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Methods of Peeling Fruits and Vegetables

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3.1 INTRODUCTION

Peeling is a common unit process for many fruits and vegetables to produce fresh-cut, minimally processed, and canned food products. The peeling process intends to remove the inedible or undesirable layer of rind or skin from raw produce. Through the peeling process, peeled products are prepared to meet high quality and safety requirements for human consumption or for other forms of subsequent processing, such as dicing, cutting, and canning. In food production lines, the peeling operation represents an important preparatory step, and it is typically performed at the initial stage [1]. After peeling, the appearance, texture, flavor, or nutrient values of the peeled product may be altered from raw materials. Hence, the peeling process can significantly contribute to changes in the storability, palatability, digestibility, and bioavailability of final food products [2].

Historically, manual peeling was the most widely adopted approach for thin skin removal and nowadays is still in practice for certain high-value fruits, such as mangoes [3]. The simplistic goal of manual peeling is to remove peels with as little loss as possible of the usable food materials [4]. Industrial peeling methods that are adaptable to large-scale process operations were successfully developed around the 1940s to 1950s to reduce labor, time, and waste involved in the peeling process [1]. Hot lye peeling and steam peeling are two widely adopted methods suitable for peeling a broad variety of fruits and vegetables, such as potatoes, tomatoes, citrus, sweet potatoes, carrots, pumpkins, pears, peaches, and apples [3]. In recent years, the reduction of energy and water consumption involved in the peeling process has become an important consideration due to the dwindling water supply and ever-tightening environment regulations [1, 4]. Producing high quality peeled products in a cost-effective manner using less water and energy drives the sustainable development of novel peeling technologies.

3.2 PEELING METHODS: CONVENTIONAL

As a unit operation, peeling can be realized by means of mechanical, chemical, or thermal treatments as well as any of their combinations. Common industrial peeling methods and emerging peeling techniques are described in the following sections.

3.2.1 MECHANICAL PEELING

Mechanical peeling utilizes knives, blades, or abrasive devices to remove the undesirable part directly from raw food materials [5, 6]. Thereafter, skin residuals are washed away using water. Since it is mostly performed in dry form at ambient temperature, mechanical peeling causes the least injury to the freshness and nutritional values of peeled products [3]. As compared to other chemical- and thermal-based methods, mechanical peeling operates using less energy and with lower capital costs, and has the minimum negative environmental impact. But relatively low throughput and high peeling losses (23–30%) limit its application to some high-value fruits and a few root vegetables that are difficult to peel using other means. Common mechanically peeled products include citrus
fruits, pears, pineapples, bulb onions, carrots, squashes, casavas, and other tubers [7, 8].

Mechanical peeling can be classified as abrasive peeling and non-abrasive knife peeling [9]. In abrasive peeling, food materials, such as carrots and potatoes, are treated in a batch or continuous process equipped with abrasive elements, such as stiff brushes, carborundum rollers, and revolving bowls or drums with abrasive surfaces along the inner wall [10]. The abrasive element removes the outer skins through the shear stress developed at the peel–flesh interface. In the non-abrasive peeling method, stationary knives or razor-like blades are used to remove tough-skinned product by pressing the cutting tool against the surface of the rotating materials [3, 4]. Abrasive peeling and non-abrasive knife peeling can be integrated into one single process, which is usually used for tough-skinned vegetables like parsnips, swedes, and turnips. Such a design allows products to be treated in sequence by the abrasive devices and knife tools with adjustable rotating speed and controlled depth of knife penetration, yielding a finished product with a much cleaner cutting surface. Cutting tools and abrasive elements can be custom-designed to match the geometrical characteristics of the food products and the mechanical properties of the skin to be peeled. Variability in product shapes and sizes, the difference in skin thickness, texture, and strength of skin adhesion to the flesh are the key considerations in the design of mechanical peeling devices.

### 3.2.2 Lye Peeling

Lye peeling, also known as caustic peeling, is a chemical method used for peel removal of thin-skinned products, where raw food materials are exposed to a heated solution containing caustic chemicals (most commonly, sodium hydroxide or potassium hydroxide) that can dissolve the skin. After treatment with lye, the loosened skins can be removed either by high-pressure water sprays or abrasive peeling elementators, usually a perforated rotary drum or a mechanical pinch roller [2].

