Innovative Food Science and Emerging Technologies 48 (2018) 111–121

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

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

Development and optimization of novel infrared dry peeling method for ginger (*Zingiber officinale* Roscoe) rhizome

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ARTICLE INFO

Keywords:
Infrared radiation
Ginger
Peeling
Peeling performance
Sustainable environment

ABSTRACT

The novel infrared dry-peeling method was developed as an alternative to the conventional lye and abrasion peeling of ginger rhizome. The experiments on infrared dry-peeling of ginger rhizome were conducted to eliminate the use of water and chemicals in peeling process, enhance the quality of peeled rhizomes and make it a sustainable method. The effects of operating parameters like infrared temperature (300°–400 °C), product to IR heater spacing (10–30 mm) and exposure time (120–300 s) on the peeling performance were investigated. The multiple response optimization was carried out using response surface methodology. The optimum conditions were obtained at 300 °C infrared temperature, 21 mm spacing and 120 s exposure time which resulted in the peeling percentage of 92.77%, 90.40% peelability, 6.94% peeling loss and unpeeled percentage of 9.6. The comparative study of optimized infrared assisted peeling with conventional abrasion and lye peeling showed that infrared dry-peeling results in lower peeling losses. The SEM images of peels showed that IR radiation causes the desirable changes in elastic and other textural properties of the peel.

1. Introduction

Ginger (*Zingiber officinale* Roscoe) is a monocotyledon tuber spice which belongs to the family Zingiberaceae. The ginger rhizome contains both the flavor and pungency of the spice and oleoresin together with the essential oils. The main constituents of oleoresin are gingerols and shogaols (Balladin, Headley, Chang-Yen, & McGaw, 1997). Several changes in the cell structure of ginger rhizomes take place during various processing operations like blanching, peeling, extraction, drying etc. (Azian, Kamal, & Azlina, 2004). Ginger is one of the worldwide cultivated and utilized spices. The global production of ginger is mainly contributed by India, China, Indonesia, Nepal, and Nigeria. India is the top ginger producing country accounting for 1.109 million tonnes followed by Nigeria, China, Indonesia and Nepal producing 0.522, 0.492, 0.340 and 0.271 million tonnes, respectively, in the year of 2016 (FAO, 2016). Among the world's total production, Asia shares about 88.9%.While considering the export scenario, China was the leading exporter in the year of 2013 which exported 0.381 million tonnes. In addition, the world market is experiencing an increasing demand for products like ginger powder, oleoresin, ginger-oil and ginger candy (FAOSTAT, 2017).

Various value-added food, pharmaceutical, beverage, and cosmetic products are prepared from different parts of ginger rhizome. Peeling off the rhizome prior to processing is not necessary especially for pharmaceuticals and cosmetic products. But being a tuber, the ginger rhizome is contaminated with various soil-borne pathogens on its surface and hence peeling of the rhizome is essential when utilizing them as a food ingredient. These include ginger powder, paste, sauce, flavoring agent in salad dressings, pickles, gravies, sausages, confectioneries, curry dishes etc. (Ravindran & Babu, 2016). Therefore, peeling plays a key role in the microbiological safety of processed products (Anonymous, 2017; Vasala, 2012). Peeling is also used in the processing of many fruits and vegetables to remove unwanted or inedible material and to improve the appearance of the final product. The process of peeling can affect the solid and nutritive loss of products (Li, 2012).

Nowadays in industry, lye, mechanical (abrasive), and steam peeling methods are commonly used. Lye peeling and mechanical peeling are most common in case of ginger. Both of these methods use water as well as energy intensive, and serious problems are posed like salinity (100–200 g/L), high BOD wastewater disposal (40% of total plants BOD) and hence causing considerable negative environmental impacts (Li, Pan, Atungulu, Wood, & McHugh, 2014; Pan, Li, Bingol, McHugh, & Atungulu, 2009; Rock, Yang, Goodrich-Schneider, & Feng, 2012). According to Environmental Protection Agency (EPA), at demonstrative level, it was found that water used in the peeling operation

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https://doi.org/10.1016/j.ifset.2018.05.021
Received 12 April 2017; Received in revised form 22 May 2018; Accepted 22 May 2018

can be reduced from 850 gal/ton peaches to 90 gal/ton peaches by using the dry peeling process (Carawan, Chambers, Zall, & Wilkowske, 1979).

Mechanical method is most commonly used for peeling of ginger rhizome both at domestic and small processing units. During mechanical peeling, there is no control of the scoring of the surface due to the irregular shape of ginger rhizome. Therefore, the serious problem of essential oil cell damage is reported, which may have an effect on the quality of the final product. There is about 25% loss of the product compared to 8–10% in flash peeling (Fellows, 2009). Lye peeling and mechanical peeling are the most common methods used in industry. Besides this, nowadays other peeling methods like steam-assisted lye peeling, pressurized steam-vacuum peeling has been used to enhance the peeling efficiency of tradition methods (Ayvaz, Santos, & Rodriguez-Saona, 2016; Garcia & Barrett, 2006).

