DEVELOPMENT OF A NOVEL TOMATO (*SOLANUM LYCOPERSICUM*) PEELING PROCESS USING POWER ULTRASOUND TECHNOLOGY

By

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To Luke Ryan Redon, my angel in heaven
(January 16, 1989-January 26, 2011)

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LIST OF ABBREVIATIONS

AMS	Agricultural marketing service
ANOVA	Analysis of variance
CFR	Code of federal regulations
CMVS	Color machine vision system
DPPH	1, 1, diphenyl, 2 picrylhydrazyl
DNA	Deoxyribonucleic acid
EDTA	Ethylenediaminetetraacetic acid
EPA	Environmental protection agency
ERS	Economic research service
FAO	Food and agricultural organization
FDA	Food and Drug Administration
FRAP	Ferric-reducing antioxidant potential
GMP	Good manufacturing practice
IR	Infrared
JBT	John bean technologies
NASS	National agricultural statistics service
ORAC	Oxygen radical scavenging activity
PBD	Process block diagrams
PG	Polygalacturonase
PME	Pectin methyl esterase
PU	Power ultrasound
PZT	Piezoelectric lead zirconate titanate

SAS	Statistical analysis system
SD	Standard deviation
SEM	Scanning electron microscopy
SFC	Solid fat content
SOD	Superoxide dismutase
SONAR	Sound navigation and ranging
SS	Soluble solids
TA	Titratable acidity
TA	Texture analyzer
TPTZ	2,4,6-Tri (2-Pyridyl)-S-Triazine
USDA	United states department of agriculture
UV/VIS	Ultraviolet/visible
CIELAB	Commission Internationale de L'Eclairage

Abstract of Dissertation Presented to the Graduate School
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DEVELOPMENT OF A NOVEL TOMATO (*SOLANUM LYCOPERSICUM*) PEELING PROCESS USING POWER ULTRASOUND TECHNOLOGY

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Peeling is one of the most important unit operations in tomato processing. Steam/hot water and lye peeling have been the most commercialized methods in the U.S. However, lye peeling is more preferred among processors due to its association with higher product yields and better product quality. In the recent years, tomato-processing industry is facing ever-toughening environmental regulations, which call for chemical-free alternatives to replace lye peeling. In this study, the development of power ultrasound (PU) as a novel alternative chemical-free method was investigated. Tomatoes were treated with lye (10%) and PU (20 kHz, 1500 W) and steam for 45, 60 and 120s at 97 ± 3°C, respectively, and peeling losses (%) in addition to peeling performance based on a subjective ease of peel score (from 1-difficult to peel to 5-very easy to peel) after treatments was determined. Effects of PU peeling on the quality parameters (firmness, pH, soluble solids (SS), titratable acidity (TA), color) were also evaluated. Results showed no significant differences ($P < 0.05$) in ease of peeling scores of lye compared to PU. Peeling losses were significantly ($P < 0.05$) lower in tomatoes treated with PU compared to and steam. The firmness (N) of PU (15.4 ± 7.3;

18.2 ± 2.8) treated samples was significantly ($P < 0.05$) higher than lye (12.9 ± 6.1; 12.8 ± 3.5) and steam (2.62 ± 0.83; 2.94 ± 0.47; 3.44 ± 1.03) at 45 and 60 s, respectively. Although there was some variability in the pH, SS, TA and color, the processing quality of the tomatoes were preserved with the exception of lycopene and color in steam peeled tomatoes. In conclusion, PU may be a promising alternative to lye and steam for tomato peeling and its technological advancement in the tomato-processing industry.. Additionally from this study, it can be suggested that PU technology as an alternative peeling technology for the conventional (lye and steam) is economically and financially feasible. Empirically, it was found that a tomato cannery plant potentially installed with PU as a peeling technology may be 10 and 12 K$ more profitable than lye and steam respectively.

CHAPTER 1
INTRODUCTION

Tomatoes (Solanum lycopersicum) are regarded an important agricultural commodity in both California and Florida, and have been rated the fourth most commonly consumed crop in the USA (United States Department of Agriculture Economic Research Service [USDA ERS] 2012). This rating may be attributed to their renowned versatility as a processing crop, as well as their essential role in the diet as a vital source of vitamins (C and E) (Rao and Choudhury 1981). Additionally, tomatoes and their products are rich in health-promoting phytonutrients, such as phenolics and flavonoids, with lycopene being the most abundant, attributing to and merited by their strong antioxidant activity and status as a functional food respectively (George and others 2004).

Approximately 80% of tomatoes produced in the USA are consumed in processed form which often requires peel removal and are available in a variety of products including juice, purees, pastes, ketchup, sauces, salsas, soups and canned tomatoes (whole or diced). Peeling is the first unit of operation performed before the manufacture of several processed tomato products (mainly whole, diced and chopped) (Arthey and Dennis 1991; Das and Barringer 2006). This process is crucial for maximizing the efficiency of processing equipment, facilitating uniform thermal processing and achieving palatability of the final product (Fellows 2000). According to literature (Fellows 2000; Das and Barringer 2006), various methods have been utilized for peeling, including the use of lye, steam, flame, cryogenics and enzymes. However, the most commonly commercialized methods in the tomato processing industry at present remain to be steam and lye (Bayindirli 1994; Fellows 2000; Garcia and Barrett 2005). As compared to steam, lye peeling is more preferred among processors due to its association with higher yields and better product quality. As a result of the concern for increased cost of the disposal of lye and its detrimental impact on the environment, several studies have investigated other “novel” non-chemical peeling methods, including the use of new technologies, such as ohmic heating and infrared (IR) heating as alternatives, neither of which has been yet commercialized due to the novelty in technology development.

The use of ultrasound technology dates back to the 18th century in science and medical innovation, in addition to industrial applications. Ultrasound is defined as sound waves at frequencies (20 kilohertz (kHz)-20 megahertz (MHz)) above the audible range which humans can perceive. Based on the difference in frequency and intensity, ultrasound can be divided into two main categories: low (20-100 kHz; high intensity) and high frequency (2-20 MHz; low intensity), respectively (Feng and Yang 2011)

Dr. Paul Langevin, a French physicist, conducted studies on using low intensity ultrasound to produce underwater sound navigation and ranging (SONAR) for submarine detection (Povey and Mason 1998). This innovation led to the birth of the modern era of ultrasonics, which includes pre-natal as well as diagnostic medical imaging for cardiac conditions, and is perhaps the best-known applications of low-intensity ultrasound.

Still in its developmental stages, high-intensity ultrasonics also referred to as power ultrasound (PU) have evolved as a novel technology in the food industry. Power ultrasound is defined as high-intensity sound waves generated at a frequency range of 20-100 kHz (1 Hertz = 1 cycle/s). Localized shearing and disruptive effects of PU due to the cavitation phenomenon associated with ultrahigh pressure (1000 atmospheric pressure (atm)), high temperature (5000 Kelvins (K)) and accelerated liquid jets (156 Km/h (kilometers/hour)) are associative attributes (Clark 2007). In the mid-1990's, PU was introduced for guillotine cutting (Povey and Mason 1998) and in several food research applications, such as extraction of bioactive compounds, bioseparation and inactivation of microbial and enzymatic activities (Feng and others 2008). However, there is no published data on the use of PU for peeling tomatoes prior to processing.

Justification of Study

Although lye peeling is one of the most preferable methods used, the USA tomato-processing industry is facing ever-toughening environmental regulations, which call for alternatives to replace the currently used caustic peeling method that is intensive in chemical use and imposes high disposal costs. In contrast, steam peeling has been regarded as more economical and environmentally friendly process; however, it has been attributed to diminished product quality and considerably high peeling losses. Therefore, the development of a novel peeling technology has become an urgent goal to achieve. Power ultrasound may be a promising alternative to lye and steam for tomato peeling due to its cavitation effect as exemplified by localized ultrahigh pressure, superheated spots and accelerated liquid jets, which may significantly enhance the peeling process. We hypothesize that PU will lead to innovation in the development of a novel technology that can effectively peel the tomato, potentially eliminating the limitations of existing commercialized methods. As a benefit, peeling losses will be minimized and improved product yield, and quality of processed tomato products will result.

Objectives

The overall objective of this study was to develop a novel tomato-peeling process using PU technology and to compare its efficacy to existing commercial methods such as lye and steam. However, the specific objectives were met in this study:

First, the effects of PU on the peeling performance of Roma tomatoes were measured by evaluating the ease of peel, peeling loss and peeled thickness, as compared to steam and lye peeling.

Second, the physiochemical properties of the treated tomatoes were evaluated by soluble solids (SS), pH, titratable acidity (TA), color and lycopene content.

Third, the effects of peeling on the mechanical properties of the tomatoes were evaluated by peeled firmness and scanning electron microscopy (SEM) to observe any microstructural changes to the pericarp.

Fourth, a process research evaluation was conducted to determine the economic and financial feasibility of the PU peeling technology.

CHAPTER 2
LITERATURE REVIEW[1]

Tomatoes

The tomato belongs to the species Solanaceae also known as the nightshade family, attributing to its taxonomic classification, Solanum lycopersicon (Heuvelink 2005). Historically, the fruit was mainly cultivated for aesthetic value since it was thought to be poisonous analogous to its relative the “deadly nightshade” (Jones 1999). Although commonly referred to as a vegetable, it is botanically a fruit of a vine since it produces seeds for reproduction similar to other fruits (e.g., grape). The tomato fruit is believed to have originated as a wild species in the Andes Mountains of Peru in South America, later becoming domesticated after its introduction to the USA in the 17th century. It has been documented (Morganelli 2007) that in the year 1893, the USA Supreme Court declared tomato a vegetable as it was consumed as a complement to main course meals rather than as a dessert like other fruits.

There are many types of tomato cultivars, which vary in their characteristics influenced by their growth conditions and ultimately the form in which they are consumed (fresh or processed) (Heuvelink 2005). As described by Jones (1999) and Heuvelink (2005), there are 5 types of tomatoes: round, cherry, beefsteak, vine and plum tomato, which are commonly used for a variety of culinary purposes including grilling and making salads. However, as compared to all other tomato varieties, the plum tomato is mainly used for processing, primarily in the manufacture of canned tomatoes (diced or whole), tomato paste, sauce, soup, puree and salsa.

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The consumption and production of tomatoes has increased significantly, ranking the USA as the world's second largest tomato producer for both export and processing. Worldwide, tomatoes are regarded as one of the most commonly consumed and produced agricultural commodity, ranking number 2 in dollar value as compared to potatoes (Gahler and others 2003; Graziani and others 2003). Per capita use, three-fourths of tomato produce is consumed in processed form due to the popularity of products such as pizza, pasta and salsa (USDA ERS 2012). In the USA alone, the USDA ERS (2012) that the primary uses of processed tomatoes are in sauces (35%), paste (18%), canned products (17%) and ketchup and juice cumulatively (15%). Other leading countries in tomato production in descending order include the following: China, Turkey, Italy, India, Egypt, Spain, Iran, Brazil and Mexico (Food Agriculture Organization (FAO) 2011). The most up-to date statistics of tomato production by country up until the year 2005 is shown in Table 2-1 (FAO 2011).

Significance of Tomatoes in the Diet

Increased tomato consumption has been attributed to the growing interest in the many health benefits associated with the antioxidant activity of bioactives such as lycopene being the most predominant (Toor and Savage 2005). In both plants and animals, antioxidants are believed to play an important role in preventing and retarding the oxidation process of biomolecules (Martinez-Valverde 2002). Additionally, they are also classified according to their applicability and scientific scope in food systems. For example, they are also regarded as substances, which are mainly used as preservatives for preventing undesirable changes such as oxidative rancidity in certain food products (e.g., fat or oil based) (Huang and others 2005).

Antioxidants can be categorized into two broad classes within biological systems: Enzymatic and non-enzymatic. Enzymatic antioxidants include antioxidative enzymes such as superoxide dismutase (SOD), catalase and glutathione peroxidases (Issa and others 2006). Primarily, they catalyze the decomposition of highly reactive species such as hydrogen peroxide (H_2O_2) (Fang and others 2002). In contrast, non-enzymatic antioxidants include enzyme cofactors (coenzymes), oxidative enzyme inhibitors (Aspirin, Ibuprofen), transition metal chelators such as ethylenediaminetetraacetic acid (EDTA) and radical scavengers (polyphenols), which are usually of dietary origin (Huang and others 2005). Since lycopene is one of the predominant bioactive compounds in tomatoes and tomato-based products in the human diet, it will be solely discussed in this review.

The bioactivity of lycopene in disease prevention attributes to its ability to act as a natural antioxidant by scavenging free radicals and facilitating non-oxidative mechanisms such as immune response and metabolism. However, the potency regarding the bioactivity of its cis isomers may be variable due to their chemical and physical characteristics (melting points, color and geometrical configuration) (Shi and Le Maguer 2000; Hadley and others 2002). Reduction of bioactivity may be due to the conversion of all-trans isomers to cis isomers (Shi and others 1999). It is believed that cis isomers of lycopene are more susceptible to oxidative biodegradation, and may reduce their functionality in terms of health benefits. This may imply that all-trans isomers may exhibit more bioactivity; however this also depends on the stability of the cis isomers after subjection to processing and subsequent storage (Shi and Le Maguer 2000).

Lycopene

As defined by Hadley and others (2002), lycopene ($C_{40}H_{56}$) is a highly unsaturated 40 carbon acyclic carotenoid compound, which consists of 13, linearly, arranged double bonds, 11 of which are conjugated, and is mainly responsible for the red color in tomatoes and derived products (Figure 2-1). Lycopene predominantly exists in the all-trans configuration, which has been regarded as the most thermodynamically stable form (Shi and Le Mauger 2000). Consequently, due to its polyene structure, it is readily susceptible to cis-trans isomerization.

Isomerization

During the isomerization process, all of the trans-isomers of lycopene are converted to 4 cis isomers: 5-cis, 9-cis, 13-cis and 15-cis (Figure 2-1), by the rotation of 7 bonds, under the influence of chemical and physical factors. These isomers can exist as monomers or polymers. The most common physical factors mentioned in the literature (Shi and Le Maguer 2000) include oxidation by light, extreme thermal processing and active surface processing such as peeling. Furthermore, chemical factors include oxidation by exposure to metal ions such as copper (Cu_{2+}) and acidic conditions.

Physical Factors

Light

The literature (Shi and Le Maguer 2000) reported that an increase of lycopene exposure to light increased its degradation. However, research shows that in combination with heat, degradation by light was less severe. Data presented by Cole and Kapur (1957) showed the combined effects of illumination and temperature regarding the loss of lycopene in tomato pulp in air for 3 h. The researchers observed that an increase in the lux of the candles used and temperature resulted in lycopene degradation. Candles with a lux of 100 ft at 60°C and 100 ft at 110°C resulted in 18.9 and 58.3% lycopene loss respectively.

Thermal Treatment

Although thermal treatment has been implicated in increasing the bioavailability of lycopene through isomerization from the all-trans form to the cis isomer, extreme thermal conditions may result in the loss of the characteristic red color of lycopene, indicative of its degradation. Data obtained from Miki and Akatsu (1970) showed that the loss of lycopene at 130°C was 17% higher than 90°C.

Active Surface Processing (Peeling)

Traditionally, lycopene rich foods such as the tomato undergo degradation as a result of the series of surface processing techniques employed to adequately loosen the skin for removal prior to its processing. During this process, the skin, along with some portion of the pericarp, is discarded as waste, accounting for more than 80-90% of the lycopene content. As described by Cole and Kapur (1957), oxidative degradation of lycopene at 50°C results in the fragmentation of lycopene producing acetone, methylheptenone, laevulinic aldehyde and possibly other products such as glyoxal.

Chemical Factors

Metal oxidation

Metal catalyzed oxidation of lycopene has been reported to be initiated by copper stearate [Cu $(C_{16}H_{35}O_2)_2$] as the source of Cu_{2+} ions. The literature (Shi and Le Maguer 2000), reported that in the presence of copper, the loss of lycopene at 65°C and 100°C was 60% and 90% respectively.

Acidic isomerization

It has been hypothesized that lycopene may be isomerized in the stomach due to low pH which constitutes acidic conditions. Research (Boileau and others 2002) has shown that in vitro incubations of lycopene in capsules and tomato puree in commercially available stimulated gastric juice or human gastric juice obtained by endoscopy increased cis isomerization. Additionally, in vitro studies conducted (Boileau and others 2002) using ferrets supports the hypothesis pertaining to the cis isomerization of lycopene in gastric acid conditions. It was observed that in ferrets orally dosed with lycopene, there was an increase of the cis isomers from 6.2% to 17.5%.

Tomato Peeling Process

In general, tomatoes are often consumed as fresh or processed. Fresh tomatoes are defined as those that are received by the consumer directly from the farm or via a retail chain without any further processing, whereas processed tomatoes are defined as those that have been blanched, cut or peeled. During the initial processing stages, the tomatoes are washed, graded, sorted and cored (manually or electronically) after being transferred to the processing plant through flumes (John Bean Technologies (JBT) Corporation, 2011). Figure 2-2 illustrates the tomato steam-peeling process performed by the JBT Corporation, Saturno tomato peeling system. Through a series of unit operations, the tomatoes are thermally treated to break open and loosen the skins on the whole fruit. After being immerse into the peeling medium (scalding hot water) in a pressurized scalder (131°C, 0-207 kPa), the tomatoes are vacuum-cooled (20”-25”) and conveyed onto pinch rollers or abrasive surfaces to facilitate the complete removal of the peel. Usually after the peeling process, tomatoes may be canned whole or chopped into dices, slices or wedges (Garcia and Barrett 2005b).

Significance of the Tomato Skin Structure in Peeling

Knowledge regarding the structure of the tomato peel is fundamental, as it influences the efficacy of the peeling process, product yield and quality. During the peeling process, disruption of the hemicellulosic fractions in the epicarp must first occur to initiate the splitting of the tomato skin. The tomato peel is comprised of the epicarp, which is attached to the exocarp (red layer) and pericarp (flesh) (Shi and Le Mauger 2000; Garcia and Barrett 2005b; Mintz-Oron and others 2008) (Figure 2-3).

Tomato Skin Structure

Epicarp

The skin, also referred to as the epicarp (Figure 2-3), is composed of an outer epidermal layer covered with a thin cuticle made of a polyester cutin (4-10μm thickness), hemicellulose and pectins (Mintz-Oron and others 2008). This layer is extremely hydrophobic and attributes to its main function as the first line of defense to the fruit from water desiccation and environmental insults such as pests and microorganisms (Yaniga 2007).

Cutin

Cutin is described (Gunning and others 1996) as the building blocks of carbon (C) [(C16) and (C18)] fatty acids, which are synthesized by hydroxylation or epoxidation enzymatically (e.g., hydroxylases or epoxidases). During the cross linking of these fatty acids by esterification, the formation of crystalline polyester that is cutin results. The hydrophobicity of the epidermal layer is primarily due to the presence of epicuticular and cuticular waxes primarily derived from metabolites such as acyl lipids and phenylpropanoids. These metabolites are implicated in the biochemical pathway for the synthesis of fatty acids such as palmatic (C16:0), stearic (C18:0) and oleic (C18:1).

These fatty acids are embedded in the cutin matrix of the epicarp (Mintz-Oron and others 2008) and play an integral role in the outer appearance of the tomato regarding color and glossiness, while contributing to the overall texture of the fruit (Mintz-Oron and others 2008).

Acyl lipids

Generally, lipids are defined as a group of hydrophobic or amphipathic (polar or non-polar) compounds. According to Murphy 2010, plant-based lipids are acyl (fatty acid containing) molecules, for example phospholipids, glycolipids, waxes and triacylglycerol that make up the bi-lipid layer of cell membranes, in this case the tomato skin cell wall.

Hemicellulose

Hemicellulose is one of the major structural carbohydrates, which provide bulk and support to the cell wall of plants and plant-based foods. This heteropolysaccharide is derived primarily from hexose and pentose sugars (Gunning and Steer 1996).

Phenylpropanoids

Phenylpropanoids are sub-components of cutin and are defined as phenolic derivatives containing phenyl rings with C_3 side chains and the amino acid Phenylalanine (Heldt and Piechulla 2010).

Pectin

As described by Vaclavik and Christian 2007, pectins are a group of plant polysaccharides primarily composed of D-galacturonic acid linked linearly with α 1-4 bonds and esterified with methanol.

Pericarp

The pericarp and its thickness (Figure 2-3) are the main factors influencing the yield of the tomato product (Garcia and Barrett 2006b). As described by Heuvelink

(2005), the pericarp is a large layer of highly vacuolated cells (parenchyma) and vascular bundles. The outer wall surrounding the pericarp denoted the exocarp is referred to as the “red layer” (1.4-3.2 μm thickness) as it is redder in color than the peripheral pericarp. The loss of pericarp as waste in the tomato peeling process could account for 25-28% of the tomato weight as waste approximately 80 to 90% of the lycopene (Garcia and Barrett 2006b; Shi and Le Maguer 2011).

Peeling

Peeling is the primary unit of processing in the fruit and vegetable industry. The literature (Fellows 2000), defines peeling as the “removal of unwanted or inedible material” from the agricultural commodity of interest. There are several general methods of peeling used: Knife, abrasion, flame, and in addition to two commonly known conventional methods of tomato peeling, namely steam and lye (8-25% caustic soda).

Knife Peeling

During knife peeling, the fruits are usually rotated on the surface of stationary blades to remove the skin (Fellows 2000). This process can be inverted where the produce is stationary and the blades are rotating (Fellows 2000). Knife peeling is suitable for fruits and vegetables where the skin is easily removed with minimal damage or loss. Primary examples are citrus fruits such as oranges or grapefruits.

Abrasive Peeling

As implied by the name, abrasive surfaces such as carborundum are utilized during the peeling process. In most cases, carborundum rollers or rotating bowls lined with this abrasive material remove the skin, which is washed away with a continuous supply of water (Fellows 2000). This method is usually employed for fruits such as tomatoes, which must be thermally or chemically treated to loosen the peel prior to peeling.

Flame Peeling

This type of peeling involves the use of flames at very high temperatures (1000°C) where the food is rotated in a heated furnace (Fellows 2000). This method is usually applicable for peeling onions, where the outer layers and hairs are easily burned off. Subsequently, high-pressure sprayers of water are used to remove the charred remains.

Conventional Tomato Peeling Methods

The tomato-peeling process involves a series of biochemical, thermal and physical changes which aid in adequately loosening the skin for removal. Biochemical mechanisms usually involve the chemical disintegration of the cutin and hemicellulosic fractions in the tomato skin causing it to weaken and ultimately break open. High temperature conditions in the peeling medium contribute to the formation of vapor under the tomato skin. Consequently, the escape of pressurized steam due to increased internalized pressure beneath the tomato skin results in its rupture. The physical changes exhibited are an amalgamation of both biochemical and thermal effects, which enhance the bio-separation between the endocarp and pericarp resulting in the splitting of the skin simultaneously (Garrote and others 2000).

Smith and others (1997) provided a comprehensive list of the peeling methods, which have been used for tomatoes. These include hot water/steam and lye, which have been the most common, cheaper and simpler approaches used. More sophisticated and expensive methods include the following: Freeze thaw and enzymatic peeling which have not been commercialized as a result of high capital costs, low production yields and feasibility issues in food processing (Li and others 2009).

Despite the variety of conventional peeling methods employed, the efficacy of the tomato peeling is greatly influenced by several factors such as cultivar, maturity stage, processing conditions, geographical location and climate where the tomatoes are cultivated and harvested, respectively (Garcia and Barrett 2006a). However, the discussion of these factors is not the focus of this review.

Hot Water and Steam Peeling

Peeling with hot water and steam has been regarded as the most common and economical methods used in tomato processing. The literature noted that in the state of California, approximately 70% of the tomatoes are peeled using either hot water or steam (Garcia and Barrett 2006a). During the peeling process, the tomatoes are passed through a boiling water bath or steam (≥98°C, 15-60 s, 165-179 kPa or 24-27 psig), via a conveyor belt or slat elevator (Figure 2-2), into a pressurized scalder. This thermal treatment of the tomatoes causes the skins to crack and loosen.

