

ABSTRACT

PASCUA CUBIDES, YVETTE THIBAUT. Continuous Flow Microwave Sterilization of Diced Roma Tomatoes. (Under the direction of Dr. Josip Simunovic).

This thesis sought to provide an assessment of: 1) the applicability, performance and quality of diced Roma tomatoes, 2) quality and consumer acceptance of a value added diced tomato product (salsa), thermally processed to commercial sterility, in a continuous flow microwave system (CFMS) followed by aseptic packaging.

In manuscript one, the effects of with varying pH (3.9 and 4.3) and calcium addition from two calcium sources, (calcium chloride (CaCl_2) and calcium lactate ($\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$)), on the dielectric properties of diced Roma tomatoes were studied in order to assess the compatibility of treated diced tomatoes in a continuous flow microwave system. Neither pH adjustment by citric acid addition, nor $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ addition, influenced the dielectric constant (ϵ') or loss factors (ϵ''). CaCl_2 addition increased ϵ'' but did not influence ϵ' .

Also in manuscript one, diced tomatoes treated with citric acid to pH 3.9 or 4.3, and CaCl_2 or $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ were processed in a CFMS followed by aseptic packaging. Diced tomato firmness, color, ascorbic acid (AA) retention and drain weight were evaluated, and achievement of commercial sterility was assessed. No growth was observed for microbial assays indicating that commercial sterility was achieved. pH adjustment resulted in similar diced tomato firmness which was significantly lower than calcium treated diced tomatoes which were also similar to each other. AA retention was greatest for non-calcium treatments. Significant loss of redness ($+a^*$ values) was observed for all treatments. No significant differences in drain weight values were observed for any treatment.

In manuscript two, the quality, consumer acceptance and storage stability of a value added product (tomato based salsa) processed to commercial sterility, was evaluated. AA retention was 72% and 66% for 3 and 56 days after processing respectively. Drain weight was 77% after processing and did not change significantly during storage. Highest peak force value for texture firmness was 90 N/100 g of drained salsa and did not change significantly during storage. Consumers perceived the salsa favorably and rated fresh flavor intensity with high average scores.

Continuous Flow Microwave Sterilization and Aseptic Packaging of Diced Roma Tomatoes

by
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DEDICATION

To my supportive, patient and loving husband Javier, my father, and his constant encouragement, and to my mother, whom without her patient ear, I could not have complete this project.

BIOGRAPHY

Yvette Thibault Pascua Cubides was born in St. Augustine, FL on December 31, 1977. She graduated from Johnson & Wales University of Charleston, SC in 1999, with an Applied Science degree in Culinary Arts. After her graduation, she joined the Fearington House Restaurant of Pittsboro, NC as the Executive Pastry Chef. During her tenure at the Fearington House Restaurant, she had the opportunity to design and execute intricate multi-component plated desserts at the four-star, five-diamond venue. In the fall of 2004, she joined the Department of Food, Nutrition and Bioprocessing Sciences at North Carolina State University (NCSU) to pursue a Bachelor of Science degree. After graduating in 2007, she joined the USDA Agriculture Research Services unit as a Biological Science Technician, focusing on sweet potato research, under the supervision of Dr. Van-Den Truong. During her tenure with the USDA, she began her Master of Science degree program in the Department of Food, Nutrition and Biological Science at NCSU working under the advisement of Dr. Josip Simunovic as a graduate research assistant. His research focuses on aseptic processing of low-acid multiphase foods in continuous flow microwave systems.

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TABLE OF CONTENTS

| | |
|---|------|
| LIST OF TABLES..... | vii |
| LIST OF FIGURES..... | viii |
| INTRODUCTION..... | 1 |
| Objectives..... | 4 |
| CHAPTER 1-Literature Review..... | 6 |
| 1.1 Tomatoes..... | 6 |
| 1.1.1. History and Origin of tomatoes..... | 6 |
| 1.1.2. Preservation..... | 7 |
| 1.1.2.1. Diced tomato unit operation for canning and aseptic processing..... | 7 |
| 1.1.2.1.1. Sorting and grading..... | 7 |
| 1.1.2.1.2. Washing..... | 8 |
| 1.1.2.1.4. Peeling..... | 9 |
| 1.1.2.1.5. Dicing..... | 10 |
| 1.1.2.2. Additives..... | 10 |
| 1.1.2.2.1. Firming agents..... | 11 |
| 1.1.3. Thermal Processing..... | 11 |
| 1.1.4. Quality issues associated with processed diced tomatoes..... | 11 |
| 1.1.4.1. Texture..... | 12 |
| 1.1.4.1.1. Middle lamella disruption..... | 13 |
| 1.1.4.1.2. Firming agents..... | 14 |
| 1.1.4.1.2.1. Calcium application methods and sensory impact..... | 15 |
| 1.1.4.2. Color..... | 17 |
| 1.1.4.2.1. Measurement systems and useful parameters..... | 17 |
| 1.1.4.2.2. Lycopene..... | 17 |
| 1.1.4.3. Vitamin C..... | 19 |
| 1.1.4.4. Drain weight..... | 21 |
| 1.1.4.5. Spoilage..... | 23 |
| 1.2. Aseptic Technology..... | 23 |
| 1.3. Microwaves..... | 26 |
| 1.3.1. Introduction to microwaves..... | 26 |
| 1.3.2. Components of a microwave heating system..... | 26 |
| 1.3.2.1. Microwave source..... | 27 |
| 1.3.2.1.1. Cathode..... | 27 |

| | |
|---|-----|
| 1.3.2.1.2. Anode and resonance cavity | 28 |
| 1.3.2.2. Wave guide | 29 |
| 1.3.2.3. Applicator | 29 |
| 1.3.3. Dielectric Properties..... | 30 |
| 1.3.3.1. Dielectric constant and loss factor | 31 |
| 1.3.3.2. Factors affecting dielectric properties..... | 32 |
| 1.3.3.2.1. Frequency..... | 33 |
| 1.3.3.2.2. Temperature..... | 34 |
| REFERENCES | 35 |
| CHAPTER 2- The effects of various calcium salts and pHs in the commercial sterilization of diced Roma tomato in a continuous flow microwave system and aseptic packaging on product quality | 47 |
| 2.1. Abstract | 48 |
| 2.2. Introduction... .. | 50 |
| 2.3. Materials and methods | 52 |
| 2.4. Results and Discussion | 59 |
| 2.5. Conclusions | 67 |
| 2.6. References | 68 |
| CHAPTER 3- Continuous flow microwave processing of tomato based salsa | 82 |
| 3.1. Abstract | 83 |
| 3.2. Introduction | 85 |
| 3.3. Materials and methods | 87 |
| 3.4. Results and discussion | 92 |
| 3.5. Conclusions | 101 |
| 3.6. References | 102 |

LIST OF TABLES

CHAPTER 2

| | |
|--|----|
| Table 1. Percentage citric acid needed to obtain desired pH in whole pack tomatoes (adapted from Gould 1992) | 71 |
| Table 2. pH, °Brix, and drain weight for processed diced tomato treatments..... | 72 |
| Table 3. Textural properties of processed diced tomato treatments..... | 73 |
| Table 4. AA before and after processing..... | 74 |
| Table 5. L*a*b* of diced tomato treatments before and after processing..... | 75 |

CHAPTER 3

| | |
|--|-----|
| Table 1. Salsa ingredients and manufacturer information..... | 105 |
| Table 2. pH, °Brix and Drain weight of Salsa after 3 and 56 days of storage at 4 and 37 °C | 106 |
| Table 3. AA retention in salsa after 3 and 56 days of storage at 4 and 37 °C..... | 107 |
| Table 4. Highest peak force and number of peak force responses in salsa after 3 and 56 days of storage at 4 and 37 °C..... | 108 |
| Table 5. Average Consumer Liking Scores for Overall Liking and Liking of Appearance, Overall Texture, Tomato Component Texture, and Flavor | 109 |
| Table 6. Mean Overall Liking Score, Percent Response and Penalty for JAR and non-JAR scores for Texture | 110 |

LIST OF FIGURES

CHAPTER 1

| | |
|--|----|
| Figure 1. Graphical representation of HTST heating regime..... | 42 |
| Figure 2. Magnetron schematic..... | 43 |
| Figure 3. Schematic of electric field orientation relative to magnetic field in microwave energy..... | 44 |
| Figure 4. Graphical representation of the Debye dielectric relaxation for polar molecules with a single relaxation time. (Adapted from: Nelson and Datta, 2001) | 45 |
| Figure 5. Simplified diagram of indicating the frequencies at which dielectric loss mechanisms occur for moist materials. Effects of temperature are also noted. (Adapted from Tang, 2005) | 46 |

CHAPTER 2

| | |
|--|----|
| Figure 1. Schematic diagram of the continuous flow microwave system | 76 |
| Figure 2. Dielectric constant (closed symbols) and loss factors (open symbols) for diced tomato treatments with respect to temperature for pH 4.3(A) or 3.9(B) and treated with CaCl ₂ (C) or Calcium lactate (D) | 77 |
| Figure 3. Loss tangent for diced tomato treatments with respect to temperature for pH 4.3(A) or 3.9(B) and treated with CaCl ₂ (C) or Calcium lactate (D) | 77 |
| Figure 4. Depth penetration with respect to temperature for diced tomatoes acidified to pH 4.3(A) or 3.9(B) and treated with CaCl ₂ (C) or Calcium lactate (D)..... | 78 |
| Figure 5. Typical time temperature history for inlet and exit streams of the first (A) and second (B) heating sections..... | 79 |
| Figure 6. Typical time temperature history for inlet and exit streams of the third heating section (A) and hold tube exit (B)..... | 80 |

| | |
|--|----|
| Figure 7. $L^*(a^*/b^*)$ before and after processing | 81 |
|--|----|

CHAPTER 3

| | |
|--|-----|
| Figure 1. Schematic diagram of the continuous flow microwave system | 111 |
| Figure 2. Dielectric constant and loss factor as a function of temperature for salsa..... | 112 |
| Figure 3. Loss tangent as a function of temperature for salsa | 112 |
| Figure 4. Typical time temperature history for inlet and exit streams of the first (A), second (B) heating sections | 113 |
| Figure 5. Typical time temperature history for inlet and exit streams of the third heating section (A) and the hold tube exit (B)..... | 114 |
| Figure 6. Highest peak force of 100g drained salsa after 3 and 56 days of storage at 4 and 37 °C | 115 |
| Figure 7. Histogram for Overall liking (A), Liking of Overall Appearance (B), liking of Flavor (C)..... | 116 |
| Figure 8. Histogram for liking of overall texture (A) and liking of tomato component texture (B) | 117 |
| Figure 9. Penalty analysis on overall liking scores for non-JAR texture | 118 |

INTRODUCTION

Tomatoes are an important source of vitamin C and are valued for their color and flavor (Madhavi and Salunkhe, 1998). Canned tomatoes are the most consumed canned vegetable, at 74.2 pounds per capita in the United States (Barringer, 2004). Diced tomatoes have become very popular because of an increased demand for value added products such as tomato based salsas (Barringer, 2004). Traditional thermal processing can have detrimental effects on vitamin C (ascorbic acid, (AA)) and texture firmness of diced tomatoes. Degradation of AA typically follows first-order reaction kinetics. The rate of this reaction is influenced by heat, oxygen concentration, pH, transition metals, water activity, and light (Gregory, 2008). According to Barringer (2004), vitamin C content of traditionally processed tomatoes is reduced by 45%. For texture firmness of diced tomatoes, texture degradation during thermal processing is a result of many factors which are mechanical, chemical or enzymatic in nature. Studies of thermal degradation kinetics for texture firmness in diced tomatoes however were limited (not found in an exhaustive literature review).