Lye peeling can be further divided into two categories: wet lye peeling and dry lye (dry-caustic) peeling. The wet lye peeling is carried out by immersing products into a concentrated lye solution of 8–25% at an elevated temperature from 60 to 100°C for a short residence time (15–30 s) [3]. Fundamentally, the presence of hydroxyl (OH–) group in lye solution cleaves the α (1–4) bonds of individual galacturonic acid units in polysaccharides of skins [11]. As it moves further into the product’s inner tissues through the diffusion mechanism, the lye solution dissolves the pectic and hemicellulosic materials and weakens the network of cellulose microfibrils, thus loosening the skin [12, 13]. In some cases, different chemical additives, such as surfactants or wetting agents, are added to the lye bath to improve peeling efficiency or to reduce lye concentration while maintaining the peeling effectiveness [1, 14].

Dry-caustic peeling is a modification of the wet lye peeling method. Instead of soaking products in a hot lye bath, a lye solution is sprayed onto product surfaces under a high-temperature environment, where thermal energy is utilized to accelerate lye peeling activities [15, 16]. The dry-caustic peeling combines the effects of chemical reaction and thermal shock to soften the skin so as to reduce the use of water and chemicals during the peeling process [17, 18]. As a result, it has fewer waste disposal concerns in comparison with the conventional wet lye peeling method.

Wet lye peeling is by far the most popular technique used in commercial peeling processes, and it has been applied for a wide variety of fruits and vegetables, like tomatoes, sweet potatoes, potatoes, peaches, guava, pears, and apricots. Its great suitability for various products, the ease of process control and automation, high peeling quality, and efficiency are practical advantages for industrial-scale operation [9]. Product immersion time in the lye solution, temperature of the hot lye bath, and lye concentrations are the three major controllable factors that affect the total usage of chemicals and final peeling quality [19, 20]. Lye diffusion coupled with heat penetration may cause cellular injury and discoloration in tissues adjacent to the skin, resulting in a “heating ring” appearance, which can become quite pronounced for certain products such as potatoes, sweet potatoes, and peaches, and considerably harm the sensory quality. Effluents from lye peeling containing organic loads (BOD and COD) with high pH values (11–13) cannot be directly released to the environment without appropriate neutralization treatments [3]. The waste disposal problem and serious salinity contamination inherent to the traditional wet lye peeling process become the major issues for food processors [21].

### 3.2.3 Steam Peeling

The steam peeling technique involves placing raw fruits or vegetables inside a pressure vessel, and exposing them to high temperatures and pressurized steam for rapid heating in a short period (15–30 s). As the pressure is released, thermodynamic changes at the product surface cause peel detachment [12, 22]. The loosened skins are subsequently removed by pressurized water spray or mechanical pinch rollers [12]. As a chemical-free method, steam peeling has been increasingly adopted by the food industry as a replacement for the lye peeling of potatoes, tomatoes, pimiento peppers, sweet potatoes, and other vegetables [12, 23–25]. The main advantages of steam are the reduction of chemical contamination and the reduced salinity issue in wastewater treatment as compared to lye peeling. Inferior appearance, decreased firmness, and high mass losses are the major drawbacks of the commercialized steam peeling technique. Modifications of the conventional steam method, such as high-pressure steam peeling with flash cooling, lye–steam peeling, and freeze–heat peeling, were investigated in the past number of decades, targeting the minimization of peeling loss and improvement in the quality of peeled products [1, 3].

### 3.2.4 Flame Peeling

In this thermal-based peeling method, a flame is used to scorch the outer layer of products at extremely high temperatures...
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(>1000°C) in a controlled short time frame (1–3 s) [3]. Products are passed through a furnace tunnel equipped with gas burners that are designed to provide adjustable and adequate thermal intensity in a uniform manner. Flame peeling is applied mainly to fruit and vegetable materials that contain extremely high moisture content, such as peppers, garlic, and onions [6, 26, 27]. Sufficient heat capacity of materials with high moisture content allows relatively easy burn-off of the outer skin of the material without overheating the product’s internal flesh [10]. The main advantages of flame peeling are (1) it can reduce the microbial populations, thus increasing the shelf stability, and (2) it can preserve the ascorbic acid content. Since flame peeling involves the relatively complicated construction, installation, and maintenance of equipment, the high capital outlay precludes its adoption by small-scale food processors [27].