Subsequently, the tomatoes are sprayed with cold water or vacuum-cooled to prevent overcooking (Smith and others 1997). In the peeling process conducted by the JBT Corporation, the tomatoes are pressure scaled, immersed into hot water (131°C) and vacuum-cooled subsequently. According to JBT Corporation, one unique feature of its Saturno steam pressured, scalding peeler (Figure 2-2) is that it has the capacity to peel large quantities (50-55 tons/h) of tomatoes, as well as the capability to adjust the scalding time according to the characteristics of the initial and final product.

As described by Garrote and others (2000), there are two main mechanisms, which contribute to the efficacy of tomato peeling using steam or hot water. The first mechanism involves biochemical changes in which the waxy cuticle of the skin, along with other chemical components such as pectin and hemicellulose, becomes altered and disintegrated affecting cell wall rigidity. The second mechanism involves the mechanical disruption (cracking) of the cell wall as a result of internalized pressure under the tomato skin due to vaporization.

Although hot water /steam peeling has been regarded as advantageous of being safe for the environment as compared to use of other conventional methods requiring chemicals (Garcia and Barrett 2006a), there are several inconsistencies regarding the efficacy. One such inconsistency is under-scalding, which may result in considerable difficulty in removing the peel (Smith and others 1997). Additionally, over-scalding may result in soft, mushy flesh causing high product losses (Smith and others 1997). Garcia and Barrett (2005a) have compared the efficacy of peeling with pressurized steam (83, 103 and 124 kPa or 12, 15 and 18 psig) at 121°C on tomato yield and quality in two selected cultivars (Halley 3155 and Heinz 8892), harvested in different geographical locations. Tomato peeling was found to be more effective at conditions of 124 kPa gauge (18 psig) for 45 and 75 s respectively, as compared to 83 (12 psig) and 103 kPa (15 psig). However, the researchers concluded that at both conditions (83 and 124 kPa), there was a significant reduction in tomato firmness when compared to a control.

Lye Peeling

Lye, commonly referred to as sodium hydroxide (NaOH) or caustic soda, is a chemical used as a pretreatment agent at varying concentrations (8-25%) to depolymerize the external layer of tomato skin facilitating its splitting (Shi and Le Maguer 2010). Lye peeling is usually performed by immersing the tomato fruit into a hot (60-100°C) solution of NaOH for a given time (15-60 s) period (Shi and Le Maguer

2010). The hot solution dissolves the epicuticular waxes in the epidermis by cleaving the α 1-4 bonds in the galacturonic units in pectin (Das and Barringer 2005). This compromises the strong network of cellulosic microfibrils, supported by the polysaccharide units of pectin, resulting in the release of the skin from the pericarp. Additionally, similar mechanisms exhibited in hot water/steam peeling due to increased temperature may result in the formation of pressurized vapor under the skin forcing it to rupture.

The usage of lye has contributed to many deleterious and costly effects to the environment (Li and others 2009). Since the disposal of lye is not prohibitive (Garcia and Barrett 2005a), many tomato-processing canneries dispose of their chemical wastes on fields, consequently affecting soil quality (Das and Barringer 2005). According to the literature (Das and Barringer 2005), soils that contain excess amounts of sodium ions ($Na+$), lead to soil compaction contributing to the formation of "saline-sodic soils." In saline-sodic soils, the positively charged sodium ions from the lye bind to the negatively colloidal particles in the soil, forming aggregates consequently inhibiting plant growth due to lack of aeration, low water permeability and increased soil pH (8.5) (Ondra and Ellis 1998).

As a result of the environmental concerns regarding the use and disposal of lye from tomato peeling, researchers have sought other chemical alternatives that may have less of an adverse effect on soil quality (Das and Barringer 2005). Such alternatives were potassium hydroxide (KOH), also referred to as "potash," and calcium hydroxide [$Ca\ (OH)_2$] (Smith and Hui 2004). It is believed that there are more environmental benefits regarding the disposal of KOH and $Ca\ (OH)_2$ on soil as both calcium (Ca^+) and potassium (K^+) ions play an important role in plant health. The K^+ serves an essential nutrient, and Ca^+ plays a role in the discrimination of Na^+, which is toxic to many plants (Smith and Hui 2004).

Das and Barringer (2005) compared the peeling efficacy of lye to KOH and Ca $(OH)_2$. They observed that KOH and lye were more effective as a peeling agents compared to Ca $(OH)_2$, which had poor solubility in water (0.077 g/100 mL) at 100°C. Additionally, they reported that KOH was more effective at lower concentrations (1.0 N, 1.4 N, 1.8 N, 2.1 N, 2.5 N) (12-14%) when compared to lye a higher concentration (4.5 N)(18%), both equally achieving peeling yields of approximately 79%. The mechanism responsible for the efficacy of KOH as being a more effective peeling agent is relative to the larger atomic radii exhibited in the K^+ than Na^+, making the ion more electronegative (Das and Barringer 2006). It is believed that this property enhances the potency of KOH making it a stronger base. This is attributed to the greater dissociation of OH^- that specifically cleaves the α 1-4 bonds in the galacturonic units in pectin as previously described (Das and Barringer 2006).

Although KOH has proven to be a more effective peeling agent compared to lye, one of the main reasons why it has not gained dominance in the tomato peeling industry is related to material costs. Based on the prices established by Fisher Scientific (2011) (Pittsburg PA), the cost of KOH is 2 times more than that of lye. While it is important to evaluate different technologies in facilitating more effective and environmentally friendly peeling processes, it is equally crucial to access the production costs and product yields that eventually affect the revenue. In some studies (Garcia and Barrett 2006a), lye peeling was reported to be more efficient with reference to tomato quality and not necessarily tomato yield, as over peeling has been described as one of the main associative problems. Over peeling is characteristic of the following: Low product yield, increased wastes, and poor product quality (Hui and others 2004).

Freeze-thaw Peeling

As described by Hui and others (2004), during the process of freeze-thaw peeling, the tomatoes are submerged into liquid nitrogen refrigerated calcium chloride ($CaCL_2$) or freon to spilt the tomato skin. Similar to lye and steam peeling, one of the main mechanisms involved in freeze-thaw peeling is the rupture of the epidermal cells to facilitate the subsequent removal of the skin. The rupturing of the tomato skin initiates the release of pectolytic enzymes, which hydrolyzes the pectin. Subsequently, the tomatoes are transferred into warm water to maintain and further stimulate enzymatic activities. Brown and others (2006) investigated the use of cryogenic peeling and found this method improved the peeling quality of tomatoes. They reported that when liquid nitrogen (Boiling Point-196°C) was used as the peeling refrigerant, peeling loses were reduced by 50% compared a control. Although it is evident that freeze-thaw peeling may be advantageous in minimizing peeling losses, refrigerants such as freon have been deemed hazardous to the environment as well as to humans (Miller and others 2004), warranting why freeze-peeling using freon has not commercialized.

Enzymatic Peeling

For fruits and vegetables, enzymatic peeling involves treating a particular commodity with enzymes specific for substrates or constituents, making up the epidermal layer of the skin. In most fruits and vegetables, the epidermal layer is primarily composed of structural carbohydrates such as pectin, cellulose and hemicellulose, which are responsible for peel adherence and rigidity (Págan and others

2010). Mechanistically, during enzymatic peeling, the network of the structural carbohydrates in the skin of the fruit or vegetable is broken down as a result of hydrolysis by corresponding enzymes such as pectinases, cellulases and hemicellulases respectively. Compared to conventional methods previously described, the enzymatic technique has been deemed environmentally and economically friendly, mainly attributed to the elimination of chemical and water effluent and reduced high costs pertaining to peeling losses and poor fruit quality (Págan and others 2010). Additionally, the texture and appearance of the commodity being peeled is preserved (Li and others 2009).

Toker and Bayindirli (2003) and Págan and others (2010) have reported the successful application of enzymatic peeling for peaches, apricots, nectarines and grapefruit respectively. However, there is limited published literature on the application of enzymes for peeling tomatoes. A study conducted by Li and others (2009) developed a novel IR tomato peeling method in combination with an enzymatic technique as a pretreatment method as an alternative to lye. The study used a subjective peeling scale to describe the ease of peel in which a score greater than 4.0 was acceptable. They researchers found that dipping the tomatoes in the enzyme solution for 10-60 min did not have a significant effect on the ease of peel as indicated by a score of 2.8 which indicated that the removal of peel was possible, but difficulties still exist. It was also observed that longer immersion times (60 min) resulted in poor product quality in which the texture of the tomatoes was too soft. Contrasting to the results reported by Toker and Bayindirli (2003) and Pagan and others (2010) the data reported by Li and others (2009), indicated a low efficacy of enzymatic peeling. Li and others (2009) concluded that when compared to other methods used in their study, enzymatic peeling was not deemed the most cost effective method, noticeably by high peeling losses (14.9%; enzyme-60 min) and quality degradation. Therefore, enzymatic peeling as an alternative to lye and pretreatment prior to IR peeling was not considered to be the most practical approach for tomato peeling. In most cases, the enzymatic preparations for experimentation and recovery can be costly, as the enzymes have to be genetically modified for specificity. Other challenges involving the use of enzymes are the maintenance of optimal conditions (e.g., temperature) to achieve maximum enzymatic activities.

Novel Tomato Peeling Methods

In response to the ever-increasing environmental concerns regarding chemical peeling and quality issues regarding steam peeling, some developments of alternative novel techniques have recently been constructed on a laboratory scale. These include IR and ohmic heating. Currently, such methods are still in their developmental stages, requiring optimization and pilot tests before they can be considered for commercialization.

Infrared Peeling

Infrared (IR) is a novel food technology that is delivered in the form of electromagnetic waves (beyond visible light within the electromagnetic spectrum (750 nm-1mm). The IR spectra can be further divided into 3 categories with different wavelengths: Long waves (4 μm-1 mm), medium waves (2-4 μm) and short waves (0.7-2 μm) (Richardson 2001). In the food industry, short wave IR is mainly utilized in the food industry for drying vegetables, fish, pasta and rice. This common use of short wave IR is due to the fact that the penetration for short waves is 10 times higher than long waves (Richardson 2001), a characteristic that makes IR technology very applicable for tomato peeling. Moreover, other applications of IR technology in food processing besides drying include one, roasting coffee and cocoa; two, baking of pizza; three, biscuits and bread; four, heating flour, and frying meat.

In the form of radiation, the electromagnetic energy from IR is usually emitted from hot objects (ceramic heaters, halogen tubes and metal heaters) and is either absorbed (α), reflected (r) or transmitted (t) by the food material (Fellows 2000). When IR energy is absorbed, the molecules within the food material vibrate at the same frequency of the electromagnetic waves to which they are being exposed. During molecular vibrational state, heat is created due to friction between vibrating molecules within the food matrix. Consequently, an increase in temperature in food material occurred.

Li and others (2009) illustrated the feasibility of IR energy as an environmentally friendly alternative for peeling tomatoes. They found that peeling with their prototype IR system (Catalytic Drying Technologies LLC, Independence, Kansas, USA) compared to the use of lye resulted in the similar ease of peeling, in addition to lower peeling losses. A score of 4.7 out of a total of 5.0 was reported for the ease of peel using IR as compared to lye (10%), which ranged from 3.9-4.0 (Li and others 2009). These results demonstrated a significant potential application for eliminating the use of chemicals as well as wastewater during tomato peeling.

Although the mechanisms of IR peeling for tomatoes are not fully elucidated, Li and others (2009) postulated that infrared heating facilitated the separation of the epicarp from the pericarp due to the thermal degradation of pectin and hemicellulose network in the skin causing it to lose its rigidity. Additionally, similar to the mechanism of tomato peeling exhibited in both lye and steam peeling, the molecular vibration of water molecules in the tomato pericarp at a certain frequency may result in the increase of temperature beneath the surface of the tomato skin. Consequently, pressurized steam accumulates causing the internalized pressure under the skin to escape, forcing the tomato peel to easily break open.

Li and others (2009) state that the two most attractive features of IR for tomato peeling are its ability to penetrate the food material to such a degree that it is possible to heat the food material without burning the product, which is an undesirable effect commonly exhibited in conventional heating. Furthermore, the process is non-chemical and does not require a medium such as water for peeling, thus reducing the environmental pressures associated with wastewater and chemical disposal.

Despite the reported advantages of IR peeling, limitations associated with the technology also exist. For example, uniform heating of the product may not be easily achieved, since the rate of heat transfer is primarily related to the surface temperature of the radiator and food product, the surface properties and the product shape, as specified in the Stefan-Boltzmann relationship (Fellows 2000).

Ohmic Heating

Ohmic heating, also referred to as “resistance or electro heating,” is a method used in food processing and preservation. In the past 15 years, ohmic heating technology has been successfully commercialized by the APV Baker Company Ltd, Crawley, UK. Its ohmic heating systems have been used for the pasteurization of liquid egg and pumpable particulate food products (Fellows 2000). Ohmic heating is accomplished by the passage of alternating electrical current through the food (liquid particulate) product via electrodes. The electrical resistance within the food results in the generation of heat, effectuating rapid and uniform heating throughout the product. Since heat generation is primarily based on the electrical resistance of the food, there is less chance for fouling or burning the product.

The advantages of using ohmic heating as a food processing method are many (Fellows 2000). The food product is heated rapidly as the rate of heating is only relevant to the electrical resistance of the particular food and not limited by the heat transfer coefficient as seen in IR heating. Based on these attributes, the energy conservation efficiencies may be >90%. Additionally, there is no limitation regarding the penetration depth as exhibited in dielectric heating technologies such as microwave and IR (Fellows 2000).

The application of ohmic heating in tomato peeling has been investigated by Wongsa-Ngasri (2004). In this particular study, the main objective was to determine the feasibility of ohmic heating as a peeling method for tomatoes. Since ohmic heating is ideal for liquid food products, the tomatoes had to be immersed into a salt solution of sodium chloride (NaCl), which served as the peeling medium, prior to experimentation.

The synergistic effects of lye peeling in combination with ohmic heating were also investigated. Results from the study of Wongsa-Ngasri (2004) indicated that the best conditions for ohmic heating were at NaCl concentrations and electrical field strengths of 0.01 (8060 V/m and 9680 V/m) and 0.03% (6450 V/m and 8060 V/m). These results were based on a peeling score of 4 and 5 and 5 and 4.5 respectively. In these conditions, it was observed that tomato peeling was achieved approximately within 1 min of exposure, and the quality attributes such as color and texture were retained.

The results from Lye-Ohmic peeling, the best conditions observed were NaCl+NaOH (0.01%+0.5%) at electrical field strengths of 1210 and 1610 V/m with ease of peeling scores and peeling losses of 5 (9.99%) and 4 (12.8%) respectively (Wongsa-Ngasri 2004). Additionally, a similar result was observed at NaCl + NaOH concentrations of (0.01%+1.0%) at electrical field strengths of 645V/m and 1450 V/m, both with an average peeling score and peeling loss of 4 and 11.6% respectively.

Similar to the mechanisms of tomato peeling exhibited in conventional methods, combinations of thermal, chemical, physical in addition to electrical effects were exhibited in ohmic peeling. According to Wongsa-Ngasri (2004), during the initial stages of ohmic heating in the tomato peeling process, both thermal and chemical effects of ohmic heating are exhibited. It is believed that the waxy cuticle of the tomato epicarp acts an insulation layer, temporarily inhibiting the passage of current through it. Subsequently, due to an increase of heat in the NaCl solution caused by the passage of electrical current, thermal degradation of the waxy cuticle is initiated. This degradation facilitates the passage of electrical current into both the epicarp and pericarp of the tomato over time to disrupt the hemicellulosic and pectic substances in the tomato skin, causing it to lose rigidity.

The physical effects of ohmic heating are exhibited by the phenomenon referred to as electroporation. Electroporation is defined as the formation of microscopic pores on the cell membrane, in this case, the skin of the tomatoes (Hui 2006). As time lapses during ohmic heating, charged ions on the surface of the tomato skin accumulate. Due to alternating current and forces exerted on these ions by the electrical field, the formation of microscopic pores may occur (Hui 2006).

Since electroporation has been regarded as the main mechanism of ohmic heating, it is believed that this phenomenon is attributed to the increased influx of the peeling medium into the skin of the tomato. This would be likely to facilitate the chemical degradation of the epicuticular and cuticular waxes. The increased flux of the peeling medium into the skin as a result of electroporation might be due to an increase in mass transfer, thus enhancing bioseparation of the tomato skin from the pericarp. In the case of lye-ohmic peeling, the diffusion of NaOH might be enhanced by electroporation. The formation of electro-pores results in faster reactions regarding the depolymerization of the galacturonic acids and pectic substances in the tomato skin, resulting in the separation of the peel from the pericarp.

In addition to both electrical and biochemical changes, physical changes may play a role in the splitting of the tomato skin during ohmic heating. As previously described in other peeling methods, upon the passage of alternating electrical current in the peeling medium, there is an instantaneous increase of temperature in the fruit. Consequently, the water within the tomato flesh (pericarp) vaporizes causing an internal pressure to build up under the skin leading to its rupture, facilitating the separation of the epicarp from the pericarp.

Ultrasound

As defined in the literature (Bhaskaracharya and others 2009), ultrasound is the application of sound or sonic waves oscillating at a particular frequency and amplitude (20kHz-1MHz), normally above the frequency range at which the human ear can discern. Based on the difference in frequency and sound intensity, the application of ultrasonics in food processing can be classified as 2 main categories including low (20-100 kHz) and high frequency (2-20 MHz) ultrasound respectively (Feng and Yang

2011). However, in this research, of particular interest are the applications of low frequency ultrasound primarily as an alternative for tomato peeling.

Low-frequency Ultrasound

Low-frequency (high intensity) ultrasound, also referred to as power ultrasound, is associated with both mechanical and chemical action through a phenomenon referred to as acoustic cavitation (Bhaskaracharya and others 2009). Acoustic cavitation is a phenomenon formed as a result of gas or vapor-filled cavities in a liquid, going through a series of rapid compression and rarefaction, analogous to the expansion and contraction of a spring (Feng and others 2008). During this process, the cavities (air bubbles) grow to an unstable size until they rupture, accompanied by the release of high temperature (5000 K), high pressure (1,000 atm) and formation of powerful micro jets, which may reach speeds up to 156 km/hr, generating shock waves. Through mechanical action, these shock waves can result in damage or fragmentation of material or cells (Suslick and Price 1999).

Furthermore, cavitation can be divided into 2 distinct categories: Transient cavitation and stable cavitation. Transient cavitation, as the name suggests, is short-lived, gas-filled cavities or bubbles formed if the ultrasound intensity exceeds 10 W/cm_2 with a residence time of less than a 100 ns (Feng and Yang 2011). As previously discussed, it is characterized by high physical shear and extreme temperatures. On the other hand, stable cavitation, as its name also suggests, possesses longer residence times such that gas-filled bubbles increase in size until they reaches a critical size and implode. Stable cavitation results when the ultrasound intensity in the medium ranges between 1-3 W/cm2 (Feng and Yang 2011).

Chemical effects are a result of the formation of free radicals due to increased temperatures in the collapsing cavitational bubble (Feng and Yang 2011). In the case of ultrasonic radiation in water, the water molecules are split into hydrogen and hydroxyl-free radicals, which can recombine to form molecular products.

High-frequency Ultrasound

High-frequency (low intensity) ultrasound, also referred to as diagnostic ultrasound, is most commonly used as an analytical tool associated with non-disruptive effects through the pulse-echo phenomenon. In low intensity ultrasound, the power levels are too small to cause a change in the material properties exposed to ultrasonic radiation (McClements 1995). A transducer generates the ultrasonic pulse, which travels across the sample and is reflected back from the wall of the measurement cell. Furthermore, the pulse travels back through the sample, which is detected by the original transducer as an echo. From this echo, an attenuation coefficient (α) is obtained which is used to determine certain characteristics, as well as quantify how easily ultrasonic waves can be transmitted throughout the material being analyzed (McClements 1995). For example, the solid fat content (SFC) of a food product can be determined by using ultrasonic attenuation in real time (Martini and others 2005).

Mechanism of Ultrasound Generation

The mechanism of how ultrasound is generated and introduced into a process plays an integral role in fully understanding its potential uses in food processing such as tomato peeling. Depending on the type of system (e.g., tank, airborne or probe), a basic ultrasonic processor consists of 2 or 3 major components: Generator, transducer or a sonotrode in the case of a probe system (Feng and Yang 2011) (Figure 2-4).

From a power source, high frequency electrical oscillations are created by the generator, which is then transmitted to the appropriate transducer (Walker 1963). The transducer is the most important component of the ultrasonic system of which they are 3 main types: Mechanical, magnetostrictive and piezoelectric. These electrical oscillations drive the transducer assembly and are ultimately converted into sound waves, which vibrate at a certain frequency producing ultrasound at different intensities. In the case of a probe system, a sonotrode is used to transfer the ultrasound to the treatment medium.

Mechanical transducers are most widely described as “whistles” in which a gas or liquid is used to convert mechanical energy to ultrasound (Feng and Yang 2011). In a typical situation, as described by Povey and Mason (1998), a liquid or gas is forced across an object serving as the transducer (e.g., a blade), causing it to vibrate (producing mechanical energy). Consequently, ultrasound is created, in which the intensity is dependent on the flow of the gas or liquid over the object employed as the transducer.

As the name implies, magnetostrictive transducers utilize ferromagnetic materials (e.g., nickel or iron), which changes conformation when a magnetic field is applied. Magnetostrictive transducers are usually constructed from a series of material, such as nickel or iron plates arranged parallel to each other wrapped with wire. When this wire is subjected to an electromagnetic field, the spontaneous elongation and contraction of the material produce ultrasound (Povey and Mason 1998; Feng and Yang 2011).

Piezoelectric transducers have been regarded as the most effective, and consequently the most common devices employed for the generation of ultrasound (Feng and Yang 2011). As described by Povey and Mason (1998), piezoelectric transducers are composed of ceramic discs (e.g., barium titanate, lithium sulfate), which expand or contract (oscillate) due to polarity when subjected to alternating current. Consequently, rapid oscillation of these discs produces ultrasound.

Table 2-1. Production statistics of the top ten tomato-producing countries for 2005.

Rank	Country production (International $ 1, 000)	Production (Metric tons)
China	7,463,295 C	31,644,040
USA	3,024,648 C	12,766,000 F
Turkey	2,298,221 C	9,700,000
Italy	1,851,584 C	7,814,899
India	1,800,668 C	7,600,000 F
Egypt	1,800,668 C	7,600,000 F
Spain	1,059,924 C	4,473,573
Iran	995, 106 C	4,200,000 F
Brazil	782, 705 C	3,303,530
Mexico	508, 956 C	2,148,130 F

The production in international $ 1,000 has been calculated based on 1999-2001 international prices. No symbol represents the official figure, the symbol F represents the FAO estimates and the C symbol represents the calculated figure. Source: FAO (2011).