When it is desirable to reduce loss of texture firmness in diced tomatoes, processors may use calcium (Ca^{2+}) salts as firming agents. Divalent Ca^{2+} cations enhance tissue firmness by what is commonly known as the “egg-box-model”, where the cations covalently bind to the demethoxylated pectate chains located in the middle lamella between parenchyma cells (Grant *et al.*, 1973). In this way, the rigidity of the parenchyma cell wall is reinforced and texture firmness is enhanced. Ca^{2+} addition in diced tomatoes is limited to 0.08% Ca^{2+} by weight of the finished product according to the United States Code of Federal Regulations Title 21 (21 CFR 1555.190). Although several Ca^{2+} sources are commonly used for this

purpose including calcium chloride (CaCl_2), calcium sulfate, calcium citrate and monocalcium phosphate (Barringer, 2004), CaCl_2 is the most common (Barrett *et al.*, 1998). Adverse sensory effects however have been reported for use of CaCl_2 at high levels. Bolin and Huxoll (1989) found that apricots dipped in CaCl_2 solutions with an uptake of 480 ppm Ca^{2+} in the tissue elicited a noticeable taste difference where those with an uptake of 200 ppm Ca^{2+} did not. Luna-Guzman and Barrett (2000) found that fresh-cut cantaloupes treated with CaCl_2 had a more bitter flavor than those treated with calcium lactate ($\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$). $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ has been used as a firming agent for canned grapefruit, canned jalapeño peppers and fresh cantaloupe (Baker, 1993; Saldana and Meyer, 1981; Luna-Guzmán and Barrett, 2000). Currently, no studies have been reported in the literature comparing the performance of CaCl_2 to that of $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ as a firming agent in diced tomato products.

It is well known that High Temperature Short Time (HTST) processes lead to improved product quality as it preserves nutrients and sensory attributes better than conventional thermal processing (Montville and Mathews, 2005). Quality optimization of thermally processed foods is due to the temperature dependency of the thermal degradation kinetics of target microorganisms and quality attributes. This phenomena constitutes the principle of HTST. Heating products for shorter times at higher temperatures allows for the inactivation of degradative enzymes, target microorganisms and spores while limiting destruction of quality attributes such as flavor, color, texture and nutrient content. Leonard *et al.*, (1986) found that vitamin C and texture firmness retention were significantly greater for whole peeled tomatoes when processed in a HTST process as compared to that in a retort cooker at an equal sterilization value.

Continuous flow microwave heating of foods is an emerging technology. Microwave energy rapidly heats food materials leading to improved nutrient retention (Fu, 2004). Thus, it is likely that the use of microwaves for thermal processing of diced tomatoes will also lead to greater texture firmness retention. Furthermore, it is well known that thermal processing induces changes in the flavor profile of foods. Traditionally processed tomato products are often described as having “browned” and “cooked” flavor characteristics depending on the degree of processing (Hongsoongnern *et al.*, 2007). The rapid heating and cooling capabilities of the CFMS followed by aseptic packaging may be capable of producing fresh tasting product. Such attributes would be beneficial in value added products, such as tomato based salsas, were fresh flavor is desirable.

Consumption of fresh refrigerated salsa is a potential health hazard. Incidences of foodborne outbreaks associated with the consumption of fresh salsa have doubled during the decade between 1998 and 2008 compared with that from the years between 1984 and 1998 (Preidt, 2010). Contaminated cilantro, green onions, and jalapeño and Serrano peppers associated with salsa preparations have been indicted as the cause of outbreaks of *Salmonella* serotype Thompson, Hepatitis A, and *Salmonella* serotype Saintpaul respectively over the past decade (Campbell *et al.*, 2001; Jungk, 2008; Wheeler *et al.*, 2005). Consumption of raw tomatoes alone has also been the cause of outbreaks of *Shigella flexneri* Serotype 2a and *Salmonella spp.* (Reller *et al.*, 2006; Cummings *et al.*, 2001; Green *et al.*, 2008). Fresh salsa contaminated with *Salmonella enteritis* by a food handler was the cause of an outbreak in 2002 (Beatty *et al.*, 2009). Ma *et al.* (2010) found that tomato based salsas inoculated with pathogenic *Salmonella spp.* were able to support the survival of these pathogens, depending

on the salsa formulation. Their study found that freshly prepared salsas formulated with lime juice, but without fresh garlic, supported the survival and growth of *Salmonella spp.* Fresh refrigerated salsas currently comprise seven to eight percent of the total salsa market in the U.S. (Chang, 2009). As consumer demand for fresh, high quality foods increases, it is likely that the market share for fresh refrigerated salsas will increase. Consequently, so too will outbreaks associated with its consumption unless appropriate safety measures are implemented.

A fresh tasting tomato based salsa which has been processed to commercial sterility may be a suitable and safer alternative for consumers who prefer fresh refrigerated salsa.

As a commercially sterile food, this type of product would have the benefit of having a shelf life that is substantially longer than fresh refrigerated salsas not only on a food safety basis but also on a sensory quality basis. Texture contributes to the overall sensory quality of a food product. Tomatoes contain endogenous textural degrading enzymes including polygalacturonase (PG). PG enzymes cleave the α 1-4 linkages of the galacturonic backbone of pectic substance which contribute to the structure and ultimately the textural integrity of a plant cell. Unless these enzymes are inactivated, such activity will result in the destruction of textural integrity. Loss of textural integrity in the components of fresh refrigerated salsa will reduce sensory quality of the product.

The objectives of this research were to:

- 1) to determine the effects of varying pH (3.9 and 4.3) and calcium addition calcium chloride (CaCl_2) and calcium lactate ($\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$), on the dielectric properties of diced Roma tomatoes,

- 2) to evaluate the performance and quality of diced Roma tomatoes processed to commercial sterility, and
- 3) to evaluate the quality and consumer acceptance of tomato based salsa, processed to commercial sterility in a CFMS followed by aseptic packaging.

CHAPTER 1

LITERATURE REVIEW

1.1. Tomatoes

1.1.1. History and origin of tomato

The tomato fruit (*Lycopersicon esculentum*) is believed to have originated in the Andes region of South American along its pacific coast between the equator and the north of Chile. Aztec populations called the fruit “xiomate” or “zitotomate.” Indigenous populations of Mexico however called the fruit “tomati” and are credited with the domestication of wild varieties. This domesticated fruit was first introduced into Europe in 1554 after the Spanish colonization of the Americas (Gould, 1992).

The first written records of the tomato by European botanists was in the Herbal of Matthiolus (1554) which stated that the fruit had appeared in Italy and was known as pomi d’oro. Literally translated, this means golden apple. After its appearance in Italy, cultivation of the plant was thought to have spread to France and England. The cultivation of the tomato for markets in Europe however did not occur until about 1800. The first mention of the fruit in the United States was by Thomas Jefferson in 1781 (Gould, 1992).

Today, cultivation and production of tomatoes on a commercial scale is evident across the globe. The top five principle tomato producers world-wide are China, the United States, India, Turkey and Egypt respectively (FAOSTAT 2008). According to the Economic Research Service (ERS), California and Florida account for two-thirds to three-fourths of tomato production for fresh market tomatoes in the U.S.. Per capita consumption of processed tomato products has increased steadily since the 1980’s. Tomatoes are processed

into a variety of products including salsas, sauces, stews, soups, puree, juice, beverages, paste, and are commonly preserved whole, halved, wedges, sliced and diced. ERS estimates suggest the largest processed use of tomatoes is in sauces (35 percent), followed by paste (18 percent), canned whole tomato products (17 percent), and catsup and juice (each about 15 percent).

1.1.2. Preservation

For the purpose of this thesis, only the processing of diced Roma tomatoes will be discussed. Current preservation techniques employed for diced tomatoes include canning and aseptic processing. The unit operations for preservation of diced tomatoes in both canning and aseptic operations typically follow the similar product preparation steps of sorting and grading, washing, coring, peeling, and dicing. Once diced however, unit operations differ. In canning, diced tomatoes are filled into cans, covered with a topping juice, exhausted, sealed then thermally processed. For aseptic processing diced tomatoes are combined with a carrier fluid, deaerated, thermally processed in tubular heat exchangers, cooled and aseptic packaged.

1.1.2.1. Diced tomato unit operations common for canning and aseptic processing

1.1.2.1.1. Sorting and grading

Upon arrival to the processing plant, tomatoes are first off-loaded into a water flume where rotten tomatoes, stems, leaves and other extraneous materials are removed. These sorted tomatoes are then conveyed under photoelectric color sensors which detect and reject

immature fruits by way of a pneumatic finger. Inclusion of green fruits in a diced product will affect the final quality and pH of the product. It is therefore desirable to eliminate immature fruits. Finally, the color sorted tomatoes are conveyed past a line of human sorters which remove extraneous materials and rotten fruits not removed at the beginning of this sorting process.

1.1.2.1.2. Washing

After sorting is complete, tomatoes are washed in agitation tanks for 3-5 minutes to further eliminate dirt, contaminants and to reduce the microbial load (Galicia-Cabrera, 2007). Chlorine may be added to the wash water (Barringer, 2004) and should be maintained at a level of 50-200 ppm. While addition of chlorine will not reduce the spore count on tomatoes, it will help to maintain the spore population in the wash water itself (Heil *et al.*, 1984). The tomatoes will then receive a final rinse under streams of water.

Although monitoring of the wash water temperature is not a requirement it should be monitored as infiltration of microorganisms is associated with negative temperature differentials between water and the tomato flesh (Zhuangry, 1995). The FDA recommends that the temperature of wash water should be at least 10°F warmer than the tomato temperature to prevent infiltration in raw fruits not intended for sterilization (FDA, 2007). If microorganisms gain entrance into the tomato flesh via infiltration, it is likely that spores will also. The flesh material could provide a degree of protection against thermal inactivation resulting in an inadequately processed product.

1.1.2.1.3. Core

In the past, tomatoes were cored by hand to remove the peduncle and the heart in the section closest to the peduncle. Over time, machinery was developed to perform this action and reduce labor requirements. Today however, most varieties of tomatoes bred for processing have very small stem scars so this step is often eliminated. Trimming to remove rot or green portions of the fruits is not practiced in the United States due to high labor costs (Barringer, 2004).

1.1.2.1.4. Peeling

Peeling is a high-cost operation. When coupled with coring, it accounts for approximately 60% of the total labor cost in tomato processing (Madhavi and Salunkhe, 1998). According to the USDA peeling is not a requirement in diced tomato operations. The inclusion of the tomato skin however will result in a lower grade of the final product. For example, in order for a diced tomato product to receive a Grade A, not more than two square inches are permitted in a can containing less than two pounds of total product (USDA, 1990).

Two methods are commonly employed for tomato skin removal, steam and lye treatment. For steam peeling, the tomato is conveyed through an enclosed steam system. The steam scalds the tomato skin which loosens it from the pulp. Typical steam times are 30 to 60s depending on variety (Gould, 1992). Upon exiting the steam chamber, the superficial cells burst, releasing the skin in response to a sudden fall in pressure. Remaining skin is removed by conveying the tomato through a series of rubber disks or through a rotating drum under high pressure water.

