using IR heating technology. Therefore, the goal of this research was to develop a new and sustainable peeling technology for jujube using IR radiation heating. The specific objectives were to 1) study the effect of IR heating on peeling performance for jujubes; and 2) optimize peeling conditions for jujubes under IR radiation heating using RSM.

2. Materials and methods

2.1. Jujubes

Jujubes of variety Li, obtained from Burkart Farms, Dinuba, CA, USA were stored at 4 °C and used within seven days. The cheek diameter (Dc) of jujube was measured using a Vernier caliper having 0.01 mm accuracy to determine the size of jujubes. The mass of the jujubes was measured with an electronic balance with an accuracy of 0.01 g. Jujube fruits with Dc of 37 mm–41 mm were selected, checked and visually inspected and defected ones were eliminated before peeling tests. Jujubes were allowed to equilibrate at the ambient temperature for 2 h to obtain uniform initial surface temperature of 22 ± 2 °C before peeling.

2.2. Infrared radiation heating system

A laboratory scale of IR heating system consisted of two electric IR emitters (245 × 60 mm size) of 1000 W capacity (6 kw/m^2), 230 V which emit radiation at wavelength of 2–10 μm (Ceramicx Ireland Ltd, Cork, Ireland). The schematic drawing of the IR heating system is shown in Fig. 1, which has the IR emitters fixed to a frame connected to a metallic arm by which the IR emitters are moved and stationed at the heating position or idle position. The vertical distance between the IR heaters in the heating position could be adjusted by tightening and loosening of the nut moving on the screws provided on the space bar. An aluminum wave guard is installed at the top of the upper emitter and bottom of the lower emitter and acts as a radiation reflector by focusing IR radiation towards the fruit holder in order to minimize the heat loss to the surrounding and improve the heating uniformity of the jujube surface. A rotatable custom-designed fruit holder has a set of fingers to hold jujubes with a firm grip by adjusting the finger positions and shaft length.

2.3. IR heating procedure

The IR heating elements were placed in the idle position (away from the fruit holders) and allowed to get heated up for 5 min at the preset power intensity by controlling the current flowing to the emitters. The jujube was weighed and held tightly exposing the cheek sides to the emitters by adjusting the fingers of the fruit holder and length of the shaft. The position of the nut in the space bar is adjusted to have the required distance between the emitters and the speed of the motor was set to give the required rotational speed of the fruit holder. After allowing 5 min to stabilize the emitter temperatures, emitters were moved to the heating position and timer was started. After heating to the required time, the IR emitters were moved to the idle position and the temperature of the jujube surface was measured using IR temperature sensor. The jujube was removed from the fruit holder and weighed to determine the moisture loss during heating. The jujube was manually peeled and evaluated for the peeling performance.

Preliminary tests were conducted to determine the upper and lower limits of the operating parameters: radiation intensity, emitter gap (distance between the emitters) and heating time. The IR intensity was measured by measuring the power input to the IR emitters. Fluke clamp meter was used to measure the current (amperes) of the IR emitter and three power levels of 787.5, 859.0 and 910.5 W were chosen for the experiments based on the preliminary experiments. The IR intensity at the above power levels were 5.25, 5.66, and 6.07 W/cm^2, respectively. The distance between emitters was set as 75 ± 1 mm, 80 ± 1 mm and 85 ± 1 mm, and the heating times were set as 40, 50, and 60 s for the RSM experiments.

2.4. Evaluation of peeling performance

Peeling performance was evaluated by determining the peelability, easiness, and weight loss. The peelability was calculated as the ratio of removed skin to the overall surface area of the jujube (Li et al., 2014c). The area of the skin remaining on the jujube surface