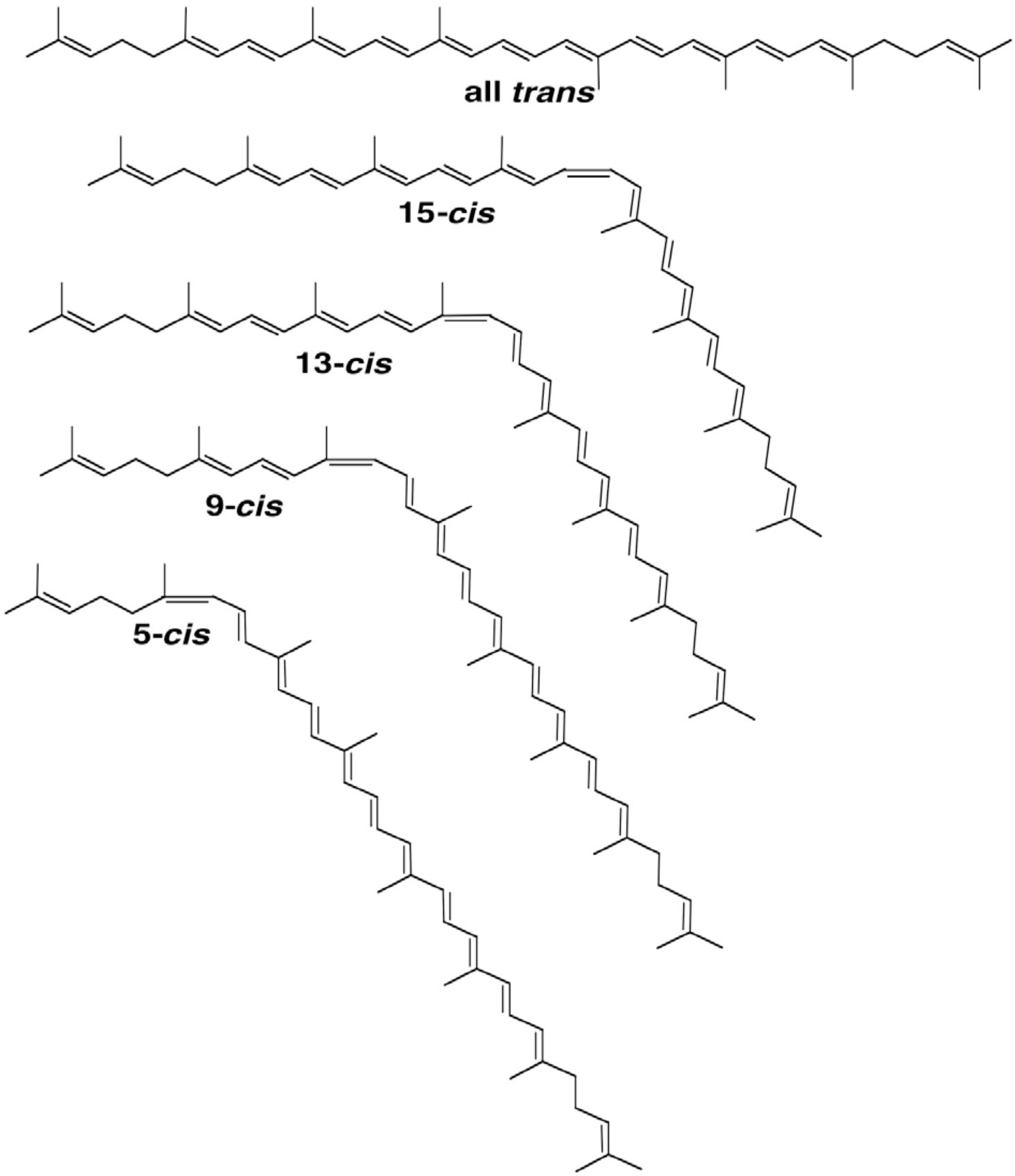


Figure 2-1. Structures of trans and cis isomers of lycopene. Source: Agarwal and Rao (2000)

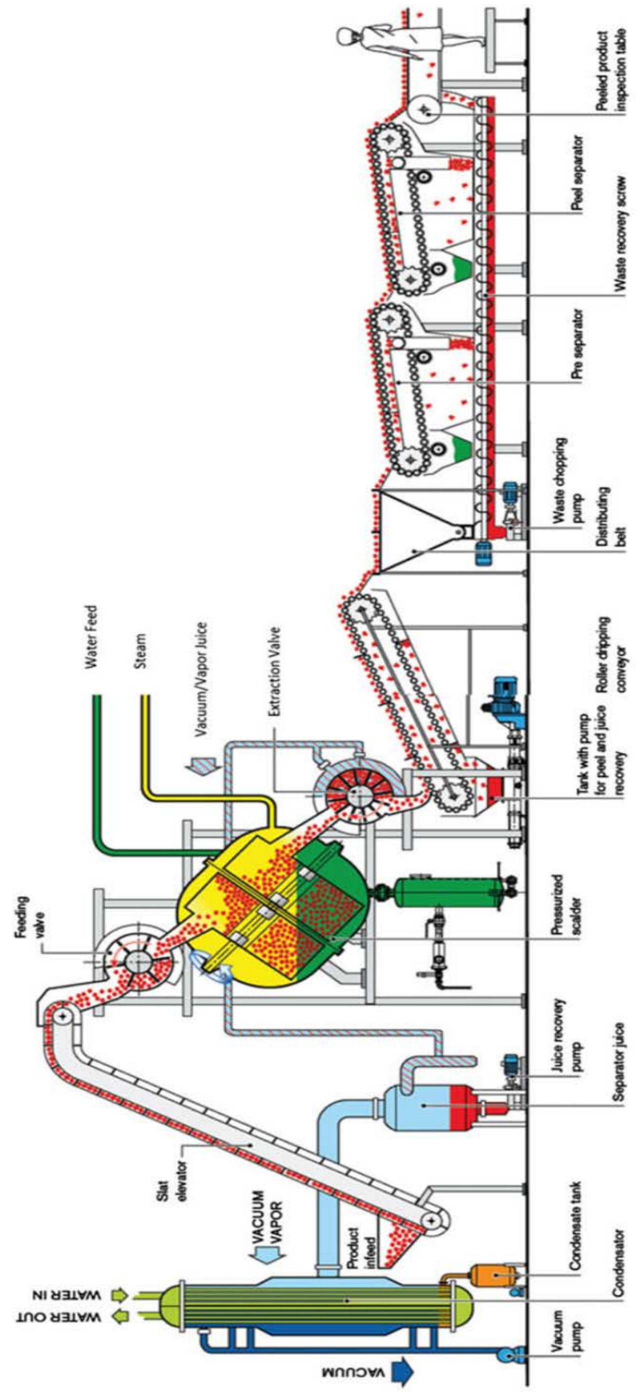


Figure 2-2. A schematic of JBT Saturno pressure scalder and tomato peeling system.
Photo credit: John Bean Technologies

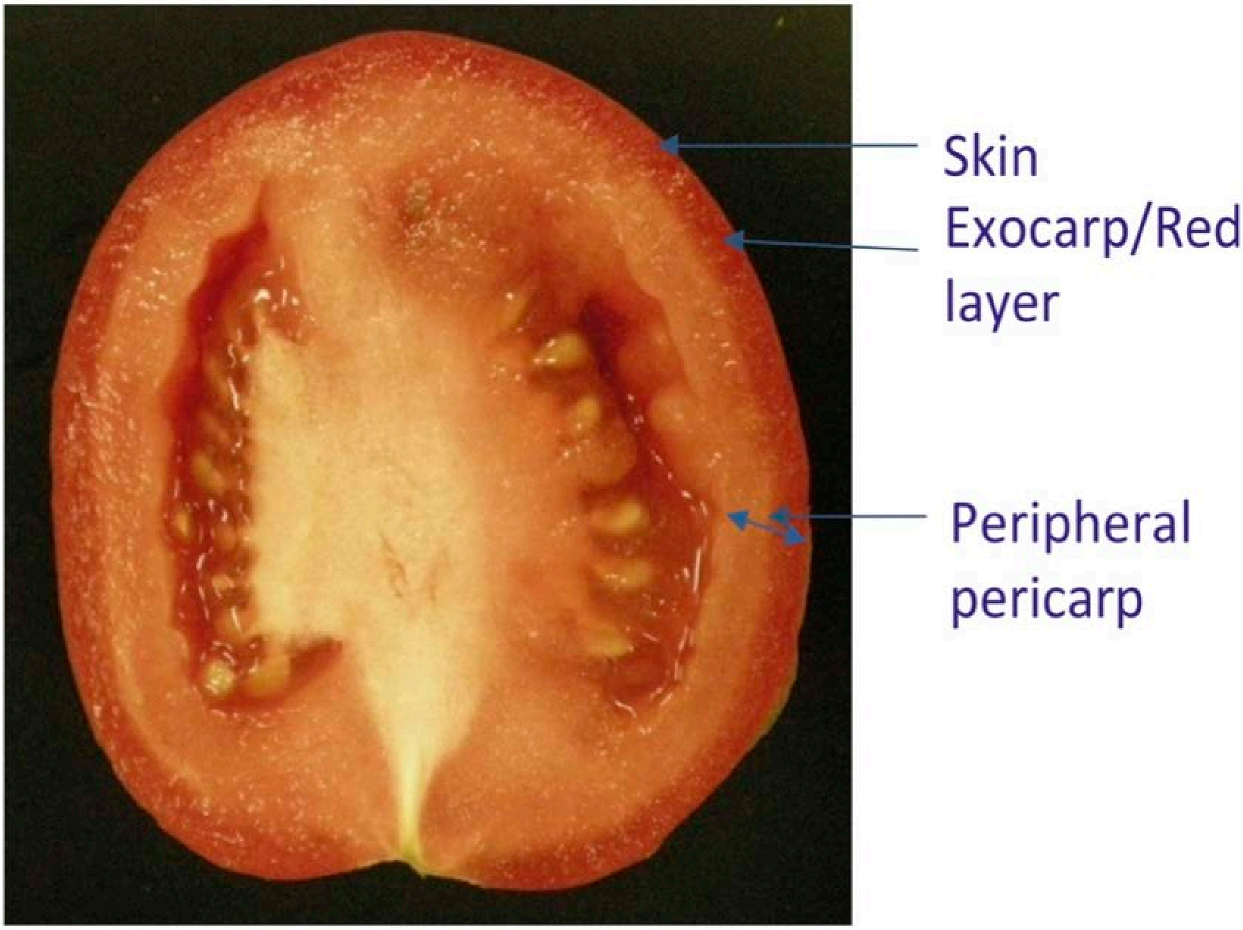


Figure 2-3. The anatomical structure of the tomato. Photo credit: University of Florida, Food Processing and Engineering laboratory.

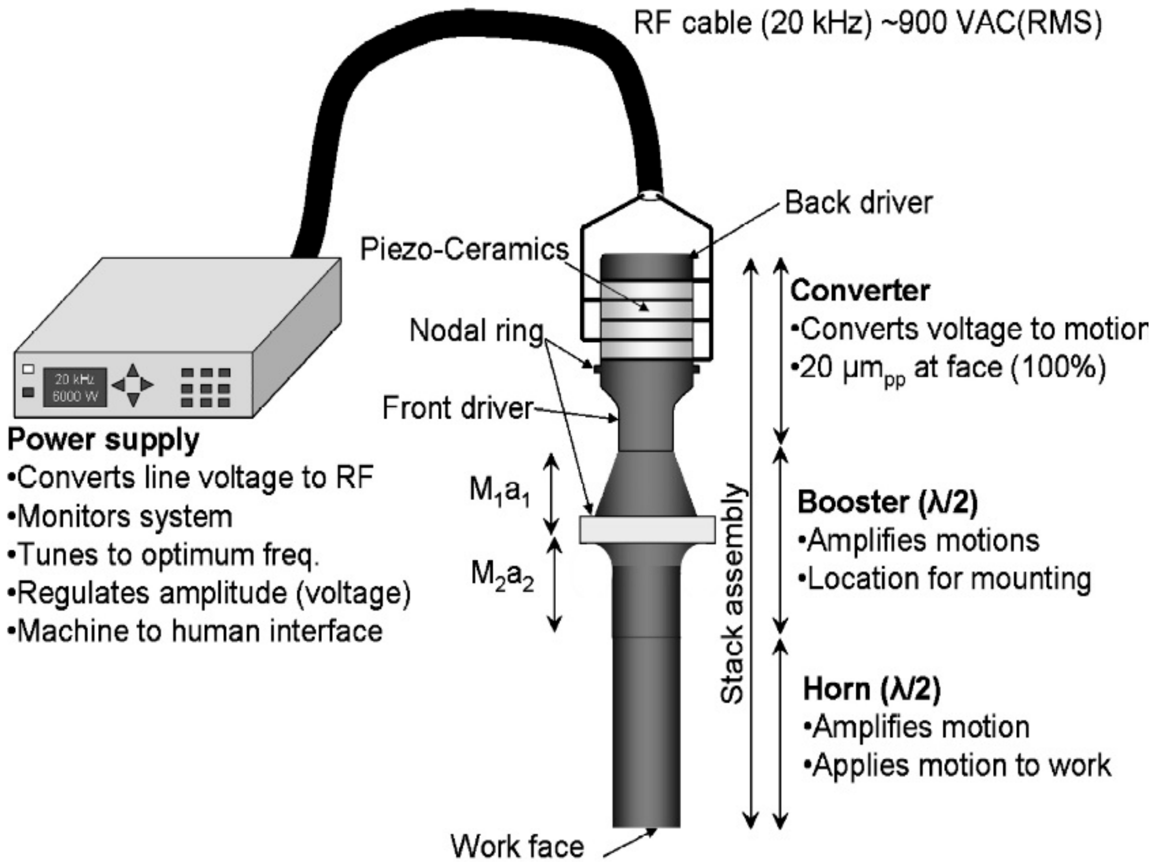


Figure 2-4. The basic components of an ultrasonic (Probe) system (20kHz). Source: Khanal and others (2007).

CHAPTER 3
EFFECTS OF PU, LYE AND STEAM ON THE PEELING PERFORMANCE OF ROMA TOMATOES

Background

As mentioned earlier, peeling is the first unit of operation prior to further processing of tomatoes into their respective products. In the literature, it was established that most tomatoes are peeled with hot lye (most desirable) or steam. According to Schlimme and others (1984), several disadvantages associated with lye peeling in particular is first the significant loss of product due to the excessive removal of the subepidermal tissues, and second, the steadily increasing cost of lye disposal in conjunction with high peeling losses.

Therefore, in the manufacture of whole peeled and diced processing tomatoes, the peeling performance (i.e., peelability) is a crucial parameter used to evaluate the efficacy of removing the skin from the fruit, minimizing any significant impacts to the product quality and yield. As stated by Milczarek and McCarthy (2011), “the concept of peelability is often equated with the amount of residual peel on the fruit after the peeling process”. Peelability (peeling performance) plays an integral role in the grading quality standards of canned-tomato products. For example, established by the USDA (Agricultural Marketing Service (AMS), the maximum amount of skin for Grade A canned tomatoes are 2.93 cm^2 of peel/kg of fruit.

However, other studies (Li and others 2009) evaluating the concept of peelability or peeling performance, utilized a subjective peeling score based on 2 parameters. The first parameter accessed was based on how easy it was to remove the skin from the tomato and second, measuring the amount of residual skin left on the tomatoes after the peeling process respectively. For commercial processors, not only the amount of residual skin on the final product is of primary importance, but also the tomato yield as it relates to profit. Additionally, the tomato yield is crucial for the drained weight in the determination and maintenance of quality standards established by the FDA and USDA. Since peeling operations which remove the peel efficiently are of much importance, in this study, a comparison of the peeling performance using PU, lye and steam was determined by three attributes including the following: Ease of peeling using a subjective grading score (Table 3-1), peeling loss as well peeled pericarp thickness.

Materials and Methods

Sample Collection and Preparation

The fruits (Roma tomatoes) utilized in this study were selected according to a tomato color classification chart (John Henry Company, 5800W, Grand River Ave, Lansing, MI, USA) established by the USDA (United States Department of Agriculture). The chart contains 12 photographs illustrating the classification requirements for tomato color pertaining to their “ripeness stage.” Based on visual assessment, “table-ripe” (Ripeness stage 6, USDA scale) tomatoes were selected for this study. Ripeness stage 6 is defined according to USDA standards for tomato color as red-fleshed tomatoes with ≤90% of red color on the surface of the skin. The fruits were purchased from a local fresh market (Gainesville, FL, USA). Prior to experimentation, they were washed with tap water; surface dried, cored manually using a paring knife and sorted according to size and net weight (g), which was recorded. Subsequently, the tomatoes were allocated to their respective treatment groups. All experiments were conducted in triplicate.

Tomato Peeling

Lye

Lye (NaOH) peeling of tomatoes was performed according to the procedure described by Li and others (2009), with slight modifications. The tomatoes were immersed into a lye solution (10% w/v) and treated for 45, 60, and 120 s at a temperature of 95 ± 5°C. After post-peeling treatment, the tomatoes were immediately immersed (30 s) into an ice - water (0°C) bath to prevent cooking of the tomatoes due to residual heat. Subsequently the fruits were rinsed thoroughly with tap water to remove any residual lye.

Steam

As defined by Garcia and Barrett (2005b), standard peeling conditions were maintained at a steam pressure of 15 psi (103 kPa) and temperature of 121°C for exposure times previously established for lye peeling. Steam peeling was performed using a Deni 9700 Electric 5 quart pressure vessel (Keystone Manufacturing Company, Inc., NY, USA). Post-peeling treatment, the tomatoes were immediately immersed into an ice-water (0°C) bath for 30 s to prevent cooking due to residual heat.

Power Ultrasound (PU)

The tomatoes were treated with PU (Vibra-cell, 20 kHz, 1500 Watt (W), Sonics and Materials Inc., CT, USA). The ultrasonic system consists of an air-cooled converter (CV 294), fabricated with piezoelectric lead zirconate titanate (PZT) crystals and a standard autoclavable titanium alloy probe (TI-6AI-4V, 1” diameter and 10” length). Power ultrasound peeling was performed at 45, 60, and 120 s in a temperature controlled water bath at 95 ± 5°C. Similar to lye and steam peeling, the samples were flashed cooled by immersing the fruits into an ice-water (0°C) bath for 30 s.

Peeling Performance of Roma tomatoes

Ease of peeling

The ease of peeling was evaluated subjectively by a method developed by Li and others (2009), using descriptors with a qualitative grade scale ranging from 1 (easy to peel) to 5 (difficult to peel) (Table 3-1). This method was performed using hand peeling calibrated by training subjects to peel untreated tomatoes versus treated tomatoes.

Peeling loss

The peeling loss was calculated based on the change of tomato weight after peeling and expressed as percentage (%) loss (Equation 3-1).

$$\%\ \text{Peeling loss} = \frac{\text{Weight of unpeeled tomato} - \text{Weight of peeled tomato} \times 100}{\text{Weight of unpeeled tomato}} \qquad (3\text{-}1)$$

Peeled-pericarp thickness

For pericarp thickness (mm) evaluation, the tomatoes were cut into 2 halves and the thickness of the pericarp (red layer and peripheral pericarp wall cumulatively) below the peel in 3 locations were measured using digital calipers (Neiko Tools, USA) equipped with a liquid crystal display (LCD) screen: (38 x 14 mm, accuracy of 0.01 mm) after peeling. A transversal cut of the Roma tomato utilized in our study is illustrated (Figure 2-3), showing the selected regions, which was measured in this experiment. This method was performed with slight modifications to a protocol described by Garcia and Barrett (2006a).

Statistical Analysis

The data obtained were analyzed using a Statistical Analysis System (SAS) Version 9.1. Analysis of variance (ANOVA) was performed and the significant differences among the means were separated using Tukey's Studentized Range test.

The data were tabulated as average of the 3 replicates ± standard error mean (SEM), and the level of significance was set at 5%.

Results and Discussion

Ease of Peeling

Table 3-2 shows the effect of PU on the ease of peeling Roma tomatoes as compared to conventional lye and steam. Statistical analysis revealed that, there were no significant ($P < 0.05$) differences among all the treatment groups regarding the ease of peeling score, which ranged from a low of 4.67 to a high of 5.00. In this study, a score of 4.00 and above was regarded as an acceptable level for ease of peeling, similar to a protocol established by Li and others (2009). The experimental results therefore suggest that PU may be a suitable alternative as the ease of peeling scores were very comparable to the conventional peeling methods.

Similarly, researchers Li and others (2009) evaluated the easiness of tomato peeling using infrared (IR) technology for 30, 45, 60 and 75 s at distances from the IR emitter at 90 ± 2 mm, 110 ± 2 mm, and 120 ± 2 mm respectively compared to conventional lye (10%), which was used as the control in their study. They observed that the ease of peeling improved with an increase in peeling time for both treatments (Lye and IR). For lye peeling, their values ranged from a low of 3.50 at 30 s to a high of 4.90 at 75 s. A similar result was observed for IR peeling regarding an increase in time, although, the ease of peeling decreased as a consequence of increasing the distance of IR emitter from the tomato. The reported average ease of peeling scores for IR peeling were of 4.90, 4.40, and 3.20 at 90 ± 2 mm, 110 ± 2 mm, and 120 ± 2 mm respectively.

Barrett and others (1998) indicated that the main objective of the peeling (PU, lye or steam) process is to split or crack (Figure 3-1) the tomato peel sufficiently enough for the peel to be removed mechanically. As alluded to previously in the review of literature, the suggested mechanism of action in lye peeling may be attributed to a series of biochemical reactions due to the cleavage of pectin bonds in the tomato peel, in addition to thermal effects (Das and Barringer 2005). Similar to steam peeling, at high temperatures (> 97°C), pressurized steam, develops under the skin of the tomato, causing the cells of the epicarp to break open. In the case of PU peeling, enhanced sonication effects during the peeling process may be due to the fact that ultrasonic energy may have increased at a rate in which the peeling medium (hot water) bombarded the epidermal cells of the tomatoes, consequently enhancing bio-separation between the endocarp and flesh. Additionally, mechanical action by high-speed pressurized bubbles “cavitation” produced by the PU may have a shearing effect on the surface of the tomato skin (Feng and others 2008).

In this study, an interesting phenomenon was observed regarding the type of skin splitting within the PU and steam-peeled tomatoes. As illustrated in Figure 3-1, the splitting of the skin in the tomatoes peeled with PU occurred on the longitudinal axis (lengthwise) of the fruit, whereas for the steam-peeled tomatoes, the splitting occurred both on the equatorial (width) and longitudinal axis (lengthwise) of the tomato fruit.

On the contrary, in a few cases upon visual inspection of the tomatoes after each peeling treatment (PU, lye and steam), it was observed that the skins of some tomatoes did not split open. Since the splitting of the skin on the surface is crucial for peel removal by mechanical peel eliminators, this observation is not favorable but not uncommon or unusual. According to researchers (Barrett and others 1998), there are many factors, which contributes to the tomato skin susceptibility to crack and include the following: Variety, maturity and skin strength, which were not determined by this study. Therefore, optimization of the peeling treatments, most importantly PU, would have to be pursued to achieve maximum skin splitting, keeping the above factors (e.g., maturity, mechanical properties such as skin strength) into consideration.

As previously discussed, ultrasound is known to generate vigorous agitation and mixing the medium being sonicated resulting in turbulent flow due to of cavitation. The authors (Monnier and others 1999) have reported cavitational bubbles with a diameter of 5-100 μm in diameter, which are comparable to liquid, eddies (30-100 μm) generated by conventional impellers used for mixing fluids (Doran 2000). The mixing efficacy of conventional impellers is relative to the amount used and their position (spacing) in the reactor vessel. Nocentini and others (1988) have reported that the use of multiple-impeller (dual) systems is more effective than single-impeller systems relative to the mixing time (t_m). Therefore optimization of the PU system with multiple transducers, maybe favorable in generating uniform cavitational effects. Thus, may facilitate uniform splitting of the tomato skin.

Peeling Loss

In evaluating novel technologies to facilitate more efficient and environmentally friendly peeling technologies, it is crucial to examine their effects on the product yield, which directly translates to production costs and revenue. The results of this study illustrated that tomatoes treated with PU at 45 s yielded the lowest peeling loss (i.e., 9.45%) among all conditions tested (Figure 3-2). Overall, the peeling losses were significantly ($P < 0.05$) lower in tomatoes treated with PU (9.45% ± 2.06, 12.5% ± 0.75 and 12.2% ± 1.37) compared to lye (16.6% ± 2.69, 19.8% ± 3.12, 19.7% ± 5.29) and steam (18.9% ± 0.80, 21.4% ± 3.00, 24.8% ± 5.45) at 45, 60 and 120 s respectively.

These results suggest that peeling tomatoes with PU may be a more attractive technology compared conventional lye and steam, respective to product yield and costs benefits. For example, on the basis of a cannery-peel operation of 10 tons/h (9070 kg/h) assuming the highest peeling losses (PU 12.5%; Lye 19.8%; steam 24.8%) from the experimental results of this study, it can approximated that 87.5%, 80.1% and 75.2% of the product respectively may be recovered after the peeling process. These values suggest that PU peeling may result in the highest product yield, an attractive attribute that may favor its commercialization.

According to the USDA National Agricultural Statistics Service (NASS) 2009, the value of USA processing tomato is $87.20 per short ton. Therefore, using the previous example of a cannery-peel operation for 10 ton/h at 16 h a day, the cost value of processing tomatoes could amount to approximately $13,920.00 per day. On the other hand, using the highest percentage peeling losses previously used to determine the approximated product yield from each peeling method in this study, the revenue lost was calculated. The estimated amount of dollars, which may be lost associated with peeling losses could equate to: PU (2.51 M$); lye (3.97 M$) and steam (4.98 M$) respectively. From these calculations it was illustrated that peeling with PU could reduce the cost for peeling losses by 1.46 and 2.47 M$ annually for lye and steam respectively. Thus, the PU peeling method could potentially save the industry millions of dollars on an annual basis with respect to peeling losses, which could bring significant benefits to the tomato peeling industry.