Currently, the research on various commodity specific novel alternative peeling methods is going on. Their potential for commercial application and validation has been reported by various researchers. Noguchi, Ozaki, and Azuma (2015) reported the enzymatic peeling for citrus fruit which was superior over conventional mechanical peeling but poses the limitation of long processing time, and applicable for commodities where the distinct separation of peel is required from the flesh (Rock, Yang, Goodrich-Schneider, & Feng, 2012). Wongsa-Ngasri (2004) studied the feasibility of ohmic heating as a peeling method for tomatoes. The electric field applied with NaCl solution enhances the peelability due to the phenomenon of thermal degradation of the waxy cuticle, disruption of the hemicellulosic and pectic substances in the tomato skin and electroporation created by ohmic heating. Rock, Yang, Nooji, Teixeira, and Feng (2010) peeled Roma tomatoes using power ultrasonication and compared with conventional lye peeling. They observed that power ultrasound treatments without the addition of any chemical were just as effective as lye peeling. But its use in continuous operation is the major limitation for its industrial application. Puértolas, Saldaña, and Raso (2016) reported the use of PEF treatment for peeling of whole fruits and vegetables at electric fields of 4 kV/cm or lower. PEF could be used to reduce the force required to remove the peel from the rest of the pulp, and therefore facilitate the peelability. Toepfl (2012) gave PEF pretreatment (1–7 kJ/kg) to tomato and observed that peel can be easily removed, similar than after a steam treatment. Literature shows an evidence of fruit and vegetable peeling using combined heating techniques. Peeling of potato and other vegetables using infrared combined with other sources of energies can result into skin removal but needs water and other mechanisms for complete removal of peel (Weaver, Huxsoll, & Graham, 1976; Willard & Miles, 1968). Singh, Gururani, and Goswami (2017) studied the microwave assisted peeling of ginger rhizome at 160–480 W power and 1–5 min exposure time. The surface cracks were observed by them on the skin of rhizome, but at the same time central core became black and gave smoky odor. The core of the rhizome contains more moisture, hence high localized temperature was reported by them in microwave environment which developed the black color due to the burning of its fibrous material. Further, the burned fibrous material developed a smoky odor. They concluded that the localized temperature generation by microwaves and burning phenomenon seriously causes the quality deterioration in the whole rhizome.

A novel sustainable infrared assisted peeling has a potential to reduce water usage and wastewater disposal while producing high quality peeled products without using lye (sodium hydroxide or potassium hydroxide) and water (Li, 2012; Pan et al., 2011; Pan et al., 2009). As infrared (IR) radiation heating, does not require any heating medium, such as lye, water, or steam, this technique could have potential to utilize as a novel dry-peeling method for soft fruits, vegetables, and tubers peeling. The higher range of operating temperature of IR can be effectively adapted for microbial decontamination of biological materials (Hamanaka et al., 2011). Fresh materials like ginger have a high surface microbial load in the form of yeast, mold, and soil born spore-forming bacteria. Although it has good antimicrobial properties, surface contamination of rhizome always affects the quality and shelf life (Staack, Ahrné, Borch, & Knorr, 2008). The peel of rhizome causes resistance to the heat and mass transfer during various processing operations like drying, cooking and hence unpeeled ginger requires more processing time and energy (Alvi, Khan, Sheikh, & Shahid, 2003; Eze & Agbo, 2011). It is recommended to remove outer peel when ginger rhizomes are used for extraction of essential oil, gingerol and other nutraceutical compounds (Graziani et al., 2003; Kate et al., 2016).

Food material in contact with far-IR radiation (3.0 to 1000 μm) and the mechanism of changes in the molecular vibrational state leads to rapid radiative heating. This rapid radiative heating is beneficial over conventional heating that causes surface deterioration, overheating, oxidation, charring, impingement damage, low yields, difficult emissions, and high energy costs. The IR heating improves product quality and safety and has not any side effect on the human health (Krishnamurthy, Khurana, Soojin, Irudayaraj, & Demirci, 2008; Pan, 2015; Rastogi, 2012). Some studies on IR peeling of tomato were already done by Li (2012), Li, Pan, Atungulu, Wood, and Mchugh (2014) and Pan et al. (2009). Also, Li et al. (2014) studied the possibilities of IR peeling of different sizes peach fruit while Wang et al. (2016) gave the feasibility of IR assisted peeling over conventional methods. Pan and El-Mashad (2018) reported the successful applications of infrared peeling of some fruits and vegetables by summarising their pilot plant results. They suggested the food industry to adopt the infrared peeling method instead of traditional lye and steam peeling to get better quality products. But the exact mechanism of skin separation of a product like ginger with uneven geometry during IR heating is still not available.

The detailed study on dry peeling of the fresh ginger rhizome is not reported in the literature. Also, there is no side effect of infrared radiation on the composition of whole ginger rhizome other than moisture loss (Jihène, Amira, Saber, & Fethi, 2013). Further, there is a great demand for alternative sustainable peeling technology from ginger processors. Hence, the present study was aimed to develop a sustainable and non-chemical IR assisted dry peeling method for ginger rhizomes and optimize the process for a high quality peeled product with a better yield.

2. Material and methods

2.1. Material collection

Fresh matured rhizomes of ginger (*Zingiber officinale* Roscoe) were procured from local market of ISPAT, Rourkela in the month of June. Collected rhizomes were preserved in a deep freezer at −18 °C. One lot of the sample was used in experiments only up to one week. Before the experiment, preserved raw ginger rhizomes were kept at ambient for 1 h to thaw the surface moisture and regain the natural softness. Each rhizome was washed thoroughly with potable water to remove the adhered foreign matters such as soil particles and other microflora. The physically spoiled and damaged rhizomes were removed.

2.2. Moisture content

Single stage hot air oven method (AOAC, 1995) was used for direct determination of moisture content of rhizome. Fresh rhizome sample was crushed in pestle and mortar. A 5 g sample of the crushed rhizome was kept in a previously dried petri dish and placed in the hot air oven, maintained at 105 ± 5 °C. After 12 h, the petri dish was taken out, covered with its lid and put into the desiccator to cool it to the room temperature. The moisture content of the sample was calculated using the following equation:

$$\mathrm{MC} = (\mathrm{W}_1 - \mathrm{W}_2)/(\mathrm{W}_0) \times 100 \tag{1}$$

where, MC is Moisture content of the crushed sample, (%wb), W_0 is initial weight of the sample (g), W_1 is weight of the sample and dish