3.3 EMERGING PEELING TECHNIQUES

Over the years, novel and sustainable peeling techniques have been increasingly studied and developed to reduce the usages of chemicals, energy, and water in the conventional peeling methods. Recently reported alternative peeling techniques include infrared dry-peeling, enzymatic peeling, ohmic peeling, and ultrasonic peeling.

3.3.1 INFRARED PEELING

Infrared peeling has been developed as a sustainable and promising peeling technique that can eliminate the use of any chemicals and any heating media like hot water or pressurized steam to promote skin separation [2, 28]. Rapid heating of the product surface at a low heat penetration depth (<1 mm) is achieved by utilizing non-ionizing radiation from far- and mid-infrared wavelengths. As a result, only a shallow layer of product surface is subjected to the intense infrared radiation, which causes the skin to loosen enough to be washed away easily. Because of the rapid surface heating characteristics of infrared, the edible inner part of the product stays at a low temperature (<30°C) during infrared peeling, thus maintaining minimal changes in the quality and nutritional values of the peeled product [29, 30]. Since no water is used during infrared heating, this process is referred to as the infrared dry-peeling method [28]. When compared to lye peeling outcomes, infrared dry-peeling produces similar peelability, less weight loss, and comparable product firmness and appearance [31].

Bench-scale and pilot-scale infrared dry-peeling systems were designed, built, and tested for tomatoes, pears, and peaches [21, 32]. Evaluations of a gas-based flameless catalytic infrared peeler and an electricity-based infrared peeler were conducted in pilot-plants and multiple commercial tomato processing facilities over several growing seasons (2010–2018) [9]. The infrared dry-peeler consisted of three major sections: an infrared heating section, a vacuum section, and a pinch roller section [9]. Infrared-peeled tomatoes showed thinner peel-off skin, better product integrity, and firmer texture than steam-peeled tomatoes [9]. Because it is a chemical-free process, tomato skins received from infrared dry-peeling can be reutilized as a byproduct [9, 30]. Further, there is a lower cost in wastewater treatment. Given these competitive advantages, this alternative technique to lye/steam peeling could herald a step-change for the food peeling process. Enhancement of the overall heating rate and uniformity for products varying in shapes and sizes while achieving an industrially acceptable throughput need to be addressed before this novel technique becomes a commercial reality [14, 29, 33, 34].

3.3.2 ENZYMATIC PEELING

Enzymatic peeling is a biological peeling method. Polysaccharide hydrolytic enzymes such as pectinases, hemicellulases, and cellulases can be used to infuse into the surface of fruits and vegetables, resulting in a weakened adherence of peel to flesh because of the degradation of the pectin matrix and the breakdown of the hemicellulose–cellulose network in fruit epidermal and hypodermal layers [3, 35]. Polygalacturonase (PG) and pectin methylesterase (PME) are commonly used enzymes to hydrolyze the pectin materials in plant cell walls and middle lamella. For different fruits to be peeled, process parameters such as temperature, pH values, enzyme type, and concentrations are the key optimizable variables to achieve successful bioseparation [36]. Enzymatic peeling has been studied in several types of fruits, including citrus, grapefruit, and stone fruit [35–38]. It is advantageous that this method does not require extensively harsh treatments often seen with chemical and thermal methods [34, 36].

3.3.3 OHMIC PEELING

The ohmic heating technique was investigated for the tomato peeling process [14]. Ohmic peeling is achieved by electro-heating of the tomato surface by controlling the electrical conductivity of the peeling medium, where the tomato product is immersed in a sodium chloride or sodium hydroxide solution [39]. During the ohmic peeling, each tomato acts as an electrical resistor and generates heat when electricity is passed through it. The dissipation of electrical energy into heat allows rapid and uniform heating throughout the tomato surface. Bench-scale studies showed some promise that the combined lye-ohmic peeling can improve the quality of peeled tomatoes and reduce the peeling losses and lye consumption [9].