Although the results of this study showed that peeling losses increased with peeling time for all peeling methods (PU, lye and steam), it can be deduced that at 45 s or 60 s at high temperature are the ideal parameters for maximizing product yield as an acceptable score of < 4 was achieved for PU, lye and steam peeling. Overall, in this study, the peeling losses ranged from about 9-20% among all the peeling and methods conditions tested. Garcia and Barrett (2006a) reported that 7-10% was the desirable range of peeling losses for hand-peeled tomatoes (Garcia and Barrett 2006a). This range was closely represented by PU peeling (Figure 3-2) in contrast to lye and steam treatments in which the peeling losses were greater. However, from a more practical stand point, at commercial scale, peeling losses (25-28%) are actually greater as a result of mechanical separation by peel eliminators, which is slightly higher than the reported values in this study. It may be concluded that lower peeling losses in PU treated samples may be attributed to the phenomenon of cavitation resultant of the high shearing action of accelerated microjets bombarding the surface of the tomato, thus reducing of the amount of flesh released with the skin.

Peeled-Pericarp Thickness

According to Garcia and Barrett 2006b, the thickness of the pericarp may contribute to the yield in tomato products. In this study, the pericarp thickness was determined for tomatoes using each method. In general, it was observed that as the peeling loss increased, the peeled pericarp thickness decreased (Figure 3-2). However, it cannot be automatically assumed that the peeling loss was the main contributing factor to the peeling loss. Researchers (Barrett and others 1998) explained that there might be a large variation of pericarp thickness within the same cultivar and maturity stage. On the contrary, Garcia and Barrett (2006b) stated that there was a positive correlation between pericarp thickness and peelability, as well as yield of tomato products. The peeled-pericarp thickness values in this study ranged from a low of 2.47

mm ± 0.66 (Steam 120 s) to a high of 4.61 mm ± 0.18 (PU 45 s). Overall PU peeled tomatoes had a higher peeled thickness compared to both lye and steam. This observation may suggest that PU was more efficient in increasing the ease of the epidermal cells from the subepidermal cells (i.e., the pericarp) minimizing amount of flesh removed during the peeling process.

Table 3-1. Descriptions used to evaluate the easiness of peel of roma tomatoes

Scale	Subjective Descriptions for Ease of Peeling
1	Very difficult to remove peel; large amounts of residual skin on tomatoes and high loss of flesh due to its adherence to the skin during peeling.
2	Difficult to remove peel on most areas of the tomatoes; residual skin on certain areas of the tomatoes.
3	Moderately difficult to remove peel; little residual skin on the surface of the tomatoes.
4	Easy to remove peel; large pieces of tomato peel can be removed with little effort.
5	Very easy to remove peel; no residual skin on the tomatoes.

Source: Li and others (2009).

Table 3-2. The effects of peeling treatments on the ease of peeling

Treatment group	Ease of peeling score
PU 45 s	4.67 ± 0.00^{a}
PU 60 s	5.00 ± 0.57^{a}
PU 120 s	4.67 ± 0.57^{a}
Lye 45 s	4.67 ± 0.57^{a}
Lye 60 s	4.67 ± 0.57^{a}
Lye 120 s	5.00 ± 0.00^{a}
Steam 45 s	5.00 ± 0.00^{a}
Steam 60 s	4.67 ± 0.00^{a}
Steam 120 s	5.00 ± 0.00^{a}

[a]Means (in columns) with the same superscript are not significantly different according to the Tukeys' studentized range test at a 5% level of significance.

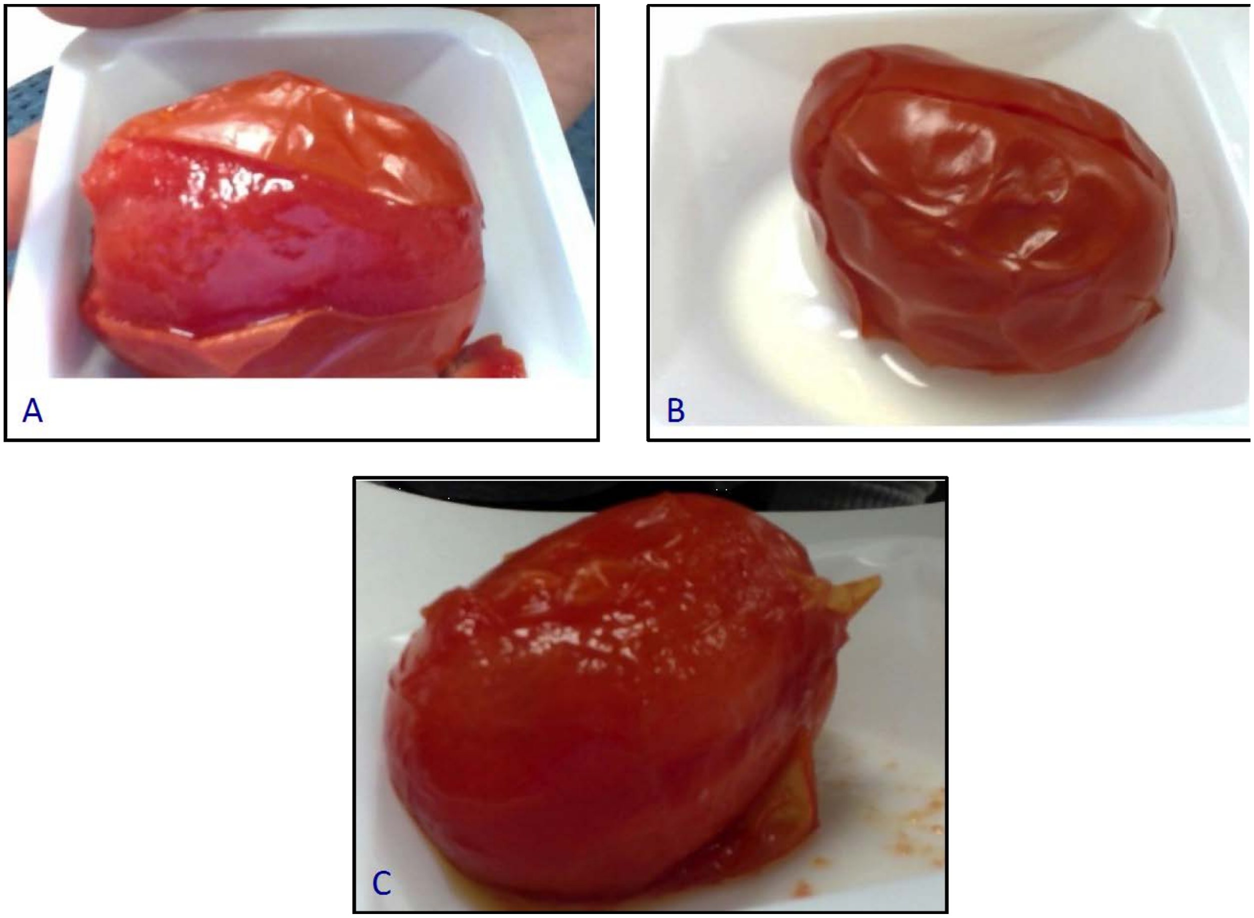
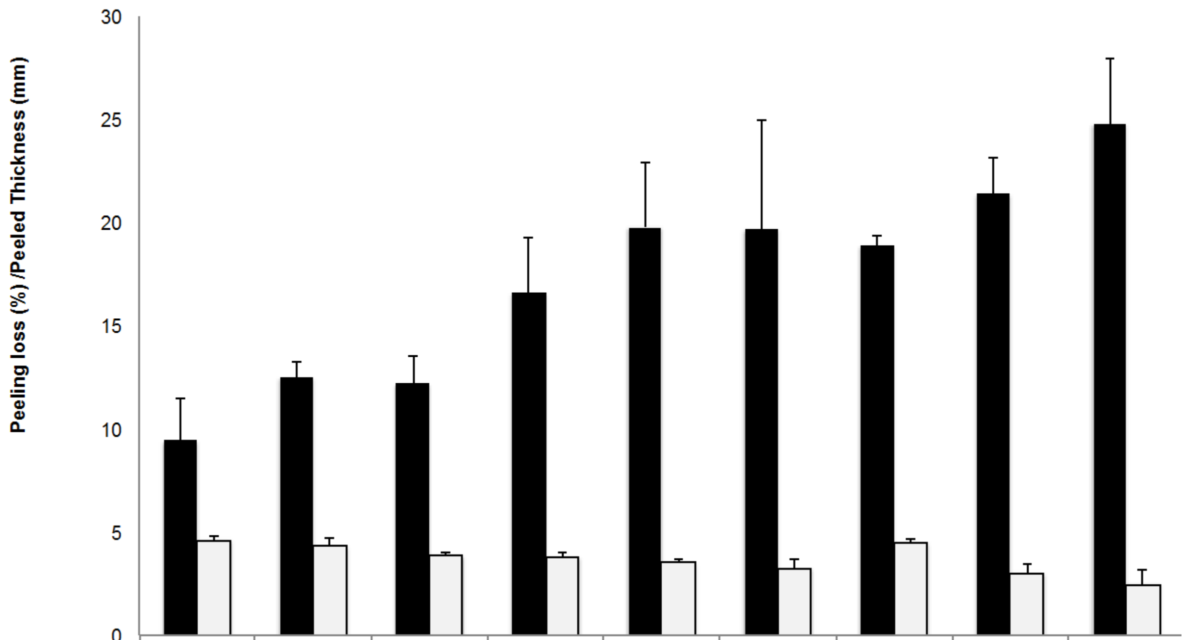


Figure 3-1. Characteristic skin splitting in tomatoes after the PU (A), steam (B) and lye (C) peeling process. Photo credit: Food Engineering and Processing laboratory. University of Florida.



	PU 45	PU 60	PU 120	Lye 45	Lye 60	Lye 120	Steam 45	Steam 60	Steam 120
■ Peeling loss	9.43	12.5	12.2	16.6	19.8	19.7	18.9	21.4	24.8
□ Peeled Thickness	4.61	4.31	3.87	3.80	3.52	3.25	4.50	3.02	2.47

Figure 3-2. The effect of peeling treatments (PU, lye and steam) on percentage peeling losses and peeled-pericarp thickness

CHAPTER 4
EFFECTS OF PU, LYE AND STEAM PEELING ON THE PHYSIOCHEMICAL PROPERTIES OF ROMA TOMATOES

Background

The physiochemical properties are those, which are concerned with those attributes related to both the chemical and physical properties of an entity. In the literature, the most common attributes relative to the physical and chemical properties of tomatoes include the following: Color, lycopene, soluble solids, pH and titratable acidity.

Color is regarded as one of the most important quality parameters of fruits and vegetables, which is indicative of maturity and postharvest life, relative to freshness. Additionally, it plays an influential role in the purchasing decision of the consumer and consumer acceptability. In the literature (Martinez-Valverde 2002) it was mentioned that the major biomolecule of interest such as lycopene, is primarily responsible for the red color of tomato fruits and derived products. In addition to color, the lycopene content has been attributed to the functional food status of tomatoes, since it has been found to possess the highest antioxidant activity among all dietary antioxidants (George and others 2004).

Moreover, it has been well established that sugars such as fructose and glucose contributes to the overall taste and is relative to the soluble solids (SS) content of tomatoes (Gomez and others 2001). Additionally, the consistency of tomato products such as paste is SS dependent (Garcia and Barrett 2006b). Furthermore, pH and titratable acidity (TA) are 2 integral quality parameters as the tomato flavor is dependent on the balance between SS and organic acid content (Citric or Mallic Acid), which is expressed as TA (Garcia and Barrett 2006b). Since tomatoes are regarded as low acid products (TA < 4.60), it is imperative that they are assessed as they dictate the conditions necessary for thermal processing and to facilitate product safety by inactivating thermophillic microorganisms. In this study, the effects of peeling on the physiochemical properties of tomatoes were evaluated by color, lycopene content, SS, pH and TA.

Materials and Methods

Peeled-tomato Color

The color of the peeled tomatoes was measured using a color machine vision system (CMVS) (University of Florida, Gainesville, FL, USA). The equipment consisted of a Nikon D200 digital color camera (Nikon Corp, Japan), housed in a light box [42.5 cm (Width) x 61.0 cm (Length) x 78.1 cm (Height)](Wallat and others 2002). The camera (focal light, 35 mm; polarization, 18.44 mm) connected to a computer was used to capture the images prior to color analysis. A software LensEye (Engineering and Cybersolutions Inc. Gainesville, FL, USA) was used to analyze the peeled-tomato color assessed on the values of L (lightness), a* (redness) and b* (yellowness). The camera was calibrated with a standard red tile (L: 48.62; a*: 49.04, b*: 25.72) (Labsphere, North Sutton, NH, USA). In this study, color was reported as the hue° shown in the Equation 4-1 below. All samples were aligned in the center of the light box before acquiring the images.

$$\text{Hue}^\circ = \tan^{-1}[b^*/a^*] \tag{4-1}$$

Lycopene Content

The determination of lycopene was performed according to Fish and others (2002). Five grams of homogenized tomato slurry samples (both fresh and peeled) were combined with 30 mL of a solvent mixture of hexane/acetone/ethanol (2:1:1 v/v/v) into 50 mL polypropylene tubes. They were covered with aluminium foil to exclude light and, using an orbital shaker, the samples were agitated for 30 min. Subsequently after, 10 mL of dionized distilled water (ddH2O) was added to the mixture which was shaken vigorously and left to separate into distinct polar and non-polar layers. The non-polar layer (hexane) was decanted, and its absorbance was measured using an ultra-violet/visible (UV/VIS) spectrophotometer (Beckman Coulter, Du 730, Lawrence, KS, USA) at a wavelength of 472 nm to determine the lycopene content (mg/g) on a fresh weight basis. Prior to analysis, the samples were diluted appropriately (1:10). The lycopene was calculated using Equation 4-2. In the equation, A denotes absorbance of the analyte at 472 nm corrected for the blank. The dilution factor and sample weight in grams were denoted by the symbols D and g respectively.

$$\text{Lycopene content (mg/g fruit)} = \frac{A \times D \times 31.2}{\text{g of sample}} \qquad (4\text{-}2)$$

Soluble Solids, Titratable Acidity and pH

The tomatoes were macerated using a commercial food processor. Soluble solids (SS) were measured using a digital refractometer (Leica Mark II Abbe Refractometer, Buffalo, NY, USA), calibrated against sucrose and expressed as °Brix. As described by Thakur and others (1996), the % titratable acidity (TA) of 10 g of the macerated tomato samples was added to 50 ml of ddH_2O and titrated with sodium hydroxide (NaOH, 0.1N) until a pH of 8.2 was achieved. The TA was calculated (Equation 4-4) and results were reported as the % equivalent weight of the predominant acid (citric acid/g fruit). In Equation 4-4, the symbol N denotes the normality of the titrant; V represents the volume (mL) of titrant; Eq.wt is the equivalent weight of the predominant acid, and 1/10 = 100/1000 relates the conversion of mg to g. The pH of the pureed tomato was measured using a pH meter (Fisher Scientific Accumet® Basic AB15/157, Pittsburg, PA, USA).

Titratable acidity (%)= $N \times V \times Eq.wt/W_S \times 10$ (4-3)

Statistical Analysis

The data obtained were analyzed using a Statistical Analysis System (SAS) Version 9.1. Analysis of variance (ANOVA) was performed and the significant differences among the means were separated using Tukey's Studentized Range test. The data were tabulated as average of the 3 replicates ± standard error mean (SEM), and the level of significance was set at 5%.

Results and Discussion

Peeled-Tomato Color

Several researchers (Calligaris and others 2002) mentioned that processing activities (e.g., peeling) are usually associated with most of the quality changes, such as loss of the color intensity in tomatoes. Researchers believe that the changes in tomato color may be attributed to the chemical or physical changes of carotenoids such as lycopene, which is discussed subsequently in this chapter. As a postharvest process, peeling may greatly influence the L* a* b* values, which together attributes to the overall color quality (Askari and others 2009). According to literature, the brightness (L*) is the main dictator for consumer acceptability. A decreasing L* value signifies the darkening of the tomato color (Camelo and Gomez 2004). In general, an L* = 100 is the co-ordinate of the color white, whereas L* = 0 is the co-ordinate of black according to the Commission Internationale de L'Eclairage (CIELAB) system. Moreover, according to Batu (2004), a* and b* values are good parameters which correlates to the fruit color as a quality factor. The a* values are indicative of red color development and are usually associated with the degree of ripeness in tomatoes. Whereas, the b* values is relative to the yellow discoloration of tomatoes (Batu 2004) and may be associated with the exposure of the vascular bundles located directly under the tomato flesh. According to Askari and others (2009), the desired tomato color qualities are represented by the following: Higher L* and a* values. Similar to other studies like Li and others (2009), the tomato color was also expressed as hue°, since it was regarded as most appropriate value to measure tomato color based on the human perception of color. Hue is normally expressed in degrees (°). For example: 0° (Red), 90° (Yellow), 180° (Green) and 270° (blue). As indicated by Askari and others (2009) and Li and others (2009), a hue value closer to 0° indicates a redder tomato.

Table 4-1 shows the peeled tomato color (hue°) and chromatic co-ordinate values (L*, a*, b*) of the CIELAB system after peeling (PU, lye and steam) treatments. Regarding the lightness of the tomato red color, there was no clear trend on whether the L* decreased among treatments since our results showed that there were no significant ($P < 0.05$) differences observed in the peeled-color between all treatment groups. This observation may suggest that the effects of peeling did not have a darkening effect in the tomatoes with respect to color intensity. This may be beneficial in terms of the consumer acceptability of a product as too dark of a color may be undesirable. The darkening effect maybe attributed to non-enzymatic Maillard reaction browning (Anese and others 2002) which was not determined in this study. The L* values in this study, ranged from a low of 35.59 ± 0.30 in lye peeled tomatoes at 45 s to a high of 43.99 ± 1.87 in steam peeled tomatoes at 45 s. Similar L* values were obtained for local tomato values grown in Spain in a study conducted by Gomez and others (2001)

As previously mentioned a higher chromatic value of a* is desirable as it is indicative of a higher degree of “redness”. From Table 4-1, significant differences ($P < 0.05$) were observed in all of the treatment groups. In fact, one general observation made was that samples with the less peeling time (45 s) had the highest a* value and that the steam-peeled tomatoes had the lowest a* values at 45, 60 and 120 s. This observation may suggest that the tomato color could have degraded as peeling time increased. With reference to the steam-peeled tomatoes, the thermal conditions (121°C) were harsher than the temperatures (95 ± 5°C) during the lye and PU peeling process and could account for loss of the tomato color. This observation was confirmed by Shi and Le Maguer (2000) in that they mentioned, “the loss in tomato juice was accelerated by higher temperatures and long treatment including processing and storage”, and with the main cause being the degradation of lycopene. In the literature (Anese and others 2002), it was mentioned that the processing and storage of tomato products might result in result in the quality some quality changes including the following: color and nutrient loss with carotenoid bleaching and ascorbic acid degradation as two common examples. Calligaris and others (2002) emphasized that a decrease in red color is one of the most crucial and may be attributed to both the physical and chemical changes of lycopene involving the isomerization of the *all*-trans lycopene and carotenoids to the *cis* forms. Another mechanism proposed is the chemical oxidation of lycopene, which from carotenoid radicals which decays to colorless species (Sahlin and others 2004). On the contrary, the researchers later emphasized that while these changes were attributed to extreme processing conditions, the oxidation process is a rather complexed one as it is dependent on other exogenous factors such as the following: Presence of lipids, prooxidants, amount of sugar and amino acids. In contrast, a study conducted by Gomez and others (2001), their values were much lower than the ones determined by this study. Their a* values ranged from a low of 17.75 ± 1.71 to a high of 32.20 ± 2.67. This may be attributed to varietal differences in tomato cultivars as compared to the variety utilized in this study.

Furthermore, as previously observed, in this study, steam peeling has resulted in relatively high losses of the pericarp in tomatoes, which may be attributed to over peeling (Shi and Le Mauger 2000). Garcia and Barrett (2006a) stated that over peeling is a problem frequently associated with improper peeling, in which many layers of the pericarp tissue is mainly lost and accounts for approximately 80-90% of the lycopene in tomatoes, this could also account for the color loss. As alluded to previously, the peeling losses were greater for the steam-peeled tomatoes which may serve as a legitimate justification as to why the a* values were much lower as compared to PU and lye-peeled tomatoes. In this study, the a* value showed the most obvious change. In contrast, the b* value did not change significantly (Table 4-1). This may be a good indication that in that there was no excessive exposure of the yellow vascular bundles that is usually apparent in over peeled tomatoes (Schlimme and others 1984), although in steam peeled tomatoes, the a* value was significantly low. Even though the b* values were low in this study, in contrast, it was observed that the reported b* values in the study by Gomez and others (2001) were much lower, where their values ranged from a low of 17.45 ± 1.13 and a high of 32.98 ± 6.87.

Once more, in this study, the color was also evaluated by determining the change in the hue°. As previously alluded to, it was established in the literature (Arias and others 2000; Li and others 2009) that the hue° is regarded as the most relevant value when referring to or measuring tomato color compared to the individual chromatic components such as the L*, a* and b* values. Although the previous results regarding the a* ("redness") values indicated that there was a loss of color in steam-peeled tomatoes, the calculated hue° (actual color) was relatively stable in the various treatment groups, which may suggest that peeling processes did not really have an effect on the quality in terms of the color, with the exception of those peeled with steam for 60 s as a significant difference ($P < 0.05$) was observed (Table 4-1). As alluded to previously, a hue° value close to zero indicates a redder tomato. The hue° values in this study ranged from a low of 35.30° ± 1.73 (PU 120 s) to a high of 42.63° ± 1.77 (Steam 60 s) which confirms that the tomatoes were all red after peeling (Table 4-1). The hue° values (Low of 29.1° to a high of 31.5°) reported by Li and others were slightly lower than the ones reported in this study, which may indicate that color may differ due to varietal differences. On the contrary, hue values for tomatoes with an average value of 40 ° was reported by Garcia and Barrett (2006b) which was very similar to our reported values for all peeling treatments.

Lycopene Content

Numerous studies have acknowledged that tomatoes constitute the main dietary source of the carotenoid lycopene. According to Shi and Le Maguer (2000), carotenoids are responsible for the bright colors of many fruits, flowers, birds and marine animals such as grapefruit, rose hip, flamingo and lobster. Most commonly, lycopene has been augmented with the maturity of tomato as its synthesis increases resulting in the development of red color. As previously mentioned, besides color, lycopene has been rated the most efficient in scavenging singlet O_2 (Graziani and others 2003). The highly unsaturated structure of the lycopene molecule attributes to its efficacy as a free-radical scavenger by conjugating with highly oxidative species such as peroxyl radicals that may cause damage to biological molecules such as deoxyribonucleic acid (DNA). Attributing to the many health benefits of lycopene such as reduction in the risk of prostrate cancer development (Arias and others 2000), there is unprecedented interest in its content as well as its stability in food products. As revealed previously, the processing and storage of tomato products may result in lycopene degradation. Therefore, as emphasized by Shi and Le Maguer (2000), “studies on the effects of processing conditions on the quantitative and qualitative changes of lycopene degradation are necessary to determine the engineering parameters for tomato processing”. Consequently in this experiment, a study was carried out to determine the effects of the various peeling treatments on the lycopene content.

Figure 4-1 shows the lycopene content measured in fresh and peeled-tomato (PU, lye, steam) samples which ranged from a low of 16.4 mg kg^{-1} ± 2.28 (steam 45 s) to a high of 35.5 mg kg^{-1} ± 3.18(PU 60 s). Significant differences ($P < 0.05$) were observed for all peeling treatments, which may be relative to the varying stability of lycopene during the processing of tomatoes. Some researchers (Graziani and others 2003) mentioned that lycopene was relatively stable during processing. This observation was exhibited in this study in the case of tomatoes peeled with PU and Lye up to 60 s respectively, since the lycopene content did not vary much from the fresh tomato samples.