In lye peeling, a solution of caustic soda (sodium hydroxide) often referred to a lye is used to selectively remove the skin. The lye selectively attacks cuticular tissue breaking down the outer tissue of the tomato. The remaining soft and gelatinous tissue is then removed in a fashion similar to that of steam blanching.

1.1.2.1.5. Dicing

As denoted in the USDA standards for grades of canned tomatoes, “diced” means tomatoes, peeled or unpeeled, that have been cut into approximate cube-shaped units (FDA 55 CFR 9412 section 52.5162). Tomatoes are commonly diced into 3/8”, 1/2” and 1” cubes (Barringer, 2004).

1.1.2.2. Additives

It is common practice for canners and aseptic processors to include organic acids, sugar, salts and/or firming agents in the packing medium or carrier fluid respectively. Tomatoes are classified as acid foods. As such, the pH of the diced tomato product must be below 4.6. Tomato pH is affected by the variety and fruit maturity and can range from 4.86 to 4.0 (Gould, 1992; Madhavi and Salunkhe, 1998). If tomato pH is too high, processors may use organic acids (most commonly citric acid) to packing mediums or carrier fluids to reduce product pH. Addition of sugar is permissible only to compensate flavor-wise for the addition of an acid. Addition of firming agents is also permissible as it is well known that thermal processing results in the loss of firmness in diced tomato pieces.

1.1.2.2.1. Firming agents

Typical firming agents used for enhanced firmness retention include calcium salts or compounds such as calcium chloride (CaCl₂), calcium sulfate, calcium citrate and monocalcium phosphate (Barringer, 2004). CaCl₂ is the most common (Barrett *et al.*, 1998). Addition of calcium however must not exceed 0.08% Ca²⁺ (w/w) of the final tomato product (FDA 21CFR155.190). The theory and mechanism for enhanced tissue firming by calcium salts has been thoroughly investigated and will be discussed in section 1.1.3.1.2.

1.1.3. Thermal processing

According to the FDA code of federal regulation (FDA 21CFR 113.3), commercial sterility of thermally processed foods means that through the application of heat the food material is free of microorganisms capable of reproducing in the food under normal non-refrigerated conditions of storage and distribution and viable microorganisms (including spores) of public health significance. Thus, the processed food product should be shelf stable and spoilage should not occur.

Processing conditions required to achieve commercial sterility are dependent on the pH of the food as well as the thermal stability of targeted microorganisms. Foods are classified according to their pH, as low acid, acid or high acid. Low acid foods have a pH \geq 4.6, acid foods have a pH 3.7-4.6. High acid foods have a pH $<$ 3.7. Spores of *Clostridium botulinum* are capable of germination and growth at pH \geq 4.6. As such, sterilization processes for low acid foods are designed such that the probability of the presence of a non-inactivated *C. botulinum* spore is 10⁻¹². This process is commonly referred to as the 12-D

concept. *C. botulinum* is not capable of growth in an environment of $\text{pH} < 4.6$. Sterilization processes for acid foods, such as tomatoes, are designed to control the survival and growth of sporeformers such as *Bacillus coagulans*, *Bacillus polymyxa*, *Bacillus macerans* and butyric anaerobes like *Clostridium butyricum* and *Clostridium pasteurianum* (Sandeep, 2008). High acid foods do not support the growth of sporeformers and therefore, thermal processed are designed to inactivate vegetative organisms.

Tomatoes are considered to be an acid food. For diced tomatoes, thermal processes are applied through canning or aseptic processes (Barringer, 2004). According to Barringer (2004), the key in thermal processing of canned whole and sliced tomato products is for the centermost tomato pulp to reach a minimum internal temperature of $88\text{ }^{\circ}\text{C}$. However, as will be discussed in section 1.1.4.2.5., tomato products have been known to be spoiled by sporeformers such as *Bacillus coagulans* and *Clostridium pasteurianum*. The National Canners Association recommendation for *Clostridium* spores is $F_{93^{\circ}\text{C}} = 5$ minutes for products of pH below 4.3 and $F_{93^{\circ}\text{C}} = 10$ minutes for products with $\text{pH} > 4.3$. For *Bacillus coagulans* spores, they recommend $F_{107^{\circ}\text{C}} = 0.7$ minutes at $\text{pH} 4.5$ (Barringer, 2004).

1.1.4. Quality issues associated with processed diced tomatoes

1.1.4.1. Texture

One of the most notable physical changes that occur during thermal processing of fruits and vegetables is degradation in texture firmness. Several definitions exist for the term texture as it refers to food. According to Bourne (2002), “texture is primarily the response of the tactile senses to physical stimuli that result from contact between some part of the body

and the food.” In processed fruits and vegetables, texture makes an important contribution to the perceived overall quality. Tissue softening is due to a loss of hydrostatic pressure which is responsible for turgor and disruption of the middle lamella matrix which acts as the support structure of parenchyma cells in fruits and vegetables (Bourne, 1989; Van Buren, 1979).

Parenchyma cells are unlignified and their primary walls are separated by a morphologically distinct region known as the middle lamella (Abbott, 2004). This middle lamella region is rich in pectic substances. Although the properties of pectic substances vary with source (BeMiller and Huber, 2008) their name is an umbrella term for a group of polysaccharides which have a backbone composed of 1-4 linked α -galacturonic acid existing at different degrees of esterification (DeMann, 1980). During thermal processing the middle lamella matrix is disrupted by water absorption, acid hydrolysis or cleavage of glycosidic bonds of pectic substances.

1.1.4.1.1. Middle lamella disruption

During thermal processing the middle lamella matrix is disrupted by water absorption, acid hydrolysis or cleavage of the glycosidic bonds of pectic substances. During heating, the uptake or adsorption of water by polysaccharides can reduce the cohesiveness of the matrix, softening the cell wall, causing a decrease in intercellular adhesion (Van Buren, 1979). Rupture of galacturonic polymers can occur by acid hydrolysis or enzymatic activity. Tomatoes are considered an acid food with pH range of 4.0-4.7 (Madhavi and Salunkhe, 1998). Heating in acidic conditions causes hydrolysis of pectic substances (DeMann, 1980).

Smidsrod *et al.*, (1966) demonstrated that that acid hydrolysis rates for polypectate decline as pH increases.

The enzyme responsible for cleaving the galacturonic polymer of pectin in the middle lamella is polygalacturonase (PG). PG is an endogenous enzyme in tomato fruit. It is thought that PG acts synergistically with pectinmethylesterase (PME) (another endogenous enzyme) in the degradation of these pectic substances in tomatoes (Pressy and Avants, 1982). As stated in section 1.1.4.1, pectic substances are a group of polysaccharides which have a backbone composed of 1-4 linked α -galacturonic acid existing at different degrees of esterification. Attached to the galacturonic backbone are uncharged methyl esters. PME enzymes cleave methyl esters attached to the galacturonic backbone of pectin. Once optimal deesterification has been achieved, PG enzymes can optimally cleave the α 1-4 linkages of the galacturonic backbone (Pressey and Avants, 1982). Unless inactivated by heat, the cleavage of pectic substances in the middle lamella by PG will result in loss of tissue firmness.

1.1.4.1.2. Firming agents

When an undesirable degree of softness results from heat processing, firming agents are often employed to enhance tissue firmness. As stated previously, the galacturonic backbone is esterified to various degrees with uncharged methyl esters. When PME cleaves the methyl group, a carboxyl group attached to the pectin backbone and formation of methanol result. This altered pectin is called pectic acid. In the presence of a cation the negatively charged carboxyl group on the pectic acid will covalently bind to it. If the cation

is divalent, the carboxyl groups of two adjacent pectic acids will bind to the cation forming a bridge-like structure. This phenomena is widely known as the egg-box-model (Grant, 1973). This bridge formation occurring between two pectins located in the middle lamella enhance the structural integrity of the parenchyma cell wall. As a divalent cation, calcium is commonly used as a firming agent in the tomato industry.

1.1.4.1.2.1. Calcium application and sensory impact

Calcium is a divalent cation. Several authors have reported the firming effects of calcium chloride on diced tomatoes (Floros *et al.*, 1992; Castaldo *et al.*, 1996; Anthon and *et al.*, 2005). In industry, calcium is applied to diced tomatoes either by direct addition or by dipping the diced tomato into a calcium solution.

In the direct addition method, calcium salts are dissolved in the packing medium or carrier fluid for canning or aseptic processes respectively. For the dipping method, diced tomatoes are conveyed through calcium solutions prior to further processing. Calcium solutions may be prepared using potable water or tomato juice.

In the dipping method, the contact time, calcium concentration, solution pH and solution temperature must be closely monitored as each of these factors affect the rate of calcium uptake. Castaldo *et al.*, (1996) found that calcium applied by the dipping method resulted in firmer processed tomatoes than those in which an equivalent amount of calcium was applied through direct addition. It was theorized that because the calcium solution pH was near neutral, an enhanced activity of PME contributed to the increased firmness. Optimization of calcium uptake into the tomato matrix has been investigated. Floros *et al.*,

(1992) investigated the effects of solution concentration, contact time and solution temperature on calcium absorption and firmness of raw diced tomato pieces. Solution concentration and contact time significantly impacted calcium uptake and tissue firmness. This study found that optimum conditions for achieving maximum firmness while maintaining calcium absorption below the legal limit was a contact time of 3.5 minutes in a solution of 0.43% CaCl_2 . Solution temperature was not found to significantly impact calcium uptake or influence diced tomato firmness. Anthon *et al.*, (2005) however found that calcium solution temperature greatly influenced firmness of the processed product. Their research demonstrated that calcium treatments applied at elevated temperatures (70°C) yielded significantly firmer processed tomatoes than those receiving calcium treatments at room temperature. Increased firmness was attributed to enhanced PME activity at elevated temperatures.

Although calcium treatments have been shown to increase the firmness of tomatoes (Floros *et al.*, 1992, Castaldo *et al.*, 1996, Anton *et al.*, 2005), addition of CaCl_2 has an effect on flavor (Luna Guzman and Barrett, 2000; Bolin, 1989). Bolin found that apricots dipped in CaCl_2 solutions with an uptake of 480 ppm calcium in the tissue elicited a noticeable taste difference where those with an uptake of 200 ppm calcium did not. Luna-Guzman and Barrett, (2000) found that fresh-cut cantaloupes treated CaCl_2 were more bitter in flavor than those treated with calcium lactate (Ca-Lactate). Sensory comparisons in the use of CaCl_2 vs. Ca-Lactate as a firming agent in tomato products have not been reported in literature to date.

1.1.4.2. Color

1.1.4.2.1. Measurement systems and useful parameters

Three tristimulus colorimetry systems have evolved over the course of the 20th century, the CIE system (1931), the Hunter Lab system (1958), and most recently the CIE L^* , a^* , b^* (CIELAB) system (1976). Today, the CIELAB system is most commonly used in the food industry for objective color measurements (MacDougall, 2002). The CIELAB system provides a uniform color space, where lightness is denoted by L^* (where 0 = black and 100 = white), red/green by $a^*(+/-)$, and yellow/blue by $b^*(+/-)$. Measurement of these three values produces a distinct coordinate in color space.