3.3.4 ULTRASONIC PEELING

Ultrasonic peeling involves using low-frequency ultrasound (20–100 kHz) to treat fruits or vegetables that are submerged in high-temperature water. The ultrasonic cavitation effect through successive compression and rarefaction of high-intensity sound waves is utilized to detach the skin from the flesh [3, 34]. The synergistic effect of power ultrasound with hot water is critical to achieving the desired peeling quality [40]. This method was primarily investigated for the tomato industry to replace the use of lye.
3.3.5 Others

Other peeling methods, such as cryogenic peeling, vacuum peeling, acid peeling, and peeling with ammonium salts or calcium chloride, have been investigated in the past few decades [1]. These methods can be considered as modifications of the above-mentioned conventional methods. Successful commercialization of these other alternatives has been hampered due to the low throughputs and/or high processing costs [3].

3.4 Peeling Fundamentals

The mode of action associated with any chemical- or thermal-based peeling process usually combines biochemical and biophysical changes occurring at the product’s outermost surface and adjacent inner layers. In steam peeling, for example, thermal shock induced by the pressurized steam strikes on the product’s outermost surface first, causing the melting and reorganization of cuticle waxes at the product’s epidermal layer which is known as the phase transition [9, 12, 41]. As the heat transfers from the surface into the product’s inner tissue, the increased temperature leads to the cell wall rupture. This vaporization of cellular fluids moves to the adjacent epidermal layer, thus accelerating various biochemical reactions at the product’s inner layers. The occurrence of various biochemical reactions (e.g., hydrolysis of polysaccharides and degradation of pectin) results in microstructural changes in the product’s epidermal and hypodermal layers, and finally causes the separation of skin from flesh [11, 12, 31]. After peeling, changes in product quality, such as texture and nutritional content, are attributed to the thermal softening or chemical degradation in the peeling process, where a kinetic modeling approach is typically employed to describe any chemical process within the product’s surface tissues [42, 43]. In terms of transport phenomena, many peeling processes involve complex heat and/or mass transport processes inside and outside of the food product that may possess a unique skin structure. Knowledge of the skin anatomy and fruit physiology can facilitate the evaluation of the multi-physicochemical transport phenomena underlying a peeling process.

An integrated approach of experimental observations and predictive modeling analysis has certainly enriched the elucidation of skin detachment behaviors in the peeling process. Numerical simulations of the transient heat transfer inside irregularly shaped tomatoes in conjugation with biomechanical measurements in the skin membrane allow an interpretation of the peel loosening and cracking phenomena (i.e., the case of infrared peeling of tomatoes) [30]. Predictions of temperature, vapor pressure, viscoelastic moduli, and shear stress evolutions in the tomato surface during the infrared heating process were quantitatively proposed and verified [13, 29, 30]. At the cellular level, a microscopic analysis evidenced that the peel loosening was observed as the melting of extracellular cuticles, collapse of surface cellular layers, thermal expansion, and severe degradation of cell wall structures. These factors contribute to the increased peel stiffness and reduced peel adhesiveness [30, 31]. Skin crack behaviors were attributed to the rapid surface heating of infrared radiation, which reduced the skin failure strength and caused a build-up of vapor pressure under the skin membrane. When the vapor accumulated to a certain level, skin cracking can occur as the shear stress in the skin membrane exceeds the critical rupture stress [30].

Mechanistic understandings of a peeling process can provide valuable insights into the development of new peeling processes and the design of new peeling equipment. For example, in the design of the first infrared peeler where the infrared heating section must accommodate tomato populations of various shapes and sizes, curve-shaped infrared emitters were custom-made to match the fruit’s geometric features. The curve-shaped infrared emitters promote intensive and uniform surface-to-surface radiation that can rapidly heat the fruit surface from room temperature to boiling temperature in about a few seconds [9, 21]. Immediately after infrared heating, a vacuum chamber was engineered to increase the formation of cracks by enlarging the pressure difference across the skin membrane, which facilitates peel cracking, allows easier subsequent peel removal and results in better peelability. Clearly, the design of peeling processes and equipment would benefit from a sound mechanistic understanding of the peeling fundamentals. Understanding the peeling basics can not only help the successful peel release but also prevents potential loss of nutritional content.