However, in contrast, the lycopene content of Lye (120 s) and steam-peeled tomatoes at 45, 60 and 120s were significantly low (Figure 4-1). As alluded to previously, reduced lycopene in steam-peeled tomatoes may be attributed to carotenoid degradation, which may involve the following: Isomerization of all-trans-lycopene. One plausible reason for this observation may be due to the fact that the temperature conditions for steam peeling was more extreme (121°C) than the conventional peeling methods (95 ± 5°C). Since the color of tomatoes are related to lycopene, the low lycopene content in the steam-peeled tomatoes as exhibited in this study may account for the lower a* values previously that were reported. The observation made in this experiment with reference to lycopene degradation due to temperature can be supported by Data obtained from Miki and Akatsu (1970), which showed that the loss of lycopene at 130 °C was 17% higher than at 90°C.

Overall, the values for lycopene content in this study were comparable to the values in some varieties (Rambo, Senior, Ramlet and Liso) reported in a study conducted by Martinez-Valverde (2002), which ranged from a low of 18.60 mg kg^{-1} ± 1.00 to a high of 32.24 mg kg^{-1} ± 0.55.

Soluble Solids, Titratable Acidity and pH

In addition to external quality parameters such as color, the SS, pH and TA contributes to the overall consumer acceptability of tomato products. The taste profile and quality of tomatoes is primarily influenced by the presence of sugars, which corresponds to the SS (fructose and glucose) and organic acids such citric (Young and others 1993). According to Gomez and others 2001, the higher the sugar content, the more tasty the fruit.

Besides taste, organic acids are believed to play a crucial role in the preservation of canned products. Young and others (1993) reported that the organic acid content in tomatoes should be high enough (approximately 0.35%) to yield a pH of < 4.4 to negate spoilage issues inflicted by thermophillic microorganisms such as *Clostridium pasterianum* and *butyriam* respectively (Thakur and others 1996). However, a pH greater than 4.4 may necessitate longer processing times which may consequently adversely product quality.

Table 4-2 shows the average SS, TA and pH of PU, lye and steam-peeled tomatoes. Literature (Garcia and Barrett 2006b) has reported that the SS in processing tomatoes usually range from 4.50 to 6.25 °Brix. In this experiment, the average SS ranged from a low of 4.00 ± 0.00 (Steam 60 s) to a high of 5.18 ± 0.67 °Brix (Steam 45 s). Statistical analysis indicated significant ($P < 0.05$) differences in the SS among PU, lye and steamed peeled tomatoes. These differences in this study may be attributed to the non-homogeneous differences in maturity stage within the same cultivar. For example, Barrett and others (1998) elaborated on the fact that although the tomato fruit is harvested at 90% “red ripe,” some fruits may mature 2-3 weeks within the same cultivar before being harvested.

As established, the tomato flavor is dependent on the balance between the organic acid content (citric acid), expressed as TA and SS (soluble sugars). The values for TA in this study ranged from a high of 0.497 to a low of 0.572% (Table 4-2). Similar values were reported in a study by Garcia and Barrett (2006b) which they evaluated the quality attributes, peelability and yield of processing tomatoes from different growing seasons. Their values ranged between 0.331 to 0.501%. However, according to Nielsen (2003), the typical acid content of tomatoes could range from 0.2-0.6%.

Since tomatoes are regarded as low acid products (pH <4.60), it is imperative that they exhibit the suitable physiochemical properties necessary for thermal processing and to facilitate product safety. Literature (Garcia and Barrett 2006b) suggested that the optimal pH values to prevent spoilage by thermophillic microorganisms and for processing tomatoes might range from 4.25 to 4.40 respectively. The pH values from this study ranged from a low of 4.36 ± 0.04 (steam 45 s) to a high of 4.64 ± 0.02 (PU 60 s). Several samples in the lye peeled group had a slightly higher pH. The slightly higher pH values could be attributed to residual lye as pH values reported in literature were within the ranges of 4.14 – 4.54 (Gomez and others 2001; Garcia and others 2006b).

Table 4-1. Effects of peeling treatments on chromaticity values in Roma tomatoes

Treatments	L*	a*	b*	Hue (°)
PU 45 s	$42.6^{ab} \pm 1.24$	$50.4^{a} \pm 0.41$	$36.9^{a} \pm 1.54$	$36.3^{b} \pm 0.95$
PU 60 s	$39.6^{ab} \pm 0.78$	$47.0^{b} \pm 0.85$	$34.3^{a} \pm 1.09$	$36.1^{b} \pm 0.36$
PU 120 s	$40.1^{ab} \pm 0.58$	$47.7^{a} \pm 1.12$	$33.8^{a} \pm 1.98$	$35.3^{b} \pm 1.00$
Lye 45 s	$41.6^{ab} \pm 0.54$	$50.2^{ab} \pm 0.23$	$37.3^{a} \pm 0.51$	$36.6^{b} \pm 0.42$
Lye 60 s	$35.6^{b} \pm 0.30$	$48.9^{ab} \pm 0.45$	$37.0^{a} \pm 1.67$	$37.1^{b} \pm 0.92$
Lye 120 s	$40.5^{ab} \pm 1.17$	$47.1^{b} \pm 0.32$	$36.2^{a} \pm 1.34$	$37.5^{b} \pm 0.85$
Steam 120 s	$44.0^{a} \pm 1.08$	$44.0^{c} \pm 1.08$	$35.3^{a} \pm 0.74$	$37.1^{b} \pm 0.81$
Steam 120 s	$42.4^{ab} \pm 1.76$	$43.5^{c} \pm 1.76$	$38.2^{a} \pm 4.17$	$42.6^{a} \pm 1.02$
Steam 120 s	$43.5^{a} \pm 0.71$	$42.4^{c} \pm 0.70$	$34.6^{a} \pm 1.31$	$35.8^{b} \pm 0.69$

^{abc}Means (in columns) with the same superscript are not significantly different according to theTukeys' studentized range test at a 5% level of significance.

Table 4-2. Physiochemical evaluation of Roma tomatoes peeled with PU, lye and steam

Treatments	SS	pH	TA
PU 45 s	$4.23^{b} \pm 0.19$	$4.37^{bc} \pm 0.00$	$0.53^{abc} \pm 0.02$
PU 60 s	$4.30^{b} \pm 0.11$	$4.43^{ab} \pm 0.02$	$0.57^{a} \pm 0.02$
PU 120 s	$4.30^{b} \pm 0.11$	$4.36^{abc} \pm 0.07$	$0.50^{c} \pm 0.07$
Lye 45 s	$4.47^{ab} \pm 0.09$	$4.50^{abc} \pm 0.20$	$0.50^{bc} \pm 0.02$
Lye 60 s	$4.33^{b} \pm 0.12$	$4.64^{ab} \pm 0.07$	$0.53^{abc} \pm 0.01$
Lye 120 s	$4.13^{b} \pm 0.06$	$4.62^{b} \pm 0.25$	$0.54^{abc} \pm 0.02$
Steam 120 s	$5.18^{ab} \pm 0.67$	$4.36^{abc} \pm 0.04$	$0.56^{ab} \pm 0.02$
Steam 120 s	$4.00^{b} \pm 0.05$	$4.45^{c} \pm 0.01$	$0.50^{bc} \pm 0.04$
Steam 120 s	$4.49^{a} \pm 0.55$	$4.42^{bc} \pm 0.07$	$0.55^{abc} \pm 0.02$

^{abc}Means (in columns) with the same superscript are not significantly different according to theTukeys' studentized range test at a 5% level of significance.

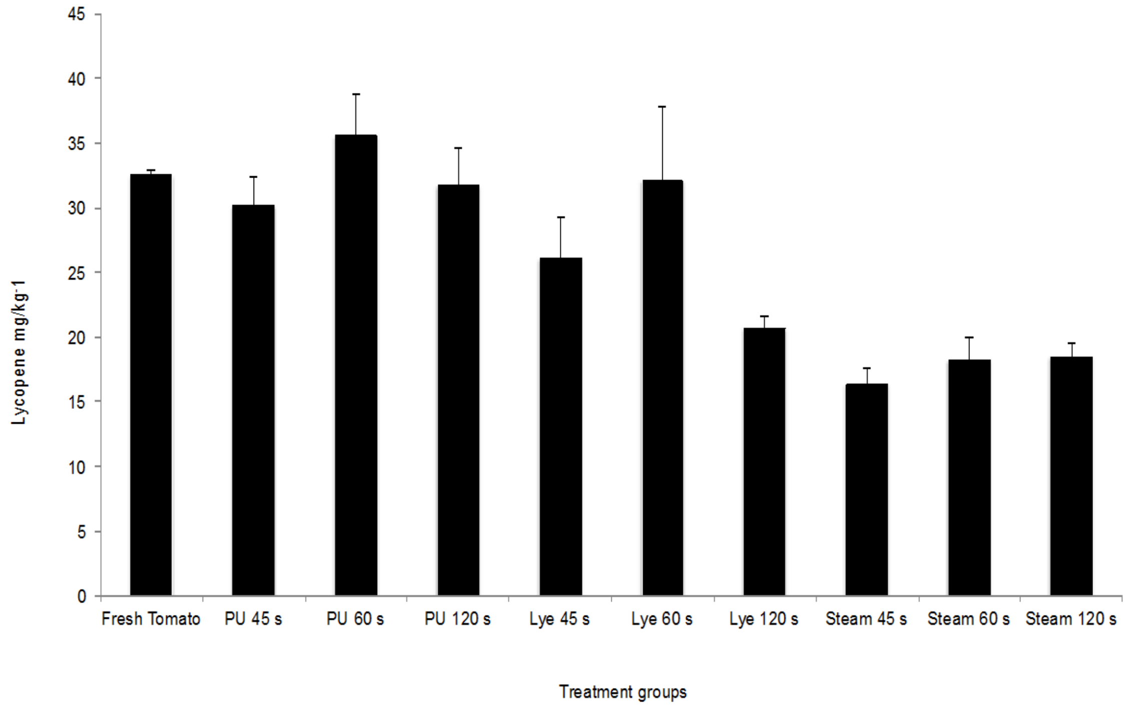


Figure 4-1. Effect of PU, steam and lye peeling on the lycopene content in Roma tomatoes

CHAPTER 5
EFFECTS OF PEELING ON THE MECHANICAL PROPERTIES OF TOMATOES EVALUATED BY TEXTURAL AND MICROSTRUCTURAL CHANGES

Background

The microstructural (e.g., cell wall) and physiological attributes (e.g., texture) are believed to associated with the physical integrity and quality of tomato fruits (Arazuri and others 2007). Approximately two-thirds of the world production of tomatoes is thermally processed (e.g., canned whole-peeled tomatoes). Therefore, as a consequence, the structural performance of the exocarp and hypodermal cells (such as the pericarp) may be compromised. Cells making up the microstructure of the tomato (such as the exocarp and pericarp) provide mechanical support attributing to firmness and thus it is regarded as the most relevant mechanical property to the whole fruit (Barrett and others 1998, Bargel and Neinhuis 2005, Arazuri and others 2007). Therefore, in this experiment the effects of PU, lye and steam peeling on the mechanical properties of whole-peeled Roma tomatoes were evaluated. The mechanical properties were evaluated by the peeled firmness and microstructural changes to the pericarp post peeling and PU treatments respectively.

Materials and Methods

Texture: Peeled Firmness

The texture of whole-peeled tomatoes was measured according to a protocol performed by Li and others (2009) with slight modifications. A texture analyzer (TA.XT Plus, Texture Technologies Corporation, Scarsdale, NY, USA) was utilized to measure the tomato firmness via a compression test. The tomatoes were horizontally aligned on the flat base plate of the texture analyzer and an aluminum cylinder (3” diameter; TA 30) was used to compress the tomato surface to a total distance of 5 mm at 5 mm/s forward speed (Figure 5-1). The firmness was expressed as the force in newtons (N) required to compress the tomato surface 5 mm from the point of contact.

Microstructure: Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) was used to analyze the microstructural changes to the tomato pericarp after PU peeling. To obtain the SEM images, segments of the tomato surfaces, approximately 8 mm in dimension were rinsed with sodium phosphate buffer (Na_2HPO_4) (0.1M, pH 7.2, 4°C) and fixed in 2.5% glutaraldehyde for 2 h at 4 °C. Next, the samples were washed 6 times with adequate Na_2HPO_4 buffer, followed by dehydration using an ethanol series (30, 50, 70, 80 an 100%) for 10 min intervals. Subsequently, all of the samples were flash frozen using liquid nitrogen in polyethylene micro-centrifuge tubes (2000 µL) and freeze-dried for approximately 24 h at 25 °C using a freeze dryer (Virtis AdVanced Plus, Gardiner NY, USA). After lyophilization, the samples were outgassed under vacuum and mounted onto aluminium studs, lined with a conductive tape, prior to examination using a Field Emission Scanning Electron microscope (JSM-633OF JEOL, Tokyo, Japan) (University of Florida, Particle Science Engineering Department, Gainesville, FL, USA). This protocol was modified slightly according to a method performed by Das and Barringer (1999).

Statistical Analysis

The data obtained for texture were analyzed using a Statistical Analysis System (SAS) Version 9.1. Analysis of variance (ANOVA) was performed and the significant differences among the means were separated using Tukey’s Studentized Range test. The data were tabulated as average of the 3 replicates ± the standard error mean (SEM), and the level of significance were set at 5%.

Results and Discussion

Texture: Peeled Firmness

Researchers (Barrett and others 1998) defined texture as a “group of physical characteristics that arise from the structural elements of the food, sensed by the perception of touch and is related to the deformation, disintegration and flow of food under a force and are measured objectively by the functions of mass, time and distance.” In the literature (Barrett and others 1998), the importance of textural integrity was emphasized as it pertains to the “character” specifications of the final canned whole-peeled tomato products. The character, a quality parameter for whole-peeled tomatoes is defined as the “ degree of firmness” when tomatoes have been processed using good manufacturing process (GMP) established in the Code of Federal Regulations (CFR), chapter 21 part 110 (USDA 1990).

With reference to whole-peeled tomatoes, the degree of firmness is dependent on the products ability to retain their shape and cell contents post-peeling processes. In this regard, the contour of the fruit should not be affected and if cracked on the surface, there should be no material loss of seeds or placenta from the fruit as a result of cell rupture resulting in the leakage of cell contents. A compromised tomato structure results in the rupture and leakage pertaining to the cell contents of the fruit affecting the drained weight (USDA 1990) as well as the texture. The “drained weight” of canned tomatoes is used as a parameter by the USDA to rank the quality of tomatoes according to a grade denoted A, B or C (Barrett and others 1998). These grades (i.e., A, B and C) specify that the processed tomato product have a drained weight of not less than 66, 58 and 50% capacity of the container respectively.

It has been established (Barrett and others 1998) that the textural integrity of whole-peeled tomatoes is essential regarding the standards implemented by both the USDA and FDA for grade and identity, quality and fill of container respectively. In addition this parameter (i.e., the textural integrity), is as equally important for comminuted tomato products such as salsa, as excessively soft (i.e., lacking character) or mushy products after the canning process are undesirable (Barrett and others 1998).

In this study, the texture relative to the firmness of the peeled-tomato samples by PU, lye and steam was assessed using a flat plate compression test (Figure 5-1). Our values ranged from a low of 2.62 N ± 1.03 in steam to a high of 19.7 N ± 0.45 in PU-peeled tomatoes respectively. Overall it was observed that there was a considerable loss of firmness of the fruits peeled with lye and steam when compared to PU at the same time conditions and with an increase in time. This was indicative by values expressed as N (Figure 5-2), which showed that it took more force to compress the surface of the tomatoes treated with PU as compared to those treated with lye and steam. Moreover, it can be deduced from our results that 120 s is too harsh of a treatment condition and that optimal peeling conditions can be most maximized at approximately 60 s for all treatments regarding the texture with the exception of the steam-peeled tomatoes. Tomatoes after the steam-peeling process were soft and mushy to the touch. In some cases, the tomatoes ruptured due to tissue failure attributed to high pressure and steam, which resulted in the leakage of seeds and locular gel and water.

In an infrared (IR) versus lye peeling study conducted by Li and others (2009), similar trends compared to this study were observed where an increase peeling time resulted in loss of firmness of the Roma tomato fruit (Figure 5-2). Their values ranged from a low of 12.7 ± 2.9 N (lye peeled at 75 s) to a high of 17.6 ± 3.9 N (IR peeled at 75 s) treatments. Reported values for the IR peeling were on average 17.6 N, which indicated that IR produced a firmer product and may be a more suitable alternative to lye.

It is believed that the factors, which affect the texture of tomatoes, may be related to the production and anatomical (i.e., plant tissue specific) characteristics of the fruit (Barrett and others 1998). Cultivar, maturity and abiotic stress (e.g., freeze stress) may be regarded as production related. Whereas, cell wall organization, turgor pressure and activity of degradative enzymes such as polygalacturonase (PG) and pectin methylesterase (PME) may be regarded as tissue specific (Barrett and others 1998).

A typical example of tissue specificity as it relates to texture is in the case of a study performed by Garcia and Barrett 2006a. The main objective of their study was to exam the efficiency of steam peeling (12-15 psig) compared to lye from two selected cultivars (cvs.) Halley 3155 and Heinz 8892. Their results show that the peeled tomato firmness ranged from a low of approximately 70 N to a high of 140 N with respect to the control (untreated Halley varieties), which was approximately 160 N for the steam peeling. For the lye peeling, the peeled tomato firmness ranged from a low of approximately 80 N to a high of 110 N compared to the control (steam peeled tomatoes), which were 160 N. Their results vastly differed from this PU study and IR study conducted by Li and others (2009) which may suggest that cultivar may influence the peeled texture of processing tomatoes after peeling.

The tomato peeling process requires heat to remove the skin from the fruits. Consequently, heat induces a change in the firmness, loss of turgor and the activation of degradative enzymes related to softening of tissues. Anthon and Barrett (2010) stated that in fruits and vegetables including tomatoes, the pectins are highly esterized contributing to the mechanical performance of the microstructure. However, the loss of firmness is usually associated with fruit softening leading to the degradation of pectin in the cell walls by the action of enzymes such as PME and PG. In a study conducted by Floros and Chinnan (1988), they examined the microstructural changes in the tissues of tomatoes during steam peeling. They described the microstructural changes as a combination of physical damage (i.e., crack, rupture and cell wall breakdown), in addition to loss of rigidity and reduced turgor pressure due to the break down of the chemical components such as polysaccharides, which is the framework for the structure of the cell wall.

As previously mentioned, in our experiment, tomatoes peeled with PU more firm than those with lye and steam. The retention of firmness in the PU treated samples may be as a result the inactivation effects of ultrasound on PME as a result of the cavitation phenomenon proposed by Raviyan and others (2005), which was not determined in our study. Two mechanisms of inactivation were proposed in the study conducted by Raviyan and others (2005). The main objective of their study was to examine the efficacy of PU on the inactivation of tomato pectinmethylesterase based on cavitational activity and temperature. The mechanisms of inactivation included the following: Mechanical and sonochemical. The mechanical effects of cavitation were described as the formation of microjets and microstreaming, which are normally affiliated with high shear. It has been proposed that the oscillation and high shear of the microbubbles may cause a loss in the structural integrity of PME. Other structural modifications due to sonochemical effects (e.g., pyrolysis of bonds in proteins) could have been inflicted by high pressures consequently affecting enzyme activity.

Microstructure: Scanning Electron Microscopy (SEM)

According to Barrett and others (1998), the textural properties of tomatoes are influenced the structural organization of cells and tissues (e.g., cuticle and pericarp). Few studies (Reeve 1970) have correlated the size, shape and appearance to texture. However in this study, our primary focus was to solely observe if there was any disruption or cellular collapse of the pericarp wall of the tomatoes due to the cavitation effects exerted by PU on the surface of the exocarp and compare the morphology of the tomato pericarp subjected to lye as well as steam peeling.

As previously noted in the review of the literature, bubble formation during the process of ultrasonication in a liquid medium produces “cavitation”. Feng and others (2011) outlined the series of events that takes place during sonication, occurring, in the following steps. First, cavitational bubbles oscillate at a given frequency fluctuating in velocity and pressure (700-100 MPa) into the surrounding medium. These changes in velocity and pressure results in the propagation of turbulence (i.e., microjets of bubbles) within intermediate surroundings also refered to as acoustic streaming (Monnier and others 1999). Acoustic steaming is divided into 3 regions (Figure 5-3). The largest and first region, Eckart streaming travels the furthest distance away from the ultrasonic probe (Figure 5-3), producing currents defined by the shape of the reaction vessel. The second region (Rayleigh streaming) exhibits much longer wavelengths than the acoustic wave in the liquid and its circulating currents are dictated by the shape and size of the probe (Figure 5-3). The third region (Schlicting steaming) is localized near the horn as well as the boundary layer of the medium being sonicated (Figure 5-3)(Khanal and others 2007).

As a consequence of acoustic streaming, polymeric chains of cuticular constituents such as pectin may break resulting in their disruption. Authors (Feng and others 2011) stated that bombardment of microjets of cavitational bubbles towards a solid surface could lead to erosive damage. Therefore in this experiment, using SEM technology, the pericarp surfaces of the tomato samples after PU peeling were examined for signs of pitting as a result of cellular collapse and compared to a control (hot water-peeled tomato). From the scanning electron micrographs (Figure 5-4), there were no noticeable differences in the pericarp morphology between the hot water (A) and the PU treated samples (B) as no pitting was observed.

One possible explanation that may warrant the observations for PU peeling may be related to the engineering theory proposed by Bargel and Neinhuis (2005). The researchers (Bargel and Neinhuis 2005) stated "from a mechanical point of view, the location at the outer perimeter of the tomato fruit indicates that the cuticle may function as an external structural element that adds mechanical support for tissue integrity, since it has been elucidated that stresses are highest at the surface of the body," (i.e. the tomato skin). Added to the theory proposed by Bargel and Neinhuis (2005), Mintz-Oron and others (2008) elaborated that protection of the cell contents against mechanical damage is attributed to the matrix of the cuticle which was discussed in detail in chapter 2. The cutin and hydrophobic properties are believed to be the main elements of the cuticle protecting the hypodermal cells (e.g., pericarp) from erosive damage such as pitting (Niklas 1992). Therefore, in this study, it is reasonable to assume that the cuticle could have attenuated most cavitational effects of ultrasound bombarding the surface of the tomato skin. Consequently, most of the mechanical damage and failure would have been limited to the epidermis, preventing damage to the pericarp, which was the desirable outcome for this experiment.

For lye (C) and steam-peeled (D) tomatoes respectively, the morphology of the pericarp appeared to be slightly different when compared to the tomatoes treated with PU (B) (Figure 5-4). As described by Barrett and others (1998), pericarp cells are usually polyhedral in shape. In this experiment it was observed that the polyhedral shape of the pericarp cells are more apparent for hot water (A) and PU-peeled (B) tomatoes when compared to lye (C) and steam-peeled (D) tomatoes (Figure 5-4). Based on this observation, it can be assumed that a significant amount of the pericarp is lost with the skin during peeling process, attributing to the differences in the pericarp morphology among the various treatment groups. For the lye-peeled (C) tomatoes, the pericarp cells seemed almost completely diminished, whereas for the steam, the cells were a little more apparent but with a flattened appearance. The flattened appearance of the cells could attribute to the loss of turgor pressure with in the cell since the steamed peeled tomatoes were processed under pressure.