Two useful parameters can be derived from L^* , a^* and b^* to aid in thermal process evaluations of tomato products: they are the overall change in color (ΔE) and $L^*(a^*/b^*)$. The overall change in color is used to compare color differences before and after processing and is determined by the formula:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

According to Rodrigo *et al.*, (2007) however, the $L^*(a^*/b^*)$ parameter combination best describes the color change in heat treated tomatoes.

1.1.4.2.2. Lycopene

In tomatoes, lycopene is responsible for the red color (Clinton *et al.*, 1996), which would be depicted by a^* in the CIELAB system described in 1.1.4.2.1. At the cellular level, lycopene is located in the chromoplasts of the fruit. The distribution of lycopene in tomato fruit is not uniform however (Toor, 2005, Sharma and Le Maguer, 1996). Toor (2005)

reported that lycopene concentration was greatest in the tomato skin followed by the pulp and seed fractions respectively. These differences in accumulation within the fruit fractions were significant. Thus, a process which removes the skin of the fruit greatly reduces the total lycopene of the final product.

Lycopene isomerization and stability are affected by heat, light, oxygen, the presence of metallic ions (Cu^{2+} , Fe^{3+} , etc.) and the food matrix containing it (Shi *et al.*, 2007). Several studies have shown that processing of tomato products leads to an increase in lycopene content of the product. It is believed that increased cellular tissue damage results in an increased release of the pigment from the cell matrix. Contrarily, other authors have clearly demonstrated reduced lycopene content due to the thermal degradation of lycopene (Shi *et al.*, 2003; Ax *et al.*, 2003). Shi and others demonstrated that temperatures between 90 and 150 °C caused degradation of total lycopene content in tomato puree and that increased holding times cause further loss of lycopene. This suggests that processing conditions of shorter times is beneficial in lycopene retention. Their study also showed that *cis*-isomer formation increased during the first two hours of heating at all temperatures. The rate of isomer formation however then decreased. This information is extremely important as it is the *cis*-isomer form of lycopene which has greater bioavailability (Boileau, 2002).

Lycopene is degraded in the presence of oxygen. Henry *et al.*, (1998) found that lycopene degraded more rapidly than other carotenoids in the presence of heat (75, 85 and 95°C) and oxygen in an aqueous model system. Ax *et al.*, (2003) found that lycopene destabilization was about three times higher in the presence of oxygen in an emulsion than

that in an oxygen free system. Therefore, deaeration of a food product is a critical step during production in order to minimize loss of lycopene and loss of red color.

1.1.4.3. Vitamin C

Vitamin C is an antioxidant that is an essential nutrient in human health. Chemically, vitamin C is known as L-Ascorbic acid (AA). AA is composed of a lactone ring in which carbons 2 and 3 are joined by a double bond which have hydroxyl groups attached to form an enediol structure. Oxidation of the two hydroxyl groups at the C-2 and C-3 positions yields dehydroascorbic acid (DHAA). The pK_{a_s} for C-3 and C-2 are 4.04 and 11.4 respectively. DHAA can be reduced back into the AA form and thereby exhibits approximately the same vitamin activity as AA. Once the lactone ring of DHAA is broken by hydrolysis 2,3-diketogulonic acid is formed (DKA). Although most texts state that hydrolysis of the lactone ring is irreversible, thereby eliminating vitamin activity, Deustch (1998) demonstrated that hydrolysis of DHAA is reversible and theorized that DHAA-DKA formations are spontaneous in an ongoing equilibrium reaction at pH 3.5.

Degradation of AA typically follows first-order reaction kinetics. The rate of this reaction is influenced by heat, oxygen concentration, pH, transition metals, water activity, and light (Gregory, 2008). However, with so many variables influencing the rate of reaction, the rate of AA degradation for one type of food system cannot adequately predict the kinetics of AA degradation in another (Gregory, 2008). Broeck *et al.*, (1998) investigated the isothermal degradation of AA in tomato juice at pH 4.5 in the temperature range of 120 – 150 °C. Their study found that degradation increases with increasing temperature and could be

accurately described by first-order reaction. Huelin (1953) demonstrated that at 100 °C, pH greatly influenced the rate of degradation under anaerobic conditions in tomato juice. The reaction rate was greatest at pH 4 which is close to pK_{a1} for AA. The presences of fructose, sucrose, and metal catalysts in tomato juice increase AA degradation reaction rates (Huelin, 1953; Lee *et al.*, 1977). Sucrose, fructose, and copper are naturally occurring in tomato fruits and their concentration is greatly influenced by variety and environmental conditions.

Degradation of AA in retorted or aseptically packaged foods will follow both aerobic and anaerobic pathways. Oxygen incorporated into the system during processing will become dissolved oxygen in the hermetically sealed container. Initially, aerobic degradation of AA will predominate. Once residual oxygen has reached equilibrium, anaerobic pathways will predominate during storage. Kenedy *et al.*, (1992) demonstrated this phenomena with reconstituted orange juice which was aseptically processed and packaged in TetraBrik cartons. In their study, initial levels of dissolved oxygen experienced a sharp decrease after processing followed by a steady decline to equilibrium. Initial levels of AA degradation corresponded well with dissolved oxygen depletion which then continued to occur independently of oxygen.

The anaerobic pathway of destruction has been identified as the predominant pathway for tomato juice during storage (Gregory, 2008). Although the mechanism for anaerobic degradation of AA has not been fully established, it is thought that AA undergoes ketonization and loss of a hydrogen atom from the hydroxyl group attached to C-3 before hydrolysis of the lactone ring. Anaerobic degradation of AA exhibits a maximum rate at pH 3-4 (Gregory, 2008). Although, the rate of anaerobic degradation is 2-3 orders of magnitude

slower than that of aerobic pathways, this rate of degradation is also enhanced by the presences of fructose, sucrose, and metal catalyts in tomato juice as well as increased by temperature and fortification with ascorbic acid (Hulen, 1953; Lee *et al.*, 1977; Gould, 1978).

1.1.4.4. Drain weight

The United States Department of Agriculture standards for grading canned tomatoes are based on several factors including drain weight, character, color, absence of defects and blemished areas, flavor and odor (USDA, 1990). Drain weight refers to the tomato material that remains on the sieve after draining under specified conditions. According to Barrett (1998), “drain weight measurements are relatively gross indicators of textural properties of diced tomatoes which assess weight loss of the product following handling or processing [and] high drain weight values are indicative of tissue moisture retention, juiciness, and relatively greater firmness”.

Drain weight must not be less than 50% of the weight of water required to fill the container. According the FDA 21 CFR 155.190, the procedure used to determine the drain weight for canned diced tomatoes is as follows:

- 1) Distribute the contents of the can over the meshes of a circular #8 sieve which has previously been weighed.
- 2) Without shifting the tomatoes, incline the sieve as to facilitate drainage of the liquid.
- 3) Two minutes from the time drainage begins, weigh the sieve and drained tomatoes.
- 4) The weight so found, less the weight of the sieve, shall be considered to be the drain weight.

The formula used to obtain the percent drain weight is:

$$\% \text{ Drain Weight} = (\text{Drained Tomato Weight}) \times 100 / \text{Net Weight} \quad (2)$$

The California League of Food Processors (CLFP) Diced Tomato Committee uses a slightly modified version of the standardized USDA drain weight procedure (CLFP, 2011). For large samples, such as those used in aseptic processing, they recommend using a core sampler to obtain approximately 100 ounces of diced tomato product. They also recommend that the product be at room temperature and the sieve used should be tilted such that one side is 2 inches higher than the other.

“Drain weight is significantly affected by tomato variety and maturity, initial raw textural quality, process conditions and fill weight” (Barrett, 1998). Wahem (1988) studied the effects of firmness of raw tomatoes on selected quality characteristics of canned products and found that firmer fruits had significantly higher drain weights than softer fruits. Drain weight differences were thought to be due to less cell rupture during processing of the firmer, less mature fruits. Porretta *et al.*, (1992) demonstrated that the packing medium also has a significant effect on the drain weight processed crushed tomatoes. In this study, crushed tomatoes (70% w/w) were covered with packing mediums (30% w/w), which had 0, 20 and 37% of the packing medium serum removed by ultrafiltration. Their results showed that increased serum removal decreased tomato pulp drain weight.

1.1.4.5. Spoilage

Specific to tomatoes, several microorganisms including bacteria, (sporeforming and non-sporeforming), yeasts and molds have been associated the spoilage of canned tomato products. *Lactobacilli* and yeasts are frequently responsible for swelled cans of tomato pulp and related products (White, 1951). Odlaug (1979) isolated the mold *Aspergillus gracilis* from a can of spoiled tomatoes and demonstrated that tomato juice inoculated with it caused an increase in pH from 4.6 to > 6.2 after 25 days at 32 °C allowing for the growth of *Clostridium botulinum* spores. *Bacillus coagulans*, *Bacillus thermoacidurans*, *Clostridium butyricum* and *Clostridium tertium* are sporeformers associated with spoilage of canned tomato products (Pallop *et al.*, 1999; Setlow and Johnson, 2001; Murdock, 1950). *Bacillus thermoacidurans*, is a non-gas-forming, facultative anaerobe having the general characteristics of the “flat-sour” type, which it produces “off-flavors in canned tomato juice (Murdock, 1950). *Bacillus coagulans* increases the pH of tomato juice from 4.5 to 5.07 after 6 days of incubation at 35 °C (Anderson, 1984). Although the sporeformer *Alicyclobacillus acidoterrestris* has not been reported to be the cause of spoiled tomato products, it is capable of growth in tomato juice and has caused the spoilage of apple, orange and grapefruit juices (Silva *et al.*, 1999).

1.2. Aseptic Technology

Aseptic processing and packaging refer to a thermal process in which a commercially sterile product has been cooled and aseptically filled into a pre-sterilized container and hermitically sealed in a sterile environment. In this process, raw product is pumped,

deareated, heated to commercial sterility then cooled and packaged in a continuous, closed system. Advantages of aseptic processing include production of foods that are shelf stable which have high nutrient retention and an extended shelf life (1-2 years), reduced operational space requirements, and small or large (200-300 gallon) containers may be used for packaging. Additionally, packages can be flexible possessing a variety of shapes. Some disadvantages however are that more stringent and extensive validation procedures are required, there is a need for better trained personnel and better quality control of raw products, it has a slower filler speed and the overall processing cost is higher (David, 1996; Sastry and Cornelius, 2002).

Aseptically processed products have been shown to yield higher nutritional and organoleptic qualities relative to retorted products. These benefits of aseptic processing stem from the use of High Temperature Short Time (HTST) or Ultra High Temperature (UHT) heating regimes (David, 1996). Quality optimization of thermally processed foods is due to the temperature dependency of the thermal degradation kinetics of target microorganisms and quality attributes. This phenomena constitutes the principle of HTST and UHT. Heating products for shorter times at higher temperatures allows for the inactivation of degradative enzymes, target microorganisms and spores while limiting destruction of quality attributes such as flavor, color, texture and nutrient content. A schematic of this principle is presented in Figure 1. Application of this principle to tomato products yields products of superior quality relative to traditional thermal processes (Leonard *et al.*, 1986). For example, Leonard *et al.*, (1986) found that vitamin C and texture retention were significantly greater for whole peeled tomatoes when processed in a HTST process as compared to that in a retort cooker for

which the process was of an equal sterilization value. Also, according to David (1996), tomato soup processed in an aseptic system has increased discernible color, flavor and taste qualities relative to retorted soup.