3.5 Peeling Performance and Product Quality

An adequate peeling process must be established to (1) achieve satisfactory peel removal with maximized peeling efficiency, (2) produce premium-quality peeled product, (3) minimize peeling loss, product quality changes, and pollution hazards resulting from a peeling process, (4) reduce the consumption of chemicals, water, and energy, and (5) save time, labor, and economic cost [1, 29]. In practice, reliable assessment of the peeling performance of incoming raw products is a challenge due to the substantial amount of variability in raw product physicochemical properties, cultivars, product defects, seasonal variations, and many other agronomic factors [30, 44]. Peeling evaluation can consist of both objective and subjective quantifications. A general guideline is that using a single grading scale or criterion in peeling evaluation can introduce bias and should be avoided [14, 30]. Instead, the creation of an inclusive metric from different efficiency, quality and product safety perspectives allows better and comprehensive assessments of the peeling process [31]. Some commonly used criteria include the peelability, peeling yield/loss, the ease of peeling, percentage of peel removal, peeled skin thickness, peeling residence time, peeling efficacy, peeling throughput, efficiency of water usage, energy consumption, and so on [11, 21, 31, 45, 46]. Additional consideration may also be given to overall economic efficiency. Different evaluation matrices can be developed to quantify the peeling performance, such as raw materials to be peeled, and the desired final products.

Commercial processors are not concerned with only the peeling performance but also the safety and quality of peeled products. During peeling, removal of the skin induces
mechanical injuries in fruits and vegetables due to cellular damage of the outer pericarp surface that protects the inner edible tissue. Levels of food safety and quality are crucial concerns in peeling processes. Because the increased susceptibilities to deterioration such as enzymatic changes and microbial contaminations can take place at the peeled surfaces anytime during food processing and handling, the quality and shelf-life of peeled products may be compromised [6, 47, 48]. Accordingly, industrial quality controls of peeled products include visual appearance, texture, flesh color, taste, nutrient loss, integrity of peeled product, and so on. A sampling protocol for incoming products and fruit tagging procedures, like the radio frequency identification (RFID) method, are practical options to monitor closely any quality changes throughout the peeling process [14]. Novel techniques for quality control by means of digital imaging analysis, analytical spectroscopic techniques, dynamic thermal analysis, and magnetic resonance imaging have been explored in order to achieve the best quality assurance and management [13, 49, 50].

3.6 PEELING SUSTAINABILITY

Conventional peeling operations can consume extensive amounts of water and energy, and inevitably generate waste that requires additional waste management to avoid contaminating the environment [4]. In recent years, the long-term water supply concerns and the enforcement of wastewater discharge regulations have exerted environmental pressure and financial burden on food processors [28, 34, 51, 52]. Such new challenges for the fruit and vegetable processing industry have created an incentive and strong desire to develop sustainable and cost-effective peeling alternatives that can reduce the peeling wastewater, water and energy usage, and overall cost of the peeling process [9, 31]. Overall, the development and appropriate selection of peeling methods need to consider the sustainable aspects in terms of reducing energy and carbon footprints, minimizing chemical contamination, and improving water-use efficiency.

3.7 FINAL REMARKS

Peeling is a widely used process to produce various premium-quality products in the fruit and vegetable industry. As a unit process, peeling can be water- and energy-intensive. The selection of a proper peeling method for different fruits and vegetables can impact the high-level production of finished products: not limited to the product quality and safety, but also the inherent waste management and operating expense. Most popular industrialized processes that were developed a few decades ago may result in enormous amounts of peeling effluents with high costs of wastewater handling and disposal. Future endeavors would be engaged with the development of sustainable and cost-effective peeling alternatives that can reduce water, chemical, and energy consumptions and minimize wastewater generation while producing high-quality products. A holistic approach must be taken to optimize any emerging peeling technique that can be effectively and economically applied to a wide range of food products.

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