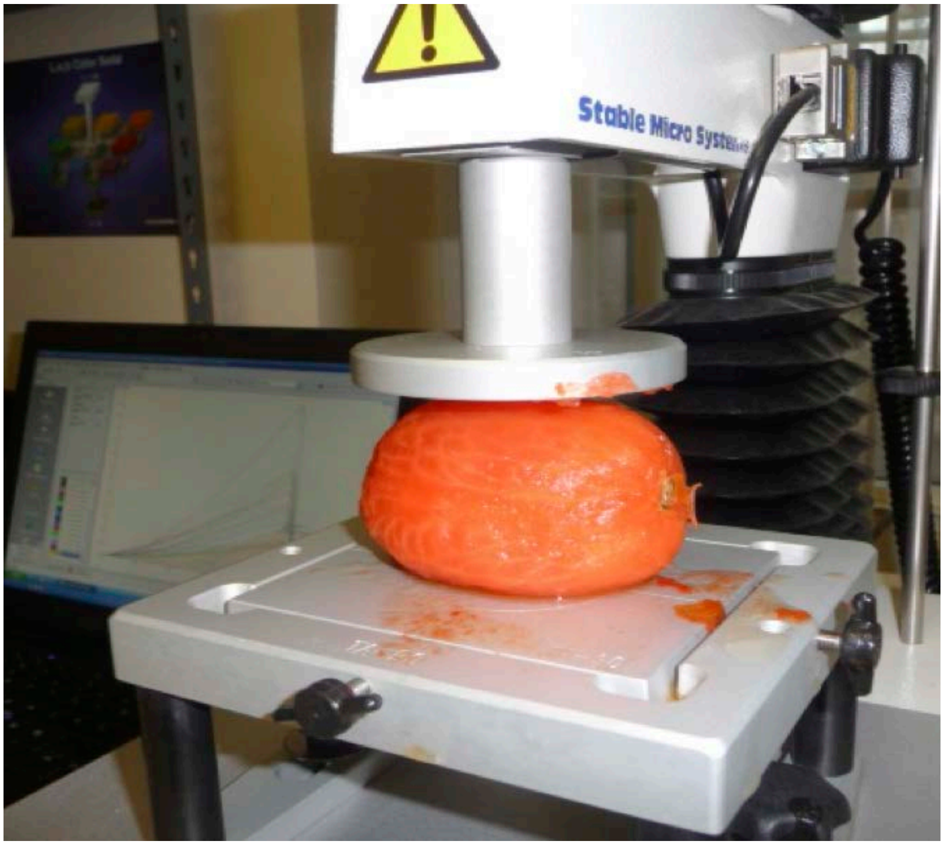


Figure 5-1. Alignment of a whole-peeled Roma tomato on the TA.TX plus texture analyzer base plate. Photo credit: University of Florida, Food Engineering and Processing Laboratory.

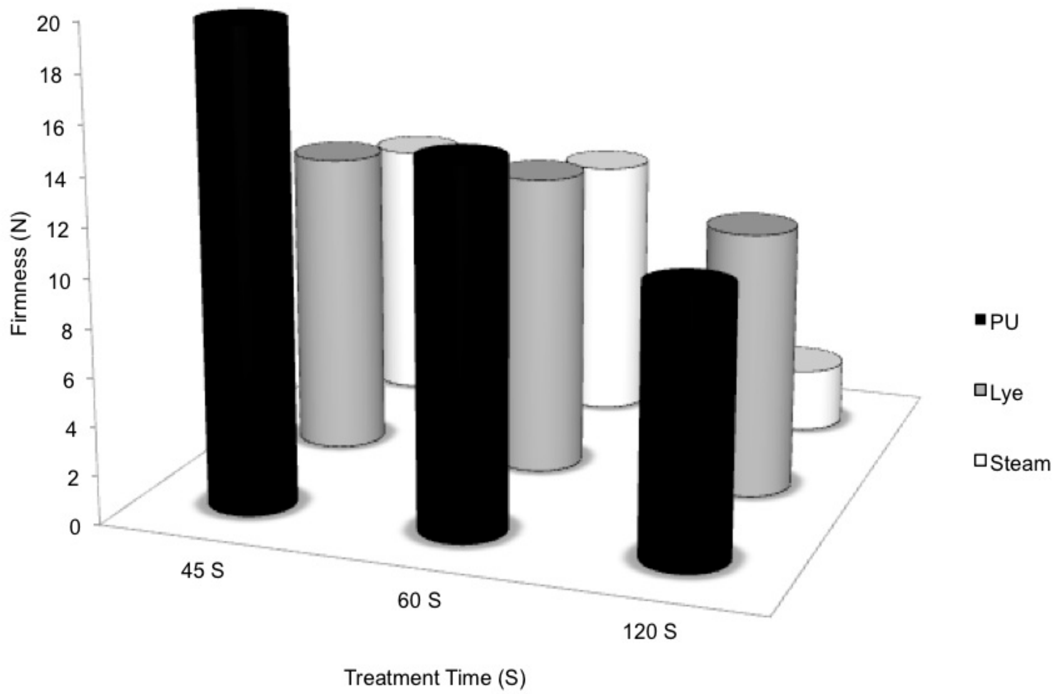


Figure 5-2. Effects of peeling (PU, lye and steam) on peeled-tomato firmness.

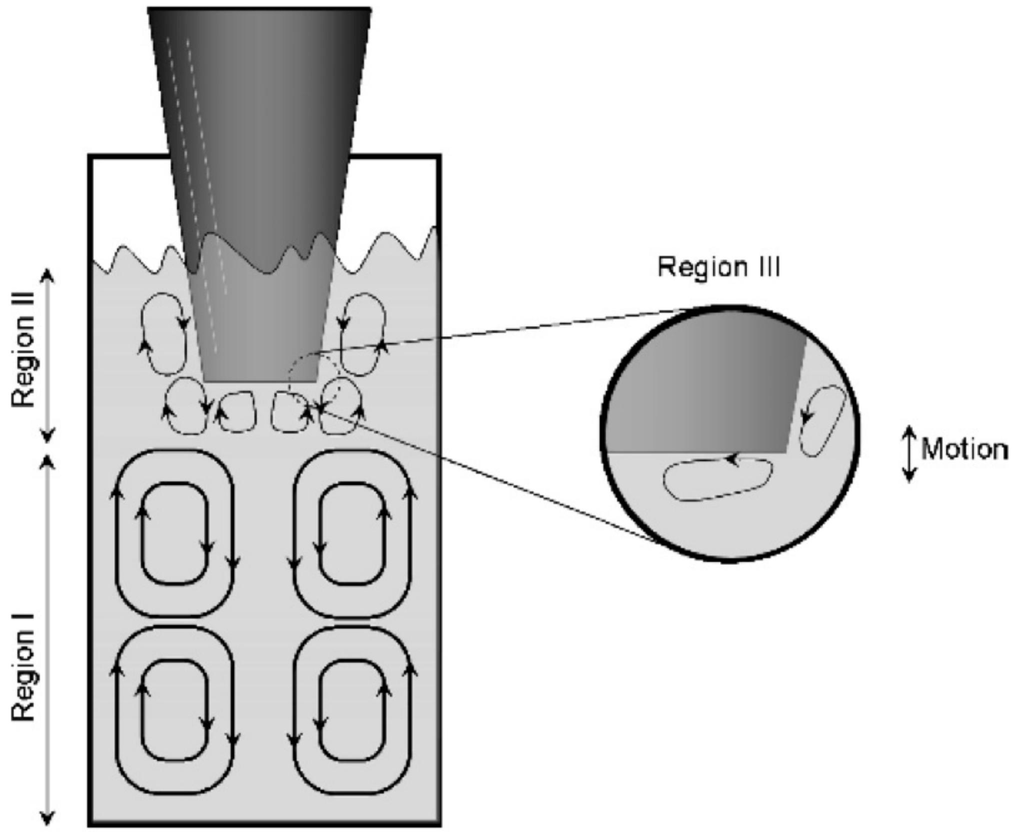


Figure 5-3. Regions of acoustic streaming. Source: Khanal and others (2007). Reprinted with permission from the Journal of Critical Reviews in Environmental Science.

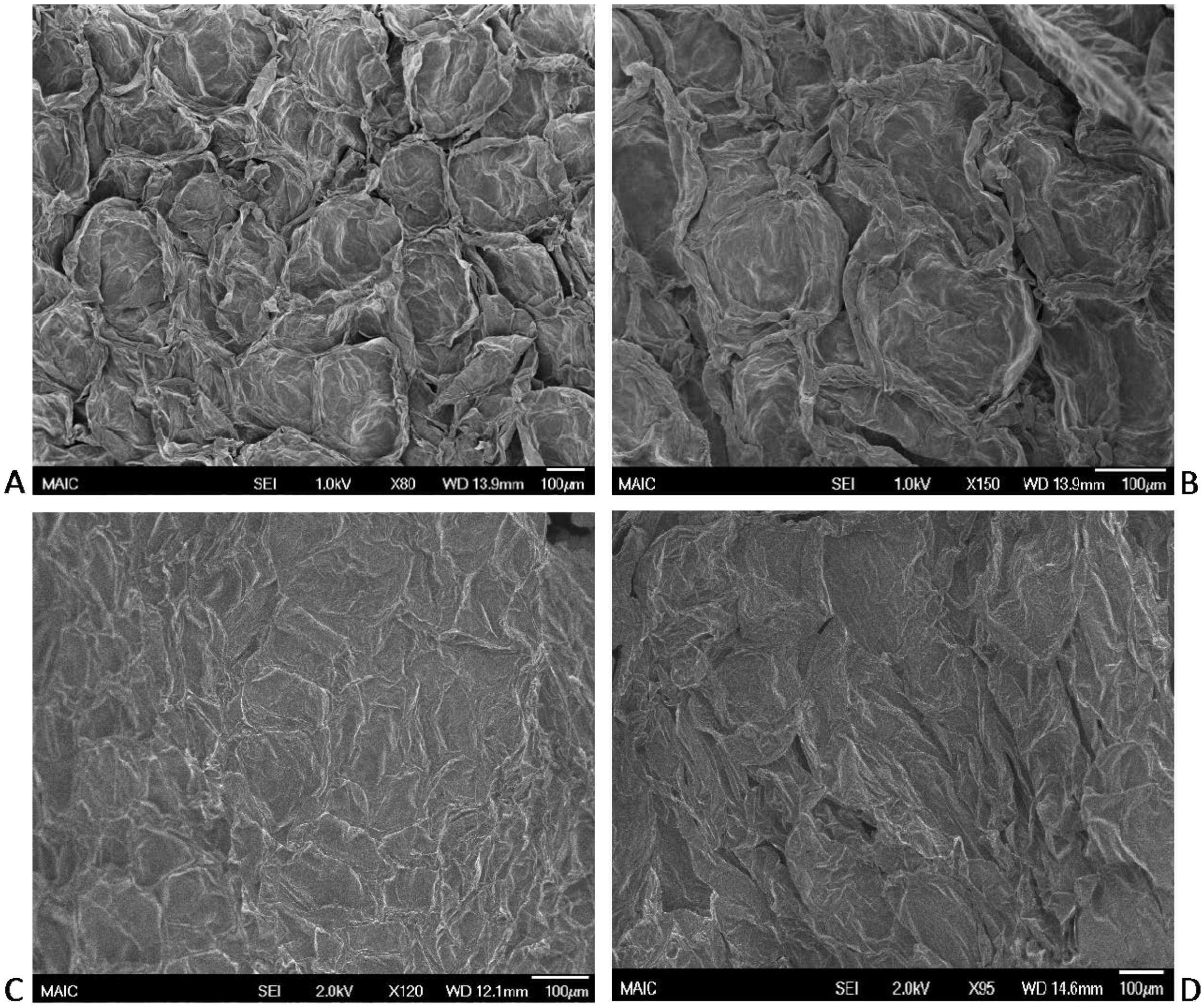


Figure 5-4. Scanning electron micrographs of (A) hot water/steamed, (B) PU peeled, (C) steam and (D) lye-peeled tomato samples respectively. Photo credit: University of Florida, Particle Science Engineering Department.

CHAPTER 6
ECONOMIC EVALUATION AND FEASIBILTY STUDY OF A NOVEL PU PEELING TECHNOLOGY VERSUS CONVENTIONAL LYE AND STEAM

Background

To meet the demands for food products with preserved or improved quality, new or improved facilities and equipment are necessary. Additionally, technology-driven change in the food industry is becoming prevalent as more companies are integrating novel technologies into food production to initiate sustainable and environmentally friendly practices ranging from, saving energy to packaging innovations (Swire-Thompson and others 2001). However, before developing a new process or plant, it is imperative that an economic evaluation is conducted. The economic evaluation of a process is crucial as it is the main determinant of whether a project or process should be implemented, abandoned or continued with further research (Silla 2003). In this research, an economic feasibility study of a novel PU tomato-peeling process compared to conventional lye and steam was performed.

Materials and Methods

Proceeding with 5 steps adapted from Saravacos and Maroulis (2007), the economic feasibility of PU as an alternative peeling technology was determined. The engineering focus of the feasibility study, mainly the first 3 steps, involved the construction of process block diagrams (PBDs), material and energy balances and sizing of the major equipment. The last 2 steps, primarily the economic focus of the process, involved estimating total capital and manufacturing costs. Estimates and quotation drafts were obtained from industry experts and suppliers of ultrasonic processing equipment and chemicals such as Sonics and Materials Inc.

Results and discussion

Step 1: Process Description and Process Flow Sheet for Peeled-Tomato Production

As described by Swire-Thompson and others (2001), a tomato plant is usually designed to facilitate the processing of 2 main product lines: Paste and peeled. Examples of paste products include the following: Tomato paste, ketchup, spaghetti and pizza sauce. Pulping the tomatoes and extracting the seeds and skin, followed by the addition of various flavoring ingredients, produce paste products. However, peeled products, the main focus of this research, include whole tomatoes, which may be further processed into salsa or diced tomatoes prior to canning and thermal treatment.

Using a process flowsheet also termed a “process block design” (PBD), the major units of operation for the processing of “peeled” tomatoes were outlined in Figures 6-1(PU), 6-2 (lye) and 6-3 (steam) respectively. Saravacos and Kostaropoulos (2002) defined the PBD as the simplest flowsheet, which graphically illustrate the material flow and energy requirements for performing economic analyses of a process.

In the PBDs (Figures 6-1, 6-2, 6-3), the major process operations of the tomato-peeling process were outlined. These included the following: Washing, distribution, presorting, peeling, sorting, dicing or cutting, filling, cooking and cooling.

Washing

After the tomatoes are harvested from the field, they are washed before distribution to the pre-sorting phase. The primary objective of washing the tomatoes is to remove contaminants from the field and reduce the microbial population. During washing, the fruits may be soaked in tanks that are aerated or paddled to loosen dirt and debris.

Distribution and presorting

Tomato fruits for processing are either allocated to the paste or peeling line based on several quality parameters (e.g., color, solids and defects). Selection of the raw product either for pasting or peeling is done through a grading process. For whole-peeled tomatoes, besides the color, texture is one of the more crucial parameters evaluated during grading, as the product must be firm enough to withstand the canning process. Moreover, in the pre-sorting phase, culls (i.e., the undesirable tomatoes) are removed from the peeling line, and used for juice used to fill the cans of peeled-tomato products (Starbird 1990). Additionally, during this stage, the fruits may be cored to remove the stem scars.

Peeling

Inevitably, for peeled-tomato products, the skin must be removed prior to processing. In the review of literature, the 2 most commonly practiced methods mentioned were both steam and lye. Steam peeling is mostly performed in California, USA, whereas, lye peeling is predominantly practiced in the Midwest, USA and Canada. In Chapter 2, the various peeling methods and their conditions were described. As previously described, steam peeling is performed at a pressure of 24-27 psig for approximately 25-40 s at 121°C. Typically, in the tomato-peeling industry, for the lye process, a solution of 50 % sodium hydroxide ($NaOH$) at 85-100°C is applied to the tomatoes for 30-60 s (JBT 2012). In the industry it can be proposed that the PU peeling process may be conducted at 18-20 kHz and 10 W at 95-98°C with the same time conditions established for both lye and steam-peeling processes.

Sorting

After the peeling process, the peeled product is inspected for discoloration, blemishes and the presence of residual peel before the cans are filled.

Dicing and calcification

Diced tomatoes are usually cut into ⅜", ½" or 1" cubes and calcified using salts of calcium: Chloride, citrate, sulfate or monocalcium phosphate to increase firmness of the product, since thermal treatment results in the loss of product texture. Anthon and Barrett (2010) explained that the main mechanism of calcium firming might be attributed to the formation of complexes between the free-carbonyl groups on the pectin in the tomato flesh and calcium salts. Approved by the Food and Drug Administration (FDA), the calcification process may be performed by immersing the product into a calcium bath at a concentration of not more than 0.08% by weight (Hui and others 2003).

Filling and cooking

The final product is canned not less than 90% of the container volume and cooked before distribution. The literature (Cash and others 1997) mentioned that canned tomatoes might be cooked using 3 methods: Non-agitating cooking, conventional retorting and rotary continuous sterilizing. Cash and others (1997) stated that the retorting process is conducted for 35-55 min depending on the can size (e.g., commonly No. 2 ½). However, it is crucial that the geometric center of the can should reach 82°C to ensure commercial sterility, as under-processed tomatoes may initiate the proliferation of spoilage bacteria (e.g., butyric acid anaerobes) such as Clostridium pasterianum and butyriam respectively. Flat-sour organisms such as Bacillus coagulan (e.g., B. thermoacidurans) may also be favored.

Cooling

After the cooking process, the cans are cooled to 30-40 °C to preserve product quality (e.g., the color and flavor) prior to distribution or storage (Sinha and others 2010).

Step 2: Material and energy balances

Material (mass) and energy (heat) balances are integral in process engineering economics of food plants as they facilitate the identification of the specific requirements such as raw materials, energy and utility costs (Marouli and Maroulis 2005). In Figures 6-1, 6-2 and 6-3, the material, as well as energy requirements of the peeled-tomato process was illustrated. The flow rate of the materials was based on production capacity of 9070 kg (10 tons/h). The tomato peeling cannery was assumed to be under operation for an annual time of 3 months and 16 h/day, at a capacity of 14 400 tons/yr. The total process water required for unit operations, such as washing, fluming, peeling and sterilization in general is approximated to be 5-15 m^3/ton of raw material (Saravacos and Maroulis 2007). In our process the assumption was made that the maximum of 15 m^3/ton of process water was utilized.

The use of thermal energy for tomato peeling is an inevitable process. Equations 6-1 and 6-2 were used to calculate the heat energy (KJ) required for the peeling processes and the weight of steam (W_s)(Kg/h) respectively required for peeling, heating and sterilizing. In equations 6-1 and 6-2, the symbol Q (KJ) is the heat energy required for the process, W_p (Kg) is the weight of the product being heated, C_p (KJ/kg°C) is the specific heat capacity of the product to be heated, ΔT (°C) is the temperature change of the product, eff (%) is the efficiency of the system, h_g, (KJ/Kg) is the latent heat of evaporation of steam. The h_g is the amount of energy required to transform a unit mass of water into vapor at atmospheric (atm) pressure. The specific heat capacity is the amount of energy (heat) required to change the temperature of substance resulting in no phase change. In our process, the specific heat capacity values of 4.18 (Singh and Heldman 2001), 3.73 (Solvay Chemicals International 2004) and 3.98 KJ/kg °C (Singh and Heldman 2001) for water, lye solution and tomatoes were used respectively. The boiler used to generate steam, was assumed to operate at an efficiency of 85%.

$$Q = Wp \times Cp \times \Delta T / Eff \tag{6-1}$$

$$Q = hg \times Ws \tag{6-2}$$

Step 3: Sizing and costing of major equipment

Sizing of the major equipment utilized in a food process is an integral prerequisite to facilitate the cost estimation and capital investment of a process. In this study, the capacity and costs of the equipment for each peeling method (PU, lye and steam) (Table 6-2 and 6-3) were approximated using the PBDs (Figures 6-1, 6-2, 6-3). Other methods used included acquiring quotations from equipment fabricators (e.g., Sonics and Material Inc., and Hielscher Ultrasonics). Table 6-1 providing food-processing equipment costs, were also utilized.

Step 4: Total capital costs (C_T)

As emphasized by Marouli and Maroulis (2003), the CT (Table 6-4) is a crucial factor for evaluating the financial feasibility and optimization of a process or technological studies involving economics. The CT invested in a processing plant is the sum of the fixed (CF) and working (CW) capital (Equation 6-3) needed for the operation of the facility (Saravacos and Maroulis 2007). The total capital cost was 33.7 M$ for steam and lye and 34.2 M$ PU.

$$C_T = C_F + C_W \tag{6-3}$$

Fixed capital costs (C_F)

The C_F are usually one-time expenses used for the purchase of equipment determined in the sizing procedure and other related factors of the purchased equipment cost. These factors are namely the installation, piping, instrumentation and control, electrical, infrastructure and maintenance, and land. Additionally, other fees such as start-up, contractors and contingency are included (Saravacos and Maroulis 2007). Empirically, a rapid estimation of the C_F may be determined by the factorial Lang (fL) method using Equations 6-4 and 6-5 (Saravacos and Maroulis 2007). In the Equation 6-4, C_o, A and A_o denotes the cost, desired size and the standard size of unit equipment respectively. It was observed that based on the size estimation, the C_{eq} for both steam and lye peeling, was approximately the same amounting to a total of 8.15 M$ (Table 6-2). In contrast, the C_{eq} for PU technology was slightly more expensive (8.31 M$) than the conventional technologies (Table 6-3).

$$C_{eq} = \Sigma\, C_o\, [A/A_o]^n \tag{6-4}$$

$$C_F = f_L C_{eq} \tag{6-5}$$

The “Lang factor” f_L is defined as the ratio of the total cost of installing a process into a plant, to the cost of its major technical components (Table 6-5) (Marouli and Maroulis 2005). In Equation 6-5, f_L is the variable dependent on the type of industry. For example, a f_L of 3.10, 4.70 and 3.60 is representative of a solid, fluid and mixed fluid chemical processing plant respectively (Marouli and Maroulis 2005). On the contrary, the f_L for a food processing plant is much smaller and is specified as 1.35 being the minimum, 1.80 being the most probable, and 2.75 being the maximum value. However, in this study, a recommended f_L of 3.00 (Table 6-5) by Saravacos and

Maroulis (2007) was considered for several reasons: Advancement in technology, process-control, instrumentation and the Environmental Protection Agency (EPA) regulations regarding waste and effluent disposal and treatment.

The calculated C_F for the peeling processes using Equation 6-5 was verified using the Guthrie chart (Figure 6-4) showing the C_F versus C_{eq}, although a fL of 3.00 was used. Figure 6-4 illustrates the cost data of various food plants considering the fLs in the ranges that were previously specified. The calculated values for C_F were 24.5 and 24.9 M$ (Table 6-3) for lye and steam in addition to PU respectively. These costs were comparable to the C_F of a dairy plant, which was 27.1 M$ (Figure 6-4).

In contrast, Saravacos and Maroulis (2007) reported a value of 3.67 M$ dollars for a tomato paste plant, which was 8 times less than the calculated C_F for all the peeling technologies evaluated in this study for a tomato peeling plant. In comparing the sizing and preliminary cost data established in the literature (Maroulis and Saravacos 2003) for a tomato-paste plant, the variation in the equipment requirements used for peeled-tomato versus paste products may be one of the factors accounting for the differences in the total C_{eq}. Currently, there is no known published feasibility cost studies on PU peeling, which may be attributed to the novelty of the technology. In comparison to the conventional peeling technologies, it was apparent that the C_F of PU was very competitive regarding installation cost compared to the conventional (Table 6-4).

Working capital (C_W)

The C_W (Equations 6-6 and 6-7) encompasses the total revenue used for acquiring the raw materials, supplies, finished product and accounts (e.g., receivables and payables) (Saravacos and Maroulis 2007). As described (Saravacos and Maroulis

2007), the working capital factor (f_{WF}) (Table 6-6) is multiplied by the C_F to determine C_W. Table 6-6 outlines the nomenclature and factors utilized for the estimation of the C_W, a fraction of the income from sales (S) which was 9.19 and 9.34 M$ respectively. The calculated values for the annual S were 36.8 and 37.4 M$ for lye and steam and PU respectively.

$$C_W = f_{WF} C_F \tag{6-6}$$

$$f_{WF} = TCR\, f_{WS} \tag{6-7}$$

Step 5: Manufacturing costs (C_M)

As defined by Saravacos and Maroulis (2007), the annual manufacturing cost (C_M) of plant is a combination of the direct and indirect manufacturing costs, which are required to operate the processing plant. The direct costs relate to the fixed manufacturing costs (C_{MF}) and include maintenance, insurance and taxes. The variable costs (C_{MV}) includes raw materials (C_{Mat}), packaging materials (C_{Pack}), utilities (C_{Util}), and labor (C_{Lab})] costs. Moreover, the indirect costs include the sales and general expenses also referred to as the "overhead" (C_{Over}) (e.g., marketing or administrative fees). Using Equations 6-8 to 6-19 and the cost factor values respectively in Table 6-7, the C_M in this study was estimated (Table 6-8).

$$C_M = C_{MF} + C_{MV} + C_{Over} \tag{6-8}$$

Fixed costs (C_{MF})

In the literature (Saravacos and Maroulis 2007), the C_{MF} have been described as being related to the general maintenance to the plant. This cost may include and not only limited to replacement of equipment and parts, which may have malfunctioned due to wear and tear. In this feasibility study, the C_{MF} was calculated in the Equation 6-9 below and displayed in Table 6-8.

$$C_{MF} = f_{MV}C_F \tag{6-9}$$

Variable Manufacturing Costs (C_{MV})

Saravacos and Maroulis (2007) stated that the C_{MV} is the one of the most crucial factors in the determination of the C_M, which is a composite of the C_{Mat}, C_{Pack}, C_{Util} and C_{Lab} denoted by Equation 6-10.

$$C_{MV} = C_{Mat} + C_{Pack} + C_{Util} + C_{Lab} \tag{6-10}$$

Raw material costs (C_{Mat})

In order for a food plant to operate, large amounts of raw material including agricultural produce are required. Processing tomatoes are the principal raw material in the manufacture of tomato products (e.g., canned whole-peeled tomatoes). The pricing information of tomatoes in this study was obtained from the USDA NASS (2010) (National Agricultural Statistics Service) vegetable summary. The most up-to-date cost value of processing tomatoes was 87.2 $/ton. Therefore, the value of processing tomatoes per/h in our study was 872 $ and 1.26 M$ /yr. The C_{Mat} can be determined by the flow rate (F_{Rj}, *ton/h*) of the raw material determined by the mass balances (Figures 6-1, 6-2, 6-3), the unit cost (C_{Rj}, *$/ton*) and the annual operating time *t* (*h/yr*), which is summarized in the Equation 6-11 below.