Microwave energy rapidly heats food in volumetric fashion (heat generated throughout rather than diffusing from a contact surface). As such, the use of continuous flow microwave (CFM) processes for product sterilization lends itself well to aseptic processing. The first commercial aseptic product processed using this type of system was orange flesh sweet potato puree (Coronel *et al.*, 2005). In this process, no significant change in color or puree viscosity was observed between samples processed to commercial sterility using a CFM system and untreated purees. Steed *et al.*, (2008) demonstrated that neither overall color nor antioxidant activity of purple fleshed sweetpotatoes processed in a CFM system followed by aseptic packaging were altered relative to untreated samples. Additionally, Kumar *et al.*, (2008) demonstrated the feasibility of processing a multi-component low acid food product (salsa con queso) in a CFM system.

Microbial validation is critical in aseptic processing. Microwave heating of food however is notorious for its un-uniform heating. To address this issue in CFM systems, placement of static stirrers and validation techniques have been investigated. Polypropylenepackaged pouches were shown to be effective bioindicators in CFM processes intended for viscous food materials (Brinley *et al.*, 2007). Also, inclusion of static mixers in product flow tubes after heating successfully minimized temperature differentials seen in the tube's cross sectional area (Coronel *et al.*, 2005).

Collectively, the CFM research efforts at North Carolina State University inspired the formation Yamco, the first company in the U.S. to utilize a CFM system followed by aseptic packaging, for the production of orange fleshed sweetpotato puree.

1.3. Microwaves

1.3.1. Introduction to microwaves

Microwaves have many applications in a variety of fields including telecommunications, radar transmission, navigation aids, cancer treatment by means of local hyperthermia as well as heating of materials. To prevent interference issues only four microwave frequencies (915 ± 13 , $2,450 \pm 50$, $5,800 \pm 75$, and $24,150 \pm 125$ MHz) are permitted by Federal Communications Commission (FCC) for industrial, scientific, and medical applications (FDA 47 CFR 18.301). In the food industry, food processors commonly use the 915 MHz frequency while microwave ovens intended for home use the 2450 MHz frequency. The remaining discussion on this topic will be dedicated to the equipment used and heating mechanisms most relevant to the food industry.

1.3.2. Components of a microwave system

In food heating applications, two types of microwave systems exist currently: the continuous flow and batch heating systems. Regardless of type, these systems are comprised of three main parts: the microwave source, waveguide and applicator. In most systems, the microwave source is attached to a waveguide, which guides propagating waves to the applicator.

1.3.2.1. Microwave source

Several devices including magnetrons, Klystrons and Gyrotrons, can generate microwaves. Due to their capability of efficiently producing high power microwaves the magnetron is used predominately for industrial food applications. The magnetron, developed intensely during the Second World War for precision radar, is capable of generating high-power microwaves (Love, 1995). Magnetrons are classified as pulsed or continuous-wave. Pulsed magnetrons are mostly used for radar applications, and the continuous-wave magnetron is used predominately for industrial heating applications (Püschner, 2005).

The magnetron is essentially a cross-field vacuum diode comprised of a circular resonant cavity positioned around a cathode that is immersed in a perpendicular magnetic field (Love, 1995). It is capable of converting an electrical current into electromagnetic energy. The components which play critical roles in this transformation are the cathode, anode and resonance cavity. Each of these components will be discussed in greater detail here. A schematic diagram of their arrangement is located in Figure 2.

1.3.2.1.1. Cathode

A cathode is a terminal by which an applied current leaves. In a magnetron, it is usually made up of a tungsten filament wound in the shape of a helix. An external electrical current is applied to the cathode. This current heats the cathode. When the cathode is heated to an operating temperature of 1300°C, it emits electrons thereby becoming the source of an electron current and has a negative potential relative to the anode (a terminal into which a current enters) (Love, 1995). Over time, the tungsten filament slowly evaporates depositing

tungsten onto the anode. Thus, the life of the filament determines the life of the magnetron (Meredith, 1998).

Electron emission from the cathode is temperature dependant. If the cathode is too cool, an insufficient electron emission results. Conversely, if the temperature is too high, the cathode will overheat causing permanent damage. Cathode temperatures are controlled by water in high-power systems and air in low-power systems.

1.3.2.1.2. Anode and resonance cavity

An anode is a terminal into which an electron current enters. In a magnetron, the anode is typically a copper ring with several resonant cavities. This copper ring surrounds the cathode.

In a normal diode, electrons drawn from the cathode will travel radially outward in a straight path toward an anode. In the presence of a magnetic field however, the electron path is altered. In a magnetron, the magnetic field is placed perpendicular to the electron field. This placement will cause the electrons to travel in a circumferential path around the cathode. The traveling electrons cannot enter the surrounding anode unless the radius of their circumferential path is at least equal to the radius of the anode bore.

An electron's circumferential radius or velocity can be controlled by adjustment of the applied direct current magnetic field and the applied external electrical current. When the magnetic-field strength is high, the outermost radius of the circumferential path is less than the radius of the anode surrounding the cathode. When the magnetic-field strength is reduced, the circumferential radius of the electron's path is increased (Meredith, 1998). The

circular motion of the electrons induces alternating currents in the anode cavities. The cavity size determines the resonant source frequency (Chow Ting Chan, 2000). The microwave energy can then be taken out of the anode cavity by coupling it with a circular loop antenna which directs it to the waveguide (Reiger and Schubert, 2005).

1.3.2.2. Waveguide

Waveguides are hollow metal conductors used to convey electromagnetic energy from the magnetron to the food source to be heated or the applicator. Because they are made of metal, they do not absorb electromagnetic energy but rather, they reflect it. Their shape can be circular or rectangular and their size defines a minimum frequency at which wave can propagate. The most common wave guide is rectangular with a width equal to double its height (Reiger and Schubert, 2005).

1.3.2.3. Applicator

Applicators are devices where the generated electromagnetic energy is supplied to the desired load. Applicators come in various shapes and sizes which are designed specifically for the properties, geometry and volume of the load. The most popular ones are categorized into three classes: traveling wave applicator, near-field applicator and resonant applicator (Chow Ting Chan, 2000). In traveling wave applicators, the waveguide itself is the applicator. Material intended for heating is introduced through wall slots. The load may be introduced by way of a conveyor belt or through a pipe composed of material that is transparent to microwave energy. In near-field applicators, microwaves originating from a

horn antenna or slot array make direct contact with the load. In resonant applicators, generated microwaves are conveyed into a cavity, which contains the load. Resonant applicators may be single or multimode (Chow Ting Chang, 2000).

1.3.3. Microwave interactions with food materials.

Microwaves are composed of two parts, an electric field and a magnetic field which are perpendicular to each other (Figure 3). The way in which the electric field component of the microwave will interact with the material is dependent on the materials' dielectric properties. This interaction can be described by the material's complex permittivity (ϵ). The permittivity of the material can tell us if the microwave will be reflected, transmitted or absorbed as it encounters the material (Chow Ting Chan, 2000). The permittivity of a material is described by the following equation:

$$\epsilon = \epsilon' - j\epsilon'' \quad (3)$$

where ϵ' = dielectric constant
 ϵ'' = loss factor
 $j = \sqrt{-1}$ (an imaginary unit)

On the other hand, the permeability of a material describes its interaction with the magnetic field portion of the microwave. Foods however do not typically have components that would interact with the magnetic field (Datta and others, 2005), so this topic will not be discussed.

Another useful term to describe microwave interactions with dielectric materials is the loss tangent ($\tan\delta$):

$$\tan\delta = \epsilon''/\epsilon' \quad (4)$$

Evaluation of $\tan\delta$ is a useful term when comparing dielectric properties as it accounts for both ϵ' and ϵ'' . Furthermore, $\tan\delta$ is a parameter which describes the attenuation of microwave power in foods (Tang, 2005). Rearrangement of equation 4 gives:

$$\delta = \tan^{-1} \frac{\epsilon''}{\epsilon'} \quad (5)$$

for which δ is the angle by which the resultant current differs from the ideal angle of 90° .

As a microwave penetrates a food material, its wavelength is shortened and power is dissipated in the material. The distance in meters over which 63% of the power has dissipated in the material, known as its penetration depth, can be calculated by:

$$d_p = \frac{c}{2\pi f \sqrt{2\epsilon'} \left[1 + \sqrt{\left(\frac{\epsilon''}{\epsilon'}\right)^2 - 1} \right]} \quad (6)$$

Knowledge of the microwaves' penetration depth in a material is useful in that it can elude to the uniformity of heating within the material.

1.3.3.1. Dielectric constant and loss factor

As demonstrated in equation 3, the ability of a food to interact with microwaves is governed by its dielectric properties. Dielectric properties consist of two parts: the dielectric constant (ϵ') and loss factor (ϵ''). The dielectric constant is a measure of the food material's ability to store electromagnetic energy. The dielectric constant decreases the speed of microwave propagation causing the wavelength inside the dielectric material to become shorter than it is in free space. This change in wavelength leads to a reflection at the interface between two materials with different dielectric constants (Ryynänen, 1995). The

dielectric loss factor describes a material's ability to convert electromagnetic energy into thermal energy (Tang, 2005). Also, the loss factor is approximately proportional to the attenuation of a propagating wave (Ryynänen, 1995). The loss factor may be expressed using the following equation:

$$\epsilon'' = \epsilon_d'' + \epsilon_\sigma'' \quad (7)$$

where d = dipole rotation contributions
 σ = ionic conductivity contribution

From the equation above, it is shown that the dominant mechanisms contributing to the loss factor are dipole rotation and ionic conduction within a material. A dipole refers to two charges of equal magnitude and opposite signs which are separated by a distance. An example of a dipolar molecule commonly found in foods is water, in which the hydrogen atom possesses a partially positive charge and the oxygen atoms possess a partially negative charge. Dipole rotation refers to the fast oscillatory movement a dipolar molecule makes as it attempts to follow an electric field. This oscillatory motion leads to friction with the surrounding material resulting in heat generation (Sing, 2001). An ion is a charged atom or group of atoms. Ionic conduction refers to the migration of a charged atom or molecule as it tries to follow an electric field. As the ion moves through the material, it collides with other objects causing a conversion of kinetic energy into thermal energy (Sing, 2001).

1.3.3.2. Factors affecting dielectric properties

The dielectric properties of a given food material are influenced largely by the microwave frequency, temperature, chemical composition, and physical structure of the

material (Ryynänen, 1995). Although food materials are affected by many factors, the amount of water in the material will play a predominant role in how the dielectric properties are affected by microwaves (Nelson and Datta, 2001).

1.3.3.2.1. Frequency

As stated previously, when an electric field passes a dipolar molecule, the molecule tries to orient itself with the electric field. As the field passes by, the molecule relaxes and returns to its original state. The time required for the molecule to return to 37% of its original state of equilibrium (preferred orientation) is known as its relaxation time (Tang, 2002). At low frequencies, the electric field passes by slowly and the polar molecule has enough time to orient itself with the field and return to its relaxed state as the field passes. In these instances, the dielectric constant is high, thus the material has a good ability to “store” electromagnetic energy. Conversely, the excitation and relaxation is very slow, not allowing for enough friction to generate heat and consequently the loss factor is low at low frequencies. As the frequency of the electric field increases, the excitation and relaxation movements become more rapid. In these instances, the polar molecule increasingly loses the ability to fully relax because the passing field is too fast. Thus, the dielectric constant is decreased. On the other hand, at higher frequencies, the loss factor increases due to increased movement by the polar molecule up to some maximum point beyond which the passing field is moving so fast that the polar molecule cannot react and thereby does not move. A graphical representation of this phenomena is presented in Figure 5.

Ionic conductivity is most prominent at low frequencies and less so at high frequencies. An illustration of dipolar and ionic contributions at a range of frequencies at constant temperature are best illustrated in Figure 5.

1.3.3.2.2. Temperature

The effect of temperature on dielectric properties is dynamic in nature as many factors are related to and influence each other. The temperature of a food system affects the viscosity of the system which in turn affects Brownian movements and ionic conduction in the system. Brownian movements are the random motions of small particles within a system (Knight, 1970). Increased temperatures cause a decrease in viscosity which allows for increased random movements of particles which in turn decreases the dielectric constant (Tang, 2005). Additionally, increased temperatures cause a decrease in relaxation time which again decreases the dielectric constant (Nelson and Datta, 2001). On the other hand, as temperatures increase and the viscosity decreases ionic can move more easily in the system which increases the loss factor.

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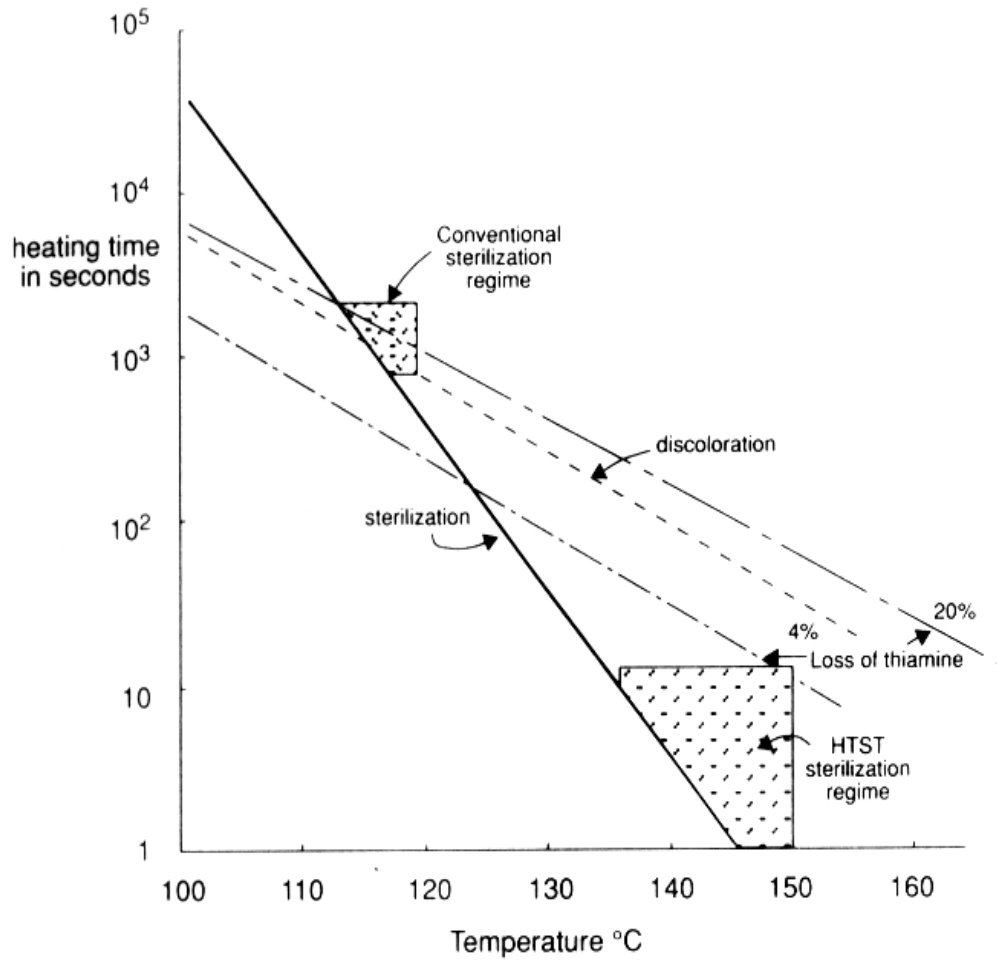


Figure 1. Graphical representation of HTST heating regime
 Source: Silva *et al.*, 1999.

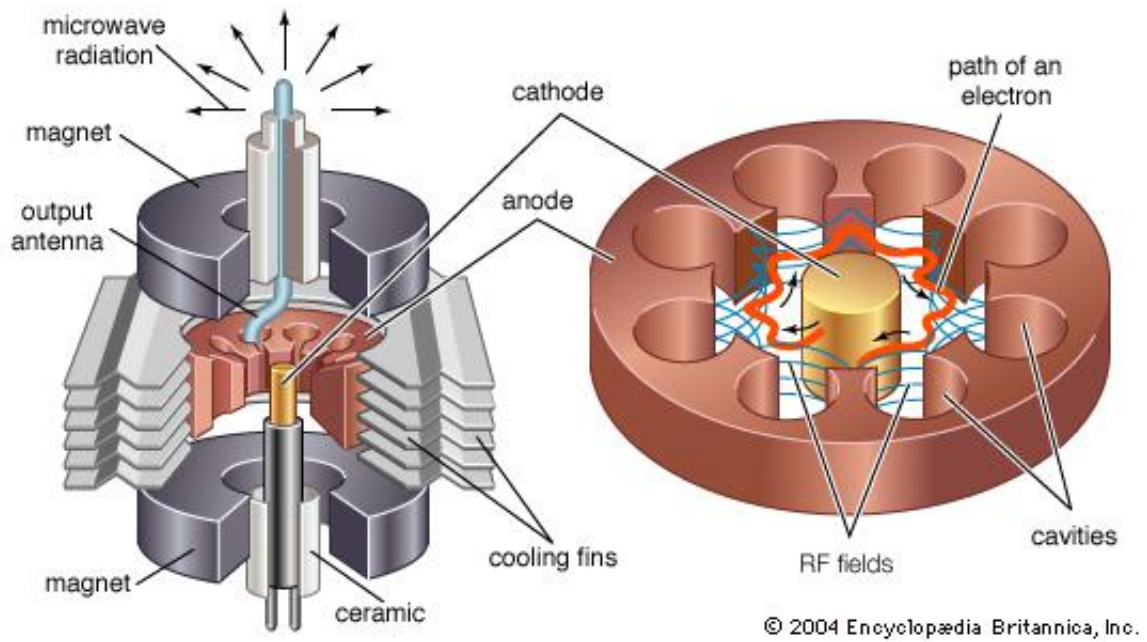


Figure 2. Magnetron schematic

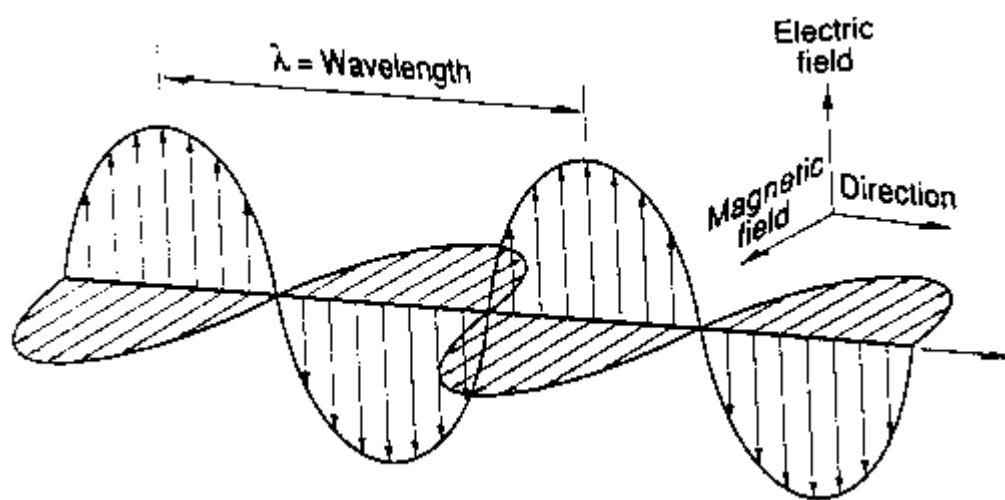


Figure 3. Schematic of electric field orientation relative to magnetic field in microwave energy

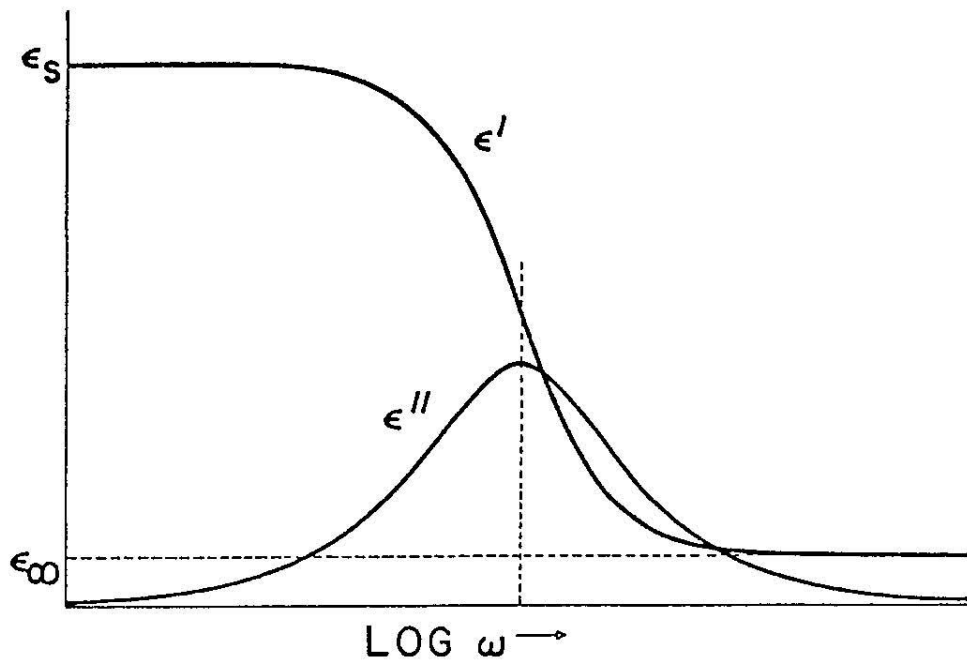


Figure 4. Graphical representation of the Debye dielectric relaxation for polar molecules with a single relaxation time.
Source: Nelson and Datta 2001.

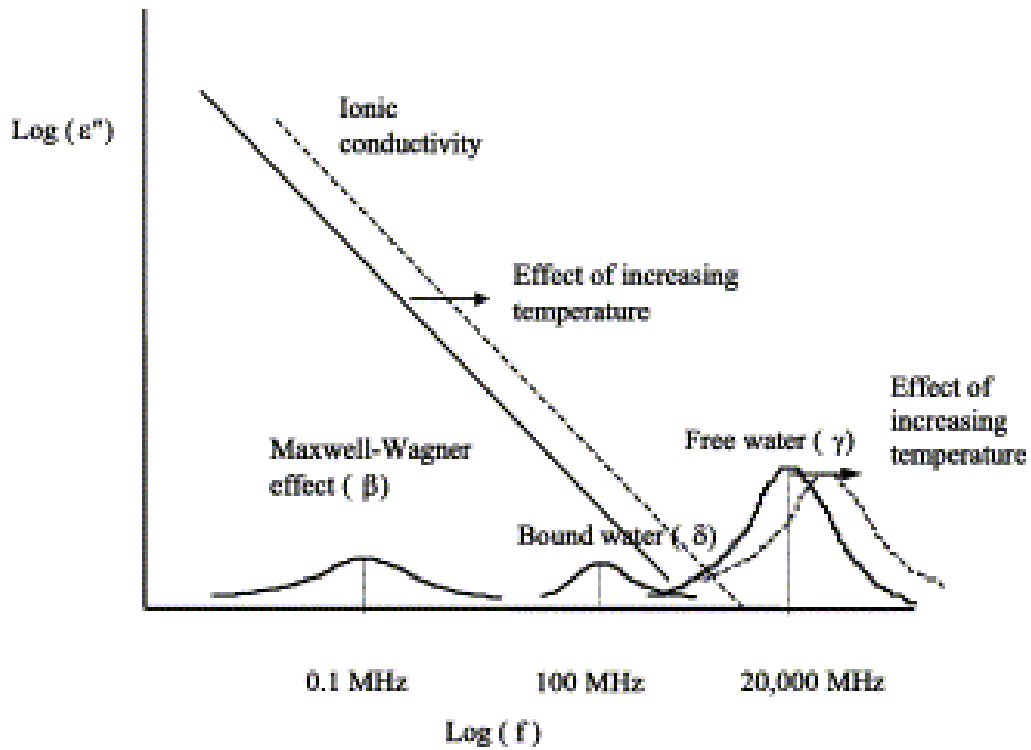


Figure 5. Simplified diagram of indicating the frequencies at which dielectric loss mechanisms occur for moist materials. Effects of temperature are also noted. (adapted from Tang, 2005) temperature

CHAPTER 2

The Effects of Various Calcium Salts and pH in the Continuous Flow Microwave Sterilization and Aseptic Packaging of Diced Roma Tomatoes on Product Quality

2.1 Abstract

Demands for processed diced tomatoes have increased due to an increased demand for value added products such as tomato based salsas. Traditional thermal processing can have detrimental effects on ascorbic acid (AA) content and texture firmness of diced tomatoes. Although calcium chloride (CaCl_2) treatments are often employed to improve the retention of tomato firmness, there are currently no reports comparing the effectiveness of CaCl_2 to that of calcium lactate ($\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$) in diced tomato firmness retention. The objectives of this research were two-fold: Firstly, to evaluate the performance and quality of diced Roma tomatoes processed in a continuous flow microwave system (CFMS) followed by aseptic packaging. Secondly, to determine the effects of pH and calcium treatments using CaCl_2 and $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ on diced tomato quality in this system.

Ripe Roma tomatoes were diced into $\frac{1}{2}$ " cubes and acidified to target pH of 4.3 or 3.9. Diced tomatoes acidified to pH 3.9 were treated with and without calcium using either CaCl_2 or $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ as a calcium ion (Ca^{2+}) source to deliver 0.02% w/w Ca^{2+} by tomato weight. Treated diced tomatoes were thermally processed in a CFMS followed by aseptic packaging. Targeted thermal process was 96 °C for 3 minutes. Treated raw tomatoes were evaluated for color, dielectric constant (ϵ'), dielectric loss factor (ϵ'') and loss tangent ($\tan\delta$) values. Packaged products were evaluated for microbial growth, texture firmness, AA retention, pH, °Brix, drain weight and color.

Results showed that neither acidification nor $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ addition effected dielectric properties or $\tan\delta$ but the CaCl_2 treatment increased ϵ'' and $\tan\delta$. No growth was observed for microbial assays indicating that commercial sterility was achieved. pH adjustment

resulted in similar ($p > 0.05$) peak force values of 47.15 and 47.37 N/100 g drained tomatoes respectively, of back extrusion tests for pH 4.3 and pH 3.9 treatments, respectively. Peak force of CaCl_2 and $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ treatments were 108.34 and 105.31 N/100 g drained tomato which were not significantly different ($p > 0.05$). AA retention was 63, 67, 56 and 52% for pH 4.3, pH 3.9, CaCl_2 and $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ treatments respectively. Significant ($p < 0.05$) loss of redness ($+a^*$ values) was observed for all treatments. Drain weight values (71, 69, 70 and 70%) were not significantly ($p > 0.05$) different for pH 4.3, pH 3.9, CaCl_2 and $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ treatments respectively.

The results suggest that use of CFM system followed by aseptic packaging of calcium treated diced tomatoes may retain greater AA retention than traditional processing. Additionally, this research demonstrated that $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ is as effective a firming agent as CaCl_2 at 0.02% w/w Ca^{2+} level.

2.2 Introduction

Tomatoes are an important source of vitamin C and are valued for their color and flavor (Madhavi and Salunkhe, 1998). Canned tomatoes are the most consumed canned vegetable, at 74.2 pounds per capita in the United States (Barringer, 2004). Diced tomatoes have become very popular because of an increased demand for value added products such as tomato based salsas (Barringer, 2004). Traditional thermal processing can have detrimental effects on vitamin C (ascorbic acid, (AA)) and texture firmness of diced tomatoes. Degradation of AA typically follows first-order reaction kinetics. The rate of this reaction is influenced by heat, oxygen concentration, pH, transition metals, water activity, and light (Gregory, 2008). According to Barringer (2004), vitamin C content of traditionally processed tomatoes is reduced by 45%. For texture firmness of diced tomatoes, texture degradation during thermal processing is a result of many factors which are mechanical, chemical or enzymatic in nature. Studies of thermal degradation kinetics for texture firmness in diced tomatoes however were limited (not found in an exhaustive literature review).

When it is desirable to reduce loss of texture firmness in diced tomatoes, processors may use calcium (Ca^{2+}) salts as firming agents. Divalent Ca^{2+} cations enhance tissue firmness by what is commonly known as the “egg-box-model”, where the cations covalently bind to the demethoxylated pectate chains located in the middle lamella between parenchyma cells (Grant *et al.*, 1973). In this way, the rigidity of the parenchyma cell wall is reinforced and texture firmness is enhanced. Ca^{2+} addition in diced tomatoes is limited to 0.08% Ca^{2+} by weight of the finished product according to the United States Code of Federal Regulations Title 21 (21 CFR 1555.190). Although several Ca^{2+} sources are commonly used for this

purpose including calcium chloride (CaCl_2), calcium sulfate, calcium citrate and monocalcium phosphate (Barringer, 2004), CaCl_2 is the most common (Barrett *et al.*, 1998). Adverse sensory effects however have been reported for use of CaCl_2 at high levels. Bolin and Huxoll (1989) found that apricots dipped in CaCl_2 solutions with an uptake of 480 ppm Ca^{2+} in the tissue elicited a noticeable taste difference where those with an uptake of 200 ppm Ca^{2+} did not. Luna-Guzman and Barrett (2000) found that fresh-cut cantaloupes treated with CaCl_2 had a more bitter flavor than those treated with calcium lactate ($\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$). $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ has been used as a firming agent for canned grapefruit, canned jalapeño peppers and fresh cantaloupe (Baker, 1993; Saldana and Meyer, 1981; Luna-Guzmán and Barrett, 2000). Currently, no studies have been reported in the literature comparing the performance of CaCl_2 to that of $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ as a firming agent in diced tomato products.

It is well known that High Temperature Short Time (HTST) processes lead to improved product quality as it preserves nutrients and sensory attributes better than conventional thermal processing (Montville and Mathews, 2005). Quality optimization of thermally processed foods is due to the temperature dependency of the thermal degradation kinetics of target microorganisms and quality attributes. This phenomena constitutes the principle of HTST. Heating products for shorter times at higher temperatures allows for the inactivation of degradative enzymes, target microorganisms and spores while limiting destruction of quality attributes such as flavor, color, texture and nutrient content. Leonard *et al.*, (1986) found that vitamin C and texture firmness retention were significantly greater for whole peeled tomatoes when processed in a HTST process as compared to that in a retort cooker at an equal sterilization value.

Continuous flow microwave heating of foods is an emerging technology. Microwave energy rapidly heats food materials leading to improved nutrient retention (Fu, 2004). Thus, it is likely that the use of microwaves for thermal processing of diced tomatoes will also lead to greater texture firmness retention. The objectives of this research were two-fold: Firstly, to evaluate the performance and quality of diced Roma tomatoes processed in a continuous flow microwave system followed by aseptic packaging. Secondly, to determine the effects of pH and calcium treatments using CaCl_2 and $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ on diced tomato quality in this system.

2.3 Material and methods

Chemicals

Analytical grade metaphosphoric acid, acetonitrile, dipotassium phosphate and L-ascorbic acid were obtained from Sigma-Aldrich (Milwaukee, Wis., U.S.A.). Calcium-L-Lactate was donated by PURAC biochem, Gorichem, The Netherlands. Calcium chloride was purchased from TETRA Technologies, The Woodlands, Tex, U.S.A.. Anhydrous citric acid was purchased from Duda Diesel LLC, Madison, Ala., U.S.A.. Citric acid, calcium chloride and calcium lactate were FCC grade.

Experimental design

Forty eight-10.89 kg batches of Roma tomatoes (Paterson Farms, Inc., China Grove, N.C., U.S.A.) of uniform ripeness and free of defects were held at 4 °C for 24 h after purchase. The 10.89 kg batches were randomly assigned to 1 of 4 treatment groups: A, B, C,

and D, to give 12 batches per treatment. For each treatment, 6 of the 12 batches were designated as replicate 1 or 2. During processing, the 4 treatments were processed consecutively in the order: A, B, C and D.

Sample preparation

From each 10.89 kg batch, 9.07 kg of tomatoes were diced to ½”cubes (Urschel, Model RA-D, Chalfont, Pa., U.S.A.). The remaining 1.81kg of whole tomatoes were pulverized in a hammer mill (FitzMill, Model D, Chicago, Ill.), set to low speed, with #5 screen. Pulverized tomato material was combined with treatment solutions (0.45 kg) and used as a carrier fluid for the diced tomato particulates. Carrier fluid was applied to the diced tomatoes as described below.

Treatments

Treatments A and B were acidified to a target pH of 4.3 and 3.9 respectively. Treatments C and D received a direct addition treatment of CaCl_2 or $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ respectively, and were acidified to a target pH of 3.9. Both Ca^{2+} treatments were designed to deliver 0.02% w/w Ca^{2+} by diced tomato weight.

De-ionized water was used in the preparation of solutions for all treatments. Citric acid (CA) was used for acidification. The CA concentrations used for each treatment were based on recommendations by Gould (1991) for which a certain percentage of CA is added to a tomato product to achieve a desired pH from a particular initial pH (Table 1). The average pH of raw, untreated tomato was 4.43 ± 0.02 . Preliminary studies revealed that tomatoes

treated with 0.02% w/w Ca^{2+} from CaCl_2 caused a 0.1 reduction in diced tomato pH. This pH reduction was accounted for when determining amount of CA required for pH adjustment.

For treatments A and B, the pulverized tomato material was immediately mixed into the diced tomatoes followed by treatment solutions containing 2.10% (w/v) and 10.80% (w/v) CA respectively. For treatments C and D, solutions containing 1.11% (w/v) CaCl_2 or 2.86% (w/v) $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ respectively, were gently mixed into the diced tomatoes immediately after dicing, followed by the pulverized tomato material. Finally, treatment solutions containing 8.4% (w/v) or 10.80% (w/v) CA respectively were added.

Microwave Processing

Raw, diced tomato particulates were processed in a 100 kW continuous flow microwave system (UltraAseptics, Raleigh, N.C.) operating at 915 MHz (Figure 1). Microwaves, generated by a magnetron, were delivered to the diced tomatoes by a rectangular waveguide in an axial traveling-wave like configuration. In this system, the propagating waves traveled concurrently with the flow of product. Pipes containing product coincided with the waveguide at three sections to yield three heating areas. Within these sections, pipes are composed of a high purity alumina ceramic-reinforced PTFE to allow for microwave penetration of the food product.

Diced tomatoes were pumped through the system at a rate of 5.68L/min by a positive displacement pump (Model A7000, Marlen Research Corp., Overland Park, Kans., U.S.A.). Diced tomatoes were heated by controlling the power of the system, which varied from 40 to

45 kW. The target minimal heat treatment was 96 °C for 3 minutes, which was based on industry recommendations. Heated product was cooled by a tubular heat exchanger to about 20 °C then aseptically packaged in aluminum-polyethylene laminated bags (Scholle Corp, Chicago, Ill., U.S.A.) using a bag-in-box unit (Model PT A.F., Astepo, Parma, Italy). Temperatures of the product were monitored by Type T thermocouples (OMEGA Engineering, Inc., Stamford, Conn., U.S.A.) positioned at the inlet and exit of the applicator and the exit of the hold tube. Aseptic bags of processed diced tomatoes were stored at 4 °C until analyzed.

Sampling

For raw sample analyses, two samples from each treatment replicate were analyzed for dielectric properties, pH, color and ascorbic acid (AA) content. For dielectric and pH analyses, samples were homogenized in an Oster blender (Model 6872) set to puree speed for 30 seconds.

For processed samples, two aseptic bags from each treatment replicate were chosen at random for microbial growth, color, texture firmness, pH, °Brix, drain weight, and AA retention analyses. All analyses were performed in duplicate except for color which was measured five times per replicate sample and texture firmness which was measured 3 times per replicate.

Dielectric Analysis

Dielectric properties for each treatment were measured under static conditions using an open-ended coaxial probe (Model HP 85070B Agilent Technologies, Palo Alto, Calif., U.S.A.) connected to a network analyzer (Model HP 8753C, Agilent Technologies). Calibration of the network analyzer was achieved by leaving the probe in contact with ambient air (22 °C ± 1°C), metal, and deionized water. Dielectric properties were measured between 20 and 130 °C at 10 °C intervals and at frequencies from 300 to 3000 MHz with an increment of 5 MHz. The variable step size for temperature increment was chosen in order to determine the dielectric properties at sterilization temperatures. Homogenized sample was placed in a pressurized cylindrical cell (35 mm inner diameter and 36.5 mm height) and heated in an oil bath (Model RTE111, Neslab Instruments Inc., Newington, N.H., U.S.A.) to attain the testing temperature. Values reported are for dielectric constant (ϵ'), loss factor (ϵ''), loss tangent ($\tan\delta$) (eqn. 1) and depth penetration (d_p) (eqn. 2).

$$\tan\delta = \epsilon'' / \epsilon' \quad (1)$$

$$d_p = \frac{c}{2\pi f \sqrt{2 \epsilon' \left[1 + \sqrt{\left(\frac{\epsilon''}{\epsilon'}\right)^2 - 1} \right]}} \quad (2)$$

where c is the speed of light in free space ($c = 3 \times 10^8 \text{ ms}^{-1}$), π is 3.1416 and f (Hz) is frequency.

Microbial Analyses

Processed samples were aseptically plated onto plate count agar (PCA), violet red bile agar (VRB) and dextrose tryptone agar (DTA). Samples were plated using a spiral microplater (Autoplate 4000, Exotech Inc., Gathersburg, Md., U.S.A.). PCA and VRB plates were incubated at 37 and 55 °C under aerobic and anaerobic atmospheres. DTA plates were incubated at 37 and 55 °C under an anaerobic atmosphere. All plates were incubated for 72 hours. Additionally, two aseptically packaged bags chosen at random per treatment replicate and incubated at 37 °C for three weeks.

Physical assessments for quality

Drain weight, pH and °Brix measurements. Drain weight was determined based on the procedure for diced tomatoes recommended by the California League of Food Processors Diced Tomato Committee (CLFP, 2011). Approximately 100 ounces of processed diced tomato at room temperature was allowed to drain for two minutes on a #8 sieve, for which one side was tilted two inches higher than the other. Percent drain weight was calculated according to the following equation:

$$\% \text{ Drain Weight} = (\text{Drained Tomato Weight}) \times 100 / \text{Net Weight} \quad (3)$$

Measurements for pH were obtained before and after processing (Accumet AR50 pH meter, Fisher Scientific). °Brix was determined for the juice of each treatment, after processing, using a hand held refractometer (Model A727275, ATAGO USA, Inc.).

Ascorbic acid.

Samples were prepared by mixing raw or processed diced tomatoes in 5% metaphosphoric acid (1:10 w/v dilution). Diluted samples were tissuezied (Type SDT-1810, Tekmar Co., Cininnati, Ohio, U.S.A.) for 1 minute and stored at -80 °C until analysis. For analysis, samples were thawed and filtered through glass wool. One ml aliquots of filtered sample was centrifuged in a microcentrifuge 210A (Model CO210, Denville Scientific, Metuchen N.J., U.S.A.) at 10,000 rpms for 10 minutes, transferred to amber vials, and analyzed for AA by a HPLC system (ThermoQuest San Jose, CA) consisting of a P2000 binary pump, AS 3000 autosampler, and SCM 1000 degasser. The amber vials containing centrifuged samples were placed in the sample tray set at a temperature of 6 °C with a light proof covering. Samples (0.8 ml) were injected onto a 3µm reverse phase column (4.6 x 150mm) (µ Bondapack-NH₂ Z-module cartridge, Waters Associates, Milford, MA) and were separated at 30 °C under isocratic conditions with an eluent flow rate of 0.8 ml/min. The mobile phase consisted of aqueous 20 mM KH₂PO₄ and acetonitrile (95:5 v/v) adjusted to pH 3.0 with phosphoric acid. Peaks were monitored at 242 nm by a UV 6000 LP Diode Array Detector. Standard solutions with concentrations from 0 to 10 mg AA/ml were used for the calculations. The R² of the standard curve was greater than 0.99 with the intercept forced through zero. ThermoQuest Chromatography Data Acquisition Software version 4.1 was used to collect and process the data.

Texture firmness measurement. Texture firmness of processed samples were measured using a TA-XT2 Texture Analyzer (Texture Technologies, Scarsdale, N.Y.,

U.S.A.) equipped with a 25 kg load cell, back extrusion rig (TA-94) and plunger with 45 mm diameter disk attachment. Processed sample, at ambient temperature, was drained in a #8 sieve, for 3 minutes, and 100 g of drained sample was compressed to 30% of its original height at a rate of 1 mm/s. Parameters used for assessment were the highest peak force and total work required for compression.

Color. Diced tomato color, before and after processing, was measured using a Minolta CR-300 Chroma Meter (Konica Minolta, Inc., Ramsey, NJ) with D65 light source. The instrument was calibrated using a standard white tile and B.C.R. Tomato Paste Reference Tile. Color values were obtained using the CIE L*a*b* system. For each sample, color was measured at 5 points of the sample vial. The colorimeter value reported for each of these points was an average of three measurements. Values reported are L* a* and b* and L*(a*/b*). According to Rodrigo *et al.*, (2007), L*(a*/b*) is the best parameter to describe color change in heated tomatoes.

2.4 Results and discussion

Dielectric properties

For each treatment, the dielectric constant (ϵ') decreased from 67.82, 68.35, 69.29, and 67.97 at 20 °C to 53.57, 54.83, 54.10 and 54.63 at 130 °C for treatments A, B, C and D respectively (Figure 2). The dielectric loss (ϵ'') increased from 8.7, 12.52, 13.3 and 10.99 at 20 °C to 27.82, 29.02, 34 and 26.84 at 130 °C for treatments A, B, C and D respectively.

The observed decreasing and increasing, ϵ' and ϵ'' , trends of all treatments are consistent with findings for tomatoes, bell peppers, jalapeños and onions by Kumar *et al.*, (2008).

ϵ' values of each treatment for all temperatures were similar. The dielectric constant of food relates to the ability of the material to store electrical energy. The decreasing ϵ' may be explained by the decreased relaxation time of free water and other polar molecules in the samples at increased temperatures (Ryynänen, 1995). In addition, raising temperatures cause increased Brownian movement which in turn decreases the static dielectric constant (Tang, 2005).

The dielectric loss factor (ϵ'') relates to a material's ability to convert stored energy into heat and is influenced by ionic conductivity. The increasing trend observed for ϵ'' may be explained by increasing ionic conductivity within the sample as temperatures increase. Ionic conduction is dependent on the mobility of ions within a matrix. Viscosity of a fluid is temperature dependant (Bourne, 2002). Decreased viscosity associated with increased temperatures would allow for greater ion mobility and ultimately a greater contribution to ϵ'' . Although ϵ'' values of each treatment were similar, the ϵ'' values for tomatoes treated with CaCl_2 were slightly higher than the other treatments. In solution, CaCl_2 will readily disassociate into Ca^{2+} and 2Cl^- ions. Theoretically, when added to tomatoes, Ca^{2+} will bind with pectic substances in the tomatoes leaving the 2-Cl^- ions in solution. The increased Cl^- ion concentration in tomatoes treated with CaCl_2 solution could explain for the slightly higher values of ϵ'' observed for this treatment.

The lack of difference in ϵ'' between non-calcium treated samples (A and B) and samples treated with $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ is most likely due to the high molecular weights of CA

(192.12 g/mol anhydrous) and lactic acid (90.08 g/mol), which is formed as $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ dissociates in solution. Gabriel *et al.*, (1998) demonstrated that increasing molecular weights of alcohols showed decreased contributions to ϵ'' . Koskiniemi (2009) reported that CA contributed very little to ϵ'' of acidified vegetables. Our observations for were consistent with this author's findings as they were not significantly different from each other. It is likely that the weight of CA and $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ decreased the mobility of these constituents in the food matrix, thereby reducing their contribution to ion conductivity.

Evaluation of $\tan\delta$ is a useful term when comparing dielectric properties as it accounts for both ϵ' and ϵ'' . Furthermore, $\tan\delta$ is a parameter which describes the attenuation of microwave power in foods (Tang, 2005). The observed $\tan\delta$ at 915 MHz ranged from 0.12, 0.18, 0.19 and 0.16 at 20 °C to 0.52, 0.53, 0.63 and 0.49 at 130 °C for treatments A, B, C and