For the lye peeling process, food grade raw materials such as NaOH is required. According to JBT Corporation (2012), a lye solution with the concentration of 50% is utilized in caustic peelers with a capacity of 8.3 L/ton. It was estimated from the mass balances (Figures 6-1,6-2, 6-3) that 83 L per 10 tons of tomatoes per hour is equivalent to 13, 280 L of lye/day. Therefore, on an annual basis, the cost of lye may amount to 1.69 M$.

$$C_{Mat} = t \Sigma F_{Rj} x C_{Rj} \quad (6\text{-}11)$$

Packaging costs (C_{Pack})

In general packaging materials for food products may include metal, paper, glass and plastic. For peeled whole-tomato products, metallic cans are the most commonly used. From the material balances (Figures 6-1,6-2, 6-3), it was determined that the number of cans required on an annual basis was 17.1 M, which equated to a total cost of 1.57 M$. The C_{Pack} was calculated according to Equation 6-12 below where t is the annual operating time; F_{Gj} is flow rate (*ton/h*) of the material and C_{Gj} is the unit cost ($/kg) of packaging per/kg of raw material.

$$C_{pack} = t \Sigma F_{Gi} x C_{Gi} \quad (6\text{-}12)$$

Food Plant Utility costs (C_{Util})

The principal utilities acquired by most food processing plants can be divided into 3 categories namely: Energy, non-energy and waste treatment related utilities (Saravacos and Maroulis 2007). Energy and non-energy related utilities in this study include fuel (e.g., natural gas), electricity (e.g., purchased), steam, cooling and process water respectively. Waste treatment related utilities include waste disposal and treatment of both lye and wastewater.

In general, the total C_{Util} was determined by Equation 6-13, where F_{Uj} is the flow rate of the utility and C_{Uj} is the ($/ton), with t as the annual operating time (h/yr). Equation 6-13 was used to directly to calculate the costs for plant effluents pertaining to the treatment and disposal. However the cost of natural gas (C_g), electricity (C_e), steam

(C_s), and cooling water (C_w) is dependent on the cost of fuel (C_f) and were determined separately using Equations 6-14 to 6-18 prior to calculating the total C_{Util}.

The plant effluent costs, which included the treatment of wastewater and disposal of both hazardous and non-hazardous waste, were calculated utilizing Equation 6-13 above. Based on the mass balances in Figure 6-2 for the lye peeling, it was determined that the lye requirement was 209 tons annually. It was mentioned (Saravacos and Maroulis 2007) that a food plant processing approximately 100 tons of product per day might discharge an estimated volume of 1000 m^3 of wastewater. According to Saravacos and Maroulis (2007), the non-energy related utility costs pertaining the disposal and treatment of non-hazardous waste is 0.35 and 0.40$ respectively. Therefore, based on the assumption regarding the volume of wastewater effluent, treatment and disposal may amount to 39.6 k$ and 3.47 M$ respectively per year. According to Saravacos and Maroulis (2007), the cost of disposal for hazardous wastes is approximately 145 $/ton. Therefore disposal costs for lye per year may cost a tomato cannery 30.2 K$.

Fuel cost (C_f)

In Equation 6-14, C_b represents the ($/bbl (oil barrel)) and C_f ($/kWh) is the fuel cost. According to the Bureau of Labor Statistics (2012), the most up-to-date average price data for a barrel (bbl) of crude oil for the month of August was $3.60. However this value may vary monthly and annually. Based on Equation 6-14, the calculated C_f was 0.144 $/kWh.

$$C_f = 8.73 \times 10^{-4}\ C_b + 1.23 \times 10^{-2} \qquad (6\text{-}14)$$

Natural gas cost (C_g)

The C_g ($/kWh) is calculated using equation 6-15, where C_f is the fuel cost ($/kWh). The C_g was determined to be 0.0850$/kWh according to Equation 6-15.

$$C_g = 0.625C_f - 0.009 \tag{6-15}$$

Electricity cost (C_e)

Electrical power for a processing plant may be purchased or self-generated and varies with the C_f. In this study the electricity is assumed to be purchased from a centralized power company and was determined (0.137$/kWh) by the Equation (6-16) below (Saravacos and Maroulis 2007).

$$C_e = 0.425C_f + 0.076 \tag{6-16}$$

Steam cost (C_s)

For canned whole-tomato products, the steam is acquired for the peeling and cooking processes. Primarily for steam generation purposes, boilers (85% efficiency [ηb]) are primarily used with the water-tube configuration at an operation pressure of approximately 100-140 bar (Saravacos and Maroulis 2007). However, in this study, the C_s was calculated (Equation 6-17) as prescribed by Saravacos and Maroulis (2007) with a reference pressure of 42.5 bar. For the peeling, the C_s was determined to be approximately 260 K$ per annum for all methods (PU, steam and lye). However for retorting, the C_s differed among the different peeling technologies. For instance, the C_s was much higher for the tomatoes peeled with PU (217 K$) as compared to lye (198 K$) and steam (190 K$). This may be attributed to the fact that there was much more product to be heated in PU peeled tomatoes due to higher product yield during the peeling process.

$$C_s = C_f / \eta b \tag{6-17}$$

Cooling water costs (C_w)

Equation 6-18 was used to calculate the C_w ($/kWh) used for cooling. It was taken into consideration that the cooling duty was 10% of the cost of power (cpr =0.100) for tower water (Saravacos and Maroulis 2007). The approximated C_w for PU, steam and lye was 12.3, 11.2 and 10.4 M$ respectively.

$$C_w = C_{pr}C_e \qquad (6\text{-}18)$$

Cost of labor (C_{lab})

In food processing plants, several personnel, accounting for the process labor, are required to facilitate the operation of the plant. The process labor can be estimated empirically utilizing mass and energy balances. However in this study, the C_{lab} (1.28 M$/y) was adapted from a cost data analysis study for a tomato paste plant by Marouli and Maroulis (2005).

Overhead costs (C_{Over})

The C_{Over} is usually classified as general and sales expenses affiliated with fees for advertisement, interest, insurance and travel expenditures for example. The C_{Over} in this study was calculated using Equation 6-19 where the cost factor (f_{Over}) and S was utilized. The annual overhead costs for both lye and steam and PU were 18.4 and 18.7 M$/y respectively.

$$C_{Over} = f_{Over}S \qquad (6\text{-}19)$$

Financial and Economic Feasibility

In the literature (Silla 2003), it is established that a project or process is economically and financially feasible when it is more profitable than other competing technologies and capital could be produced for its implementation respectively. The tomato peeling plant profitability in this feasibility study was determined by calculating the annual gross profit (*PGn*) in equation 6-20, by subtracting the sales income (*S*) from the manufacturing cost (C_M).

$$P_{Gn} = S_n - C_{Mn} \qquad (6\text{-}20)$$

From the results in this study it can be suggested that PU technology as an alternative peeling technology to the conventional (lye and steam) is economically and financially feasible. It was found that the tomato cannery plant installed with PU as a peeling technology was 10 and 12 K$ (Table 6-4) more profitable than lye and steam respectively. Based on this feasibility study, there is a possibility that the capital could be produced to facilitate the implementation of PU as a novel peeling technology. This conclusion was made due to the fact that the S annually was sufficient to compensate the installation costs for the tomato-peeling plant (Table 6-4).

Table 6-1. Unit cost of mechanical, thermal and packaging equipment for a food processing plant.

Equipment		Ton/h	K$
Mechanical process equipment			
Fruit and vegetable prep		20.0	50.0
Unloader		10.0	50.0
Washing machine		10.0	30.0
Inspection belt		5.00	50.0
Sorter/sizer		5.00	100
Vegetable peeler			
Thermal Processing			
Rotary cooker/cooler	1500 cans/h	1.26	500
Packaging Equipment			
Can seaming	1500 cans/h	1.26	250
Can labelling	1500 cans/h	1.26	50.0

Adapted from Saravacos and Maroulis (2007).

Table 6-2. Sizing and preliminary cost estimation of a tomato cannery manufacturing whole peeled tomato products processed with Lye and Steam.

Equipment	Capacity	Quantity	Cost M$
Vegetable Preparation			
Vegetable unloader	10 tons/h	1	0.03
Washing machine	10 tons/h	1	0.03
Inspection belt	10 tons/h	1	0.05
Sorter	10 tons/h	2	0.20
Vegetable peeler	10 tons/h	2	0.20
Cutter	10 tons/h	1	0.20
Thermal Processing			
Rotary cooker/cooler	1.26 tons/h	8	4.00
Boiler	10 MW/h	1	0.01
Processing vessel	1 m3	1	0.01
Packaging Equipment			
Can seaming	1.26 ton/h	8	3.20
Can labelling	1.26 ton/h	8	0.40
		Total cost	8.15

Table 6-3. Sizing and preliminary cost estimation of a tomato cannery manufacturing whole peeled tomato products processed with PU.

Equipment	Capacity	Quantity	Cost M$
Vegetable Preparation			
Vegetable unloader	10 tons/h	1	0.03
Washing machine	10 tons/h	1	0.03
Inspection belt	10 tons/h	1	0.05
Sorter	10 tons/h	2	0.20
Vegetable peeler	10 tons/h	2	0.20
Cutter	10 tons/h	1	0.20
Thermal Processing			
Rotary cooker/cooler	1.26 tons/h	8	4.00
Boiler	10 MW	1	0.01
PU unit/vessel	10 kW	1	0.17
Packaging Equipment			
Can seaming	1.26 ton/h	8	3.20
Can labelling	1.26 ton/h	8	0.40
		Total cost	8.31

Table 6-4. Total Capital costs estimation of a tomato cannery plant manufacturing peeled tomato products.

		Steam and Lye M$	PU M$
Equipment cost	Ceq	8.15	8.31
Lang factor	fL	3.00	3.00
Fixed capital	CF	24.5	24.9
Working capital	CW	9.18	9.34
Total capital	CT	33.7	34.2
Sales income	S	36.8	37.3

Table 6-5. Breakdown of Lang factors for food processing plants.

	Plant Expansion		
Purchased Equipment	1.00		
			1.00
Installation	0.50		
Piping	0.25		
Instrumentation and Control	0.15		
Electrical	0.10		
			1.00
Buildings	0.35		
Yard Improvement	0.05		
Land	0.10		
			0.50
Off-site facilities	0.00		
			0.00
Engineering		0.25	
Start-up		0.10	
Contractors fee		0.05	
Contingency		0.10	
			0.50
Lang Factor			3.00

Adapted from Saravacos and Maroulis (2007)

Table 6-6. Working capital factors cost estimation for peeled tomato manufacturing plant operating for ninety days.

Working Capital Factors	
FWS=tcol=Cw/S	tcol= Collection Period
FWF=TCRfWS	
tcol=0.25	0.25 y = 90 days
TCR=Turnover capital ratio	TCR=1.50 for foods
S=TCRC_F	

Table 6-7. Fixed manufacture cost factors of a food processing plant.

Manufacturing cost	Fixed capital	Sales income
Fixed		
Maintenance	0.12	
Insurance	0.01	
Taxes	0.01	
Royalties	0.01	
	fMF = 0.15	
Variable		
Raw Materials		0.20
Packaging		0.05
Utilities		0.05
Labor		0.20
		fMV = 0.50
Overheads		0.05
Sales expenses		0.05
General expenses		$f$over = 0.10

Table 6-8. Total manufacturing cost estimation of a tomato cannery plant manufacturing peeled tomato product per annum.

		Lye M$	Steam M$	PU M$
Raw Materials	C_{Mat}	2.94	1.26	1.26
Packaging	C_{Pack}	1.57	1.57	1.57
Utilities	C_{Util}	0.47	0.46	0.50
Waste Treatment	C_{Wst}	0.07	0.04	0.04
Labor	C_{Lab}	1.28	1.28	1.28
Variable Manufacturing	C_{Mv}	6.26	5.82	4.59
Fixed Manufacturing	C_{Mf}	3.66	3.66	3.78
Overheads	C_{Over}	18.4	18.4	18.7
Manufacturing	C_M	28.3	27.9	26.8
Total Annualized	TAC	31.1	29.4	29.9
Plant Profitability	P_{Gn}	8.50	10.2	10.3

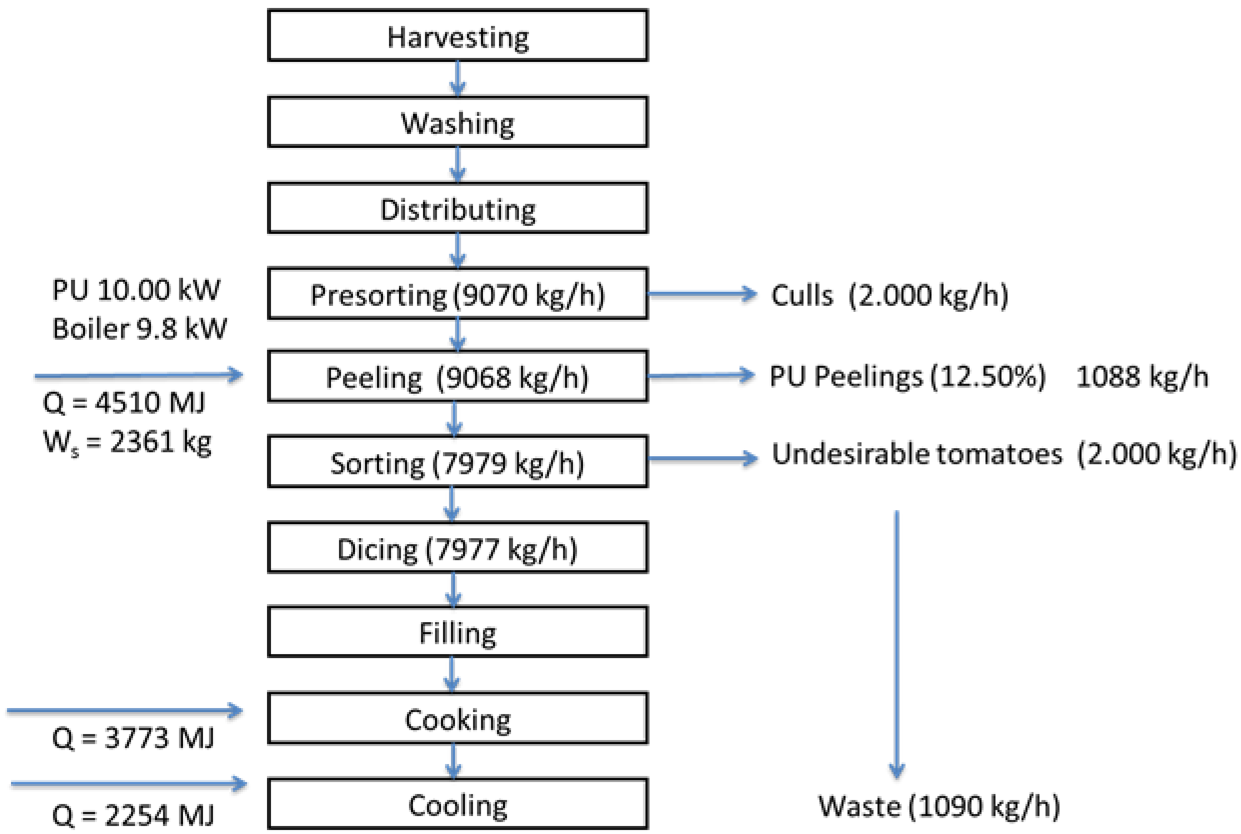


Figure 6-1. Process block diagram (PBD) showing the estimated material and energy requirements for PU tomato peeling process on a basis of a raw material flow rate of 9070 kg/h.

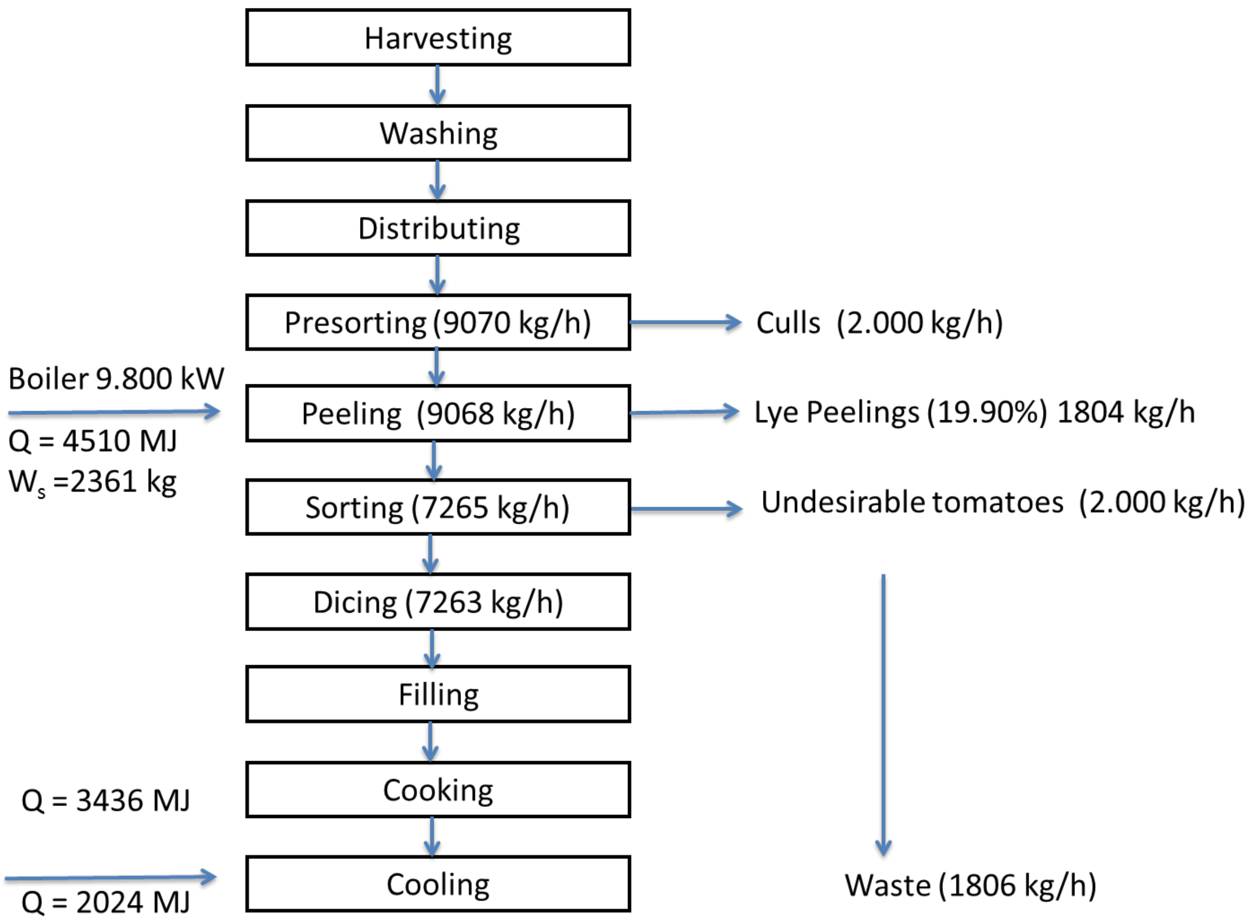


Figure 6-2. Process block diagram (PBD) showing the estimated material and energy requirements for lye tomato peeling process on a basis of a raw material flow rate of 9070 kg/h.

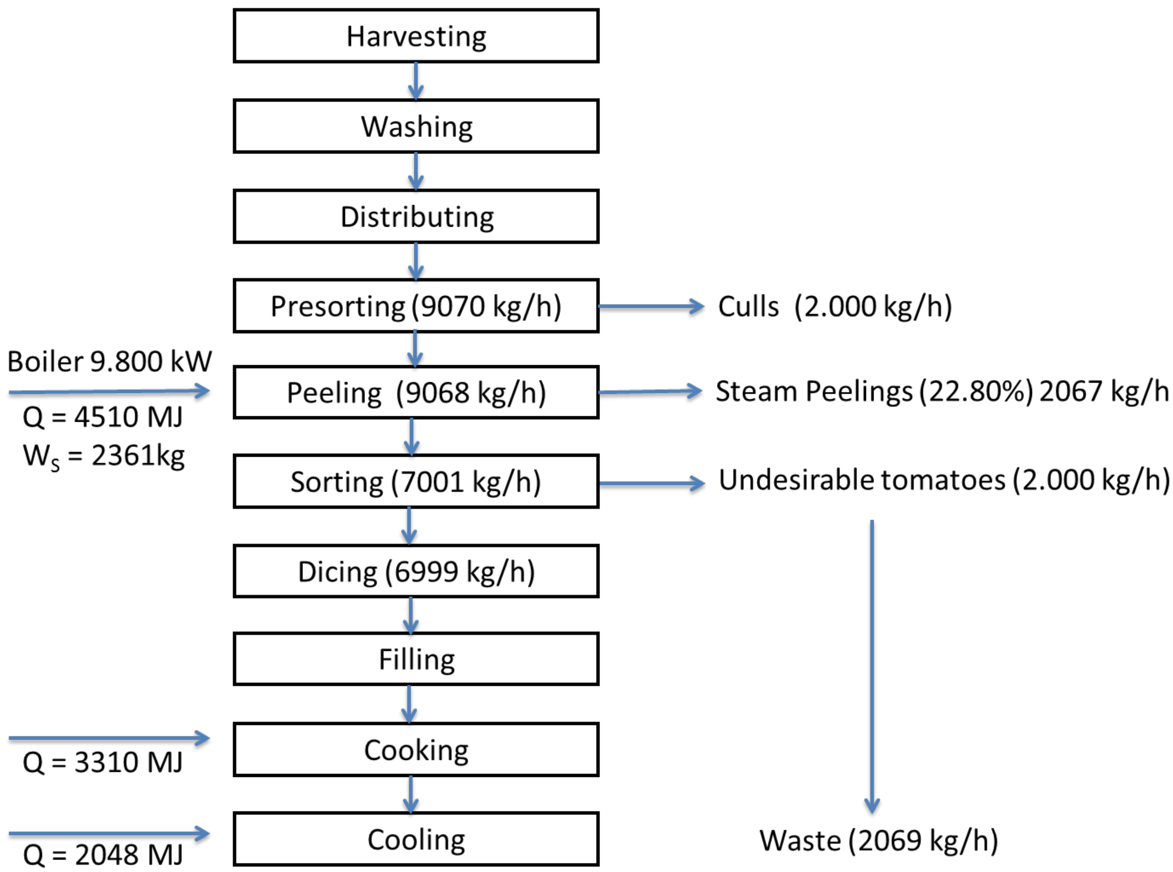


Figure 6-3. Process block diagram (PBD) showing the estimated material and energy requirements for steamed tomato peeling process on a basis of a raw material flow rate of 9700 kg/h

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

In this study, the feasibility of using PU as a novel tomato peeling technology was studied and compared with the two most predominant methods used which are lye and steam. According to results obtained, the following conclusions were drawn: PU peeling produced whole-peeled tomatoes with peeling losses approximately 2 times less than the conventional lye and steam. These results were observed, even though all of the peeling methods ranked the same degree of ease of peeling (peeling score ≥4) after treatments. It can be also assumed that peeling losses may have been associated with amount of flesh (i.e., the pericarp) removed with the skin, as there was high relationship between peeling loss and peeled-pericarp thickness. In this study, the peeling time ranged from 45-120 s; however, it was found that 60 s was the most desirable time for achieving the desired peeling performance as well as minimizing the peeling losses and retaining the lycopene content of the tomatoes. Experimentally, it was found that PU was able to reduce peeling losses by approximately 9 and 15% when compared to lye and steam respectively. Based on the fact that PU has the potential to improved product yield, it may be an attractive alternative technology for commercialization.

On the contrary, even though it was possible to achieve the desirable peeling performances, one general observation made throughout all peeling methods in that a small percentage of the tomato skins under peeling conditions did not split. Therefore before commercialization of PU, there is a need to optimize the configuration of the ultrasonic system. This can be acheived by increasing the number of transducers used as well as fabricating the shape of the ultrasonic probe to enhance the intensity of the cavitation.

Many studies have evaluated the effects of peeling on the mechanical properties (i.e., mainly texture) of tomatoes. Texture, is one of the most critical quality parameters as it plays an integral role establishing a “standard of identity” for canned-tomato products based on their “degree of firmness”. It can be concluded from this study that not only PU proved to be the superior technology as it pertains to ease of peeling but also maintenance of the textural integrity of the product even with its high cavitational effects. Several studies proposed the possibility of PU inactivation of PME. Since PU inactivation studies were not performed in this study, future studies should be conducted to evaluate the effects of PU on the PME activity and or its inactivation in peeled tomatoes and how it correlates with the peeled firmness before any conclusions are drawn.

Additionally, it was found that although there was some variation in the values pertaining to other quality parameters such as color, lycopene, pH, TA and SS that were evaluated, the values in this study was comparable to other studies conducted on the processing effects of tomatoes. However one obvious observation was that steam peeling resulted in the greatest diminishing of peeled-tomato quality.

An economic feasibility study was performed for the peeling methods evaluated in this research with a plant capacity to process 160 tons of tomatoes per day. This study was used to determine the profitability and the competitiveness of PU versus the conventional peeling methods such as lye and steam. It was proven that PU technology had a very strong potential for commercialization, as it was approximately 1.2 M$ more profitable than lye and steam. Other added benefits could be related to the fact that equipment cost did really differ from the conventional for capital installation and most importantly the elimination of lye in preventing the chemical and environmental contamination.

APPENDIX
NOMENCLATURE

%	Percentage
°C	Degree celsius
A	Absorbance of analyte
a*	Redness
Atm	Atmosphere
b*	Yellowness
Bbl	Barrel
C	Carbon
CaOH	Calcium hydroxide
C_{eq}	Purchased equipment cost
C_F	Fixed capital cost
C_L	Labor rate cost
C_{lab}	Labor cost
C_M	Manufacturing cost
cm^2	Centimeter squared
C_{Mat}	Raw material cost
C_{MF}	Fixed manufacturing cost
C_{MV}	Variable manufacturing cost
C_o	Owned capital
C_{Over}	Overhead cost
C_{Pack}	Packaging cost
CPR	Cost of power

C_S	Sales income
C_T	Total capital cost
C_{Util}	Utility cost
C_W	Working capital cost
D	Dilution factor
ddH_2O	Dionized distilled water
Eff	Efficiency
Eqt Wt	Equivalent weight
f_L	Lang factor
f_{Lab}	Labor cost correction factor
f_{Mat}	Material cost correction factor
f_{MF}	Fixed manufacturing cost correction factor
f_{Over}	Overhead cost factor
f_{Pack}	Packaging cost correction factor
f_{Util}	Utilities cost correction factor
f_{WF}	Working capital factor
f_{WS}	Working capital factor
g	Gram
h	Hour
K	Kelvin
K$	Thousand dollars
Kg	Kilogram

Kg/h	Kilogram per hour
KHz	Kilohertz
KJ	Kilojoule per hour
KJ/Kg	Kilojoule per kilogram
Km/h	Kilometer/hour
Km/h	Kilometers per hour
KOH	Potassium hydroxide
kPa	Kilopascals
KWH	Kilowatt hour
L*	Lightness
L/ton	Liters per ton
M$	Million dollars
m^3	Meter cubed
Δ T	Delta T (temperature change)
hg	Latent heat of evaporation
μL	Microliter
Na_2PO_4	Sodium phosphate
η_b	Boiler efficiency
mg	Milligram
MHz	Megahertz
mL	Milliliter
mm	Millimeter
MPa	Megapascals

N	Normality
NaCL	Sodium chloride
NaOH	Sodium hydroxide
nm	Nanometer
ns	Nanosecond
P_G	Gross profit
Psig	Pounds per square inch gram
Q	Heat capacity
S	Annual sales
t	Annual operation time
Tan^{-1}	Inversed tangent
V	Volume of titrant
V/m	Volts per meter
W/cm^2	Watt per centimeter squared
Ws	Weight of sample
Ws	Weight of steam
α	Attenuation coefficient
α	Absorbed
μm	Micrometer

LIST OF REFERENCES

Agarwal S, Rao A. 2000. Tomato Lycopene and its Role in Human Health and Chronic Diseases. Canadian Medical Association Journal 163: 739-44.

Anese M, Falcone P, Fogliano V, Nicoli M and Massini R. 2002. Effect of Equivalent Thermal Treatments on the Color and the Antioxidant Activity of Tomato Purees. Journal of Food Science 67 (9): 3442-3446.

Anthon G, Barrett Diane. 2010. Changes in pectin and methylesterification and accumulation of methanol during production of diced tomatoes. Journal of Food Engineering 97:367-72.

Arias R, Tung-Ching L, Logan L and Janes H. 2000. Correlation of Lycopene Measured by HPLC with the L* a* b* color Readings of a Hydroponic Tomato and the Relationship of Maturity with Color and Lycopene Content 48:1697-1702.

Arthey D, Dennis C. 1991. Vegetable Processing. Blackie USA: VCH Publishers, New York.

Askari G, Emam-Djomeh Z and Tahmasbi M. 2009. Effect of Various Drying Methods on Texture and Color of Tomato Halves. Journal of Texture Studies 40: 371-89.

Arazuri S, Jaren C, Arana J, Perez de Ciriza J. 2007. Influence of Mechanical Harvest on the Physical Properties of Processing Tomatoes (Lycopersicon esculentum Mill.) Journal of Food Engineering 80: 190-98.

Barrett D, Garcia E, Wayne J. 1998. Textural Modification of Processing Tomatoes. Critical Reviews in Food Science and Nutrition 38 (3):173-258.

Bargel H, Neinhuis C. 2005. Tomato (Lycopersicon esculantum Mill.) Fruit Growth and Ripening as related to the Biomechanical Properties of Fruit Skin and Isolated Cuticle 56 (413): 1049-1060.

Batu A. Determination of Acceptable Firmness and Color Values of Tomatoes. 2004. Journal of Food Engineering 61:471-475.

Bayindirli L. 1994. Mathematical Analysis of Lye Peeling of Tomatoes. Journal of Food Engineering 23: 225-31.

Benzie IF, Strain JJ. 1996. The Ferric Reducing Ability of Plasma (FRAP) as a Measure of ‘‘Antioxidant Power’’: the FRAP Assay. Analytical Biochemistry. 239: 70-6.

Bhaskaracharya R, Kentish S, Ashokkumar M. 2009. Selected Applications of Ultrasonics in Food Processing. Food Engineering Reviews 1: 31-49.

Boileau T, Boileau A, Erdman J. 2002. Bioavailability of all-trans and cis-Isomers of Lycopene. Experimental Biology and Medicine 227: 914-9.

Brown H, Meredith F, Saldama G, Stephens T. 2006. Freeze Peeling Improves the Quality of Tomatoes. Journal of Food Science 35:(4) 485-8.

Bureau of Labor Statistics. Databases, Tables and Calculators by Subject: Fuel Oil. Accessed 3 Sept 2012. Availiable from: http://data.bls.gov/cgi-bin/surveymost

Calligaris S, Falcone P and Anese M. 2002. Color Changes of Tomato Purees During Storage at Freezing Temperatures. Journal of Food Science 67 6):2432-2435.

Clark P. 2007. Ultrasonics in Food Processing. Food Technology 61(3): 67-9.

Camelo A and Gomez P. 2004. Comparison of Color Indexes for Tomato Ripening. Horticultura Brasileira 22(3): 534-537.

Cole, ER, Kapur NS. 1957. The Stability of Lycopene. I. Degradation by Oxygen. Journal of Science in Food Agriculture 8: 32-6.

Das DJ, Barringer SA. 1999. Use of Organic Solvents for Improving Peelability of Tomatoes. Journal of Food Processing and Preservation 23: 193-202.

Das DJ, Barringer SA. 2006. Potassium Hydroxide Replacement for Lye (Sodium Hydroxide) in Tomato Peeling. Journal of Food Processing and Preservation 30 (1): 15-9.

Doran P. 2000. Bioprocess Engineering Principles. New York: Academic Press, New york, NY.

Fang YZ, Yang S, Wu G. 2002. Free Radical, Antioxidants and Nutrition. Nutrition. 18:872-9.

Feng H, Yang W, Hielscher T. 2008. Power Ultrasound. Food Science and Technology International 14: 433-6.

Feng H, Yang W. 2011. Ultrasound Processing. In: Nonthermal Processing Technologies for Food. Blackwell Publishing Ltd. and Institute of Food Technologists. DOI: 10.1002/9780470958360.ch10.

Fellows P. 2000. Peeling. Food Processing Technology Principles and Practice, 2nd Edition. CRC Publishing, Boca Raton, FL, USA: p 95-7.

Fish W, Perkins-Veazie P and Collins J. 2002. A Quantitative Assay for Lycopene that Utilizes Reduced Volumes of Organic Solvents. Journal of Food Composition and Analysis 15: 309-317.

Food and Agricultural Organization (FAO) of the United Nations. 2011. Top Production-Tomatoes. Food and Agricultural Commodities Production. Accessed 3 Sep 2012. Available from: http://faostat.fao.org/site/339/default.aspx

Garcia E, Barrett DM. 2006a. Peelability and Yield of Processing Tomatoes by Steam or Lye. Journal of Food Processing and Preservation 30(1): 3-14.

Garcia E, Barrett DM. 2006b. Evaluation of Processing Tomatoes from Two Consecutive Growing Seasons: Quality Attributes, Peelability and Yield. Journal of Food Processing and Preservation 30: 20-36.

Garrote R, Silva, Bertone R. 2000. Effect of Thermal Treatment on Steam-Peeled Potatoes. Journal of Food Engineering 45:67-76.

Gahler S, Otto K, Bohm V. 2003. Alterations of Vitamin C, Total Phenolics, and Antioxidant Capacity as Affected by Processing Tomatoes to Different Products. Journal of Agricultural Food Chemistry 51:7962-8.

George B, Kaur C, Khurdiya DS, Kapoor HC. 2004. Antioxidants in Tomato (Lycopersium esculantum) as a Function of Genotype. Food Chemistry 24: 45-51.

Graziani G, Pernice R, Lanzuise S, Vitaglione P, Anese M, Fogliano V. 2003. Effect of Peeling and Heating on Carotenoid Content and Antioxidant Activity of Tomato and Tomato-Virgin Olive Oil Systems. European Food Research and Technology 216: 116-21.

Gunning B, Steer M. 1996. Wax and Cuticle. Plant Cell Biology: Structure and Function. Jones and Bartlett Publisher Inc. Sudbury, MA, USA. p 52.

Hadley C, Miller E, Schwartz S, Clinton S. 2002. Tomatoes, Lycopene, and Prostrate Cancer: Progress and Promise. 227:869-80.

Heldt H, Piechulla B. 2010. Phenylpropanoids Comprise a Multitude of Plant Secondary Metabolites and Cell Wall Components. Plant Biochemistry. Fourth Edition. P 431-42.

Huang D, Boxin O and Prior R. 2005. The Chemistry behind Antioxidant Capacity Assays. Journal of Agricultural Food Chemistry. 53:1841-56.

Hui Y, Ghazala S, Graham D, Murrell K, Nip W. 2004. Canned Tomatoes: Production and Storage Handbook of Vegetable Preservation and Processing. Marcel Dekker Inc, New York, NY, USA. p109-116.

Hui Y.2006. Novel Uses of Ohmic Heating. Handbook of Food Science, Technology and Engineering, Volume 3. CRC Publishing New york, NY, USA. p126-7.

Heuvelink E. 2005. Crop Production Science in Horticulture: Tomatoes. CABI Publishing, Cambridge, MA, USA: p 1-16.

Issa AY, Volate SR, and Wargovich S. 2006. The Role of Phytochemicals in Inhibition of Cancer and Inflammation: New Directions and Perspectives. 19: 405-19.

Jones J.1999.Tomato Plant Culture: in the field, green house and home garden. CRC Press, Boca Raton, FL, USA. p 1-6.

John Bean Technology Corporation. 2011. John Bean Technologies Corporation Tomato Peeling System. Accessed 13 Aug 2011. Available from: http: www.jbtfoodtech.com/en/solutions/processes/tomato-processing

John Bean Technology Corporation. 2012. Tomato Caustic Peelers Model CA-30 and CA-50. Accessed 5 July 2012. Available from: http://www.jbtfoodtech.com/en/solutions/equipment/peelers/~/media/JBT%20Food Tech/Files/Brochures%20Canning/Peelers/Tomato%20Coustic%20Peelers.ashx

Khanal S, Grewell D, Sung S, Leeuwen J. 2007. Ultrasound Applications in Wastewater Sludge Pretreatment: A Review. Critical Reviews in Environmental Science and Technology 37 (4): 277-313.

Kim D, lee KW, lee HJ and Lee CY. 2002. Vitamin C Equivalent Antioxidant Capacity of Phenolic Phytochemicals. 50:3713-17.

Li X, Pan Z, Gokan B, Tara M, Griffith G. 2009. Feasibility Study of Using Infrared Radiation Heating as a Sustainable Tomato Peeling Method. University of California Davis, CA, 95616. Paper number: 095689 (American Society of Biological Engineers presentation).

Mandal P, Misra T, Ghosal M. 2009. Free-Radical Scavenging Activity and Phytochemical Analysis in the Leaf and Stem in Drymaria Diandra Blume. International Journal of Integrative Biology 7 (2): 80-4.

Marouli A, Maroulis Z. 2005. Cost Data Analysis for the Food Industry. Journal of Food Engineering 67: 289-99.

Martínez-Valverde I, Periago M, Provan G, Chesson A. 2002. Phenolic Compounds, Lycopene and Antioxidant Activity in Commercial Varieties of Tomato (Lycopersicum esculantum). Journal of Science of Food and Agriculture 82 (3): 323-30.

Martini S, Bertoli C, Herrera M, Neeson I and Marangoni.2005.In situ Monitoring of Solid Fat Content by Means of Pulsed Nuclear Magnetic Resonance Spectrometry and Ultrasonics. Journal of American Oil Chemist Society (82): 305-11.

McClements D.1995. Advances in the Application of Ultrasound in Food Analysis and Processing. Trends in Food Science and Technology 6: 293-9.

Miller R, Miller R, Anderson E. 2004. Freon Refrigerants. Audel Air Conditioning Home and Commercial 5th Edition. Wiley Publishing Ind. IN, USA. p 156-8.

Mintz-Oron S, Mandel T, Rogachev L, Feldberg L, Lotan O, Yativ M, Wang Z, Jetter R, Venger I, Adato A, Aharoni A. 2008. Gene expression and Metabolism in Tomato Fruit Surfaces. Plant Physiology 147: 823-51.

Miki N, Akatsu K. 1970. Effect of Heating Sterilization on Color of Tomato Juice. Journal of Japan Food Industry 17(5): 175-81.

Maroulis Z and Saravacos G. Project Evaluation and Cost Estimation. Food Process Design. CRC press, Boca Raton, FL, USA: p 62.

Morganelli A. 2007. The Biography of Tomatoes. Crabtree Publishing Company. New York, NY, USA: p 4-10.

Monnier H, Wilhelm A, Delmas H. 1999. The influence of ultrasound on micromixing in a semi-batch reactor. Chemical Engineering Science 54:2953-61.

Murphy D. 2011. Lipids. Plant Biotechnology and Agriculture. Cambridge University Press, Cambrige UK. p 74-5.

Nocentini M, Fajner D, Pasquali G, Majeli F. 1988. A fluid dynamic study of a gas-liquid, non standard vessel stirred by multiple-impellers. Chemical Engineering 37: 53-9.

Odriozola-Serrano I, Soliva-Fortuny R and Martin-Belloso O. 2008. Effect of Minimal Processing on Bioactive Compounds and Color Attributes of Fresh-Cut Tomatoes. LWT 41: 217-226.

Ondra N, Ellis B.1998. Saline or Sodic Soils. Soils and Composting: The Complete Guide to Building a Healthy Fertile Soil. Houghton Mifflin Company New York, NY, USA.p 43-4.

Ou B, Huang D, Hampsch-Woodill M, Flanagan J, Deemer. 2002. Analysis of Antioxidant Activities of Common Vegetables Employing Oxygen Radical Absorbance Capacity (ORAC) and Ferric Reducing Antioxidant Power (FRAP) Assays: A Comparative Study. Journal of Agricultural and Food Chemistry 50: 3122-8.

Págan A, Conde J, Ibarz A, Págan J. 2010. Effluent Content from Albedo Degradation and Kinetics at Different Temperatures in the Enzymatic Peeling of Grapefruits. Food and Bio-Products Processing 88: 77-82.

Phipps SM, Sharat MHM and Butterweck V. 2007. Assessing Antioxidant Activity in Botanicals and other Dietary Supplements. Pharmacopeial Forum. 33:810-14.

Povey J, Mason T. 1998. Power Ultrasound in Food Processing-the Way Forward. Ultrasonics in Food Processing. Blackie Academic and Professional, New York, NY, USA. p 105-25.

Rao MR, Choudhury B. 1981. Studies on Canning-Qualities of Tomato. Scientia Horticulturae 14 (4): 299-305.

Richardson R. 2001. Infrared Technology. Thermal Technologies in Food Processing. Woodhead Publishing, Boca Raton, FL, USA. p 210-3.

Sahlin E, Savage G and Lister C. 2004. Investigation of the Antioxidant Properties of Tomatoes after processing. Journal of Food Composition and Analysis 17: 635-647.

Saravacos G, Kostaropoulos A. 2002. Design of Food Processes and Food Processing Plants. Handbook of Food Processing Equipment. Plenum Publisher, New York, NY, USA. p 2-13.

Saravacos G, Maroulis Z. 2007. Food Plant Economics. CRC Press, Boca Raton, Florida, USA. p 26-296.

Schlimme D, Corey KA, Frey BC.1984.Evaluation of Lye and Steam Peeling Using Four Processing Tomato Cultivars. Journal of Food Science 49:1415-18.

Shi J, Le Maguer M, Kakuda Y, Liptay A, Niekamp F.1999. Lycopene Degradation and Isomerization in Tomato Dehydration. Food Research International 32: 15-27.

Shi J, Le Maguer M. 2000. Lycopene in Tomatoes: Chemical and Physical Properties Affected by Food Processing. Critical Reviews in Food Science and Nutrition 40(1): 1-2.

Silla H. 2003. Production and Capital Cost Estimation. Chemical Process Engineering Design and Economics. Marcel and Dekker Inc. New York, NY, USA. p 29-30.

Singh P, Heldman D. 2001. System of Units and Conversion Factors. Introduction to Food Engineering, 3rd Edition. Academic Press. New York, NY, USA. p 591-596.

Sinha N, Hui Y, Evranuz E, Siddiq M, Ahmed J. 2010. Handbook of Vegetables and Vegetable Processing.

Smith D, Cash J, Nip W .1997. Tomato Products. Processing Vegetables: Science and Technology. Technomic Publishing Company Inc. Lancaster PA. p 389-409.

Smith J, Hui Y. 2004. Canned Whole or Sliced Tomato Production. Food Processing: Principles and Applications. Blackwell Publishing, Ames, Iowa, USA. p 475-7.

Starbird A. 1990. A Metamodel Specification for a Tomato Processing Plant. Journal of Operational Research Society 41: 229-240.

Solvay Chemicals International. 2004. Liquid Caustic Soda-Specific Heat. Product Characteristics. Accessed 6 June 2012. Availiable from: http://www.solvaychemicals.com/Chemicals%20Literature%20Documents/Caustic_soda/PCH-1110-0004-W-EN_WW_.pdf

Suslick K, Price G. 1999. Applications of Ultrasound to Materials Chemistry. Annual Reviews of Material Science 29: 295-326.

Swire-Thompson A, Sporleder T, Hahn D, Bash W. 2001. Evaluating Optimal Product Mix Using Dynamic Stimulation: A Tomato Processing Case. Journal of Food Distribution Research 32: 156-167.

Thakur B, Singh R, Tieman D and Handa, A. 1996. Tomato Product Quality from Transgenic Fruits with Reduced Pectin Methylesterase. Journal of Food Science. 61(1): 85-7.

Toker I, Bayindirli A. 2003. Enzymatic Peeling of Apricots, Nectarines and Peaches. Lebensmittel-Wissenschaft und Technologie 36(2):215–21.

Toor R, Savage G. 2005. Changes in Major Antioxidant Components of Tomatoes during Post-Harvest Storage. Food Chemistry 99 (4): 724-7.

United States Department of Agriculture Agricultural Marketing Service. 1990. Canned Tomatoes (including stewed tomatoes) Grading Manual. Accessed: 5 Nov 2011. Availiable from: http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRD3105831

United States Department of Agriculture Economic Research Service. 2012. Vegetables and Pulses: Tomatoes. Assessed: 5 Nov 2011. Available from: http://www.ers.usda.gov/topics/crops/vegetables-pulses/tomatoes.aspx

Vaclavik V, Christian E. 2007. Pectin and Gums. Essentials of Food Science Third Edition. New York, NY, USA. p 69-71.

Wallat GK, Chapman FA, Luzuriaga DA, Balaban MO. 2002. Analysis of Skin Color Development in Live Goldfish using a Color Machine Vision System. North American Journal of Aquaculture 64: 79-84.

Walker W. 1963. Ultrasonics in Production Processes. Ultrasonics 1:123-9.

Wongsa-Ngasri P (2004) Ohmic Heating Biomaterials: Peeling and Effects of Rotating Electric Field. Ph.D. Dissertation, Ohio State University, Columbus.

Yaniga B. 2007. Mitigation of the Tomato Lye Peeling Process. Masters Thesis. The University of Toledo, Toledo, Ohio.

Young T, Juvik J and Sullivan J.1993. Accumulation of the Components of Total Solids in Ripening Fruits of Tomato. Journal of American Society Horticultural Science 118 (2): 286-92.

BIOGRAPHICAL SKETCH

Cheryl Rosita Rock is a native of Barbados. In the year of 2002, she matriculated from the Barbados Community College, Barbados, West Indies, and was awarded an associate's degree in Science with a concentration in biology and chemistry. In 2004, she was awarded a full Academic Scholarship from the Alabama Agricultural and Mechanical University, Huntsville, AL. There, she pursued her bachelor's degree in food science and technology with a minor in chemistry. During her undergraduate years, she received many honors and awards respectively including: Dean's List, Honor Roll, President's Cup, Who's Who Among American Colleges and Universities and the Most Outstanding Senior in the School of Agriculture and Environmental Sciences, graduating with an exceptional GPA of 4.00. In 2007, she continued with her master's degree in food science at the same university specializing in nutritional biochemistry and carcinogenesis.

In 2009, Cheryl was offered a Graduate Assistantship to pursue her doctoral studies at the University of Florida, Gainesville, FL. During her tenure, she served as the Graduate Student Representative of the food science department and earned several awards such as Best Student Paper at the Florida Horticultural Society annual conference in 2010 and Outstanding Student in the College of Agriculture and Life Sciences in 2011 and 2012. She also placed 3rd in the Fruits and Vegetable Division Graduate Paper Competition at the Institute of Food Technologists annual conference in 2012. Moreover, she also authored 2 and co authored 1 peer-reviewed article(s) respectively in the Journal of Food Engineering Reviews, Florida State Horticultural Society Proceedings and Sustainable Agriculture Research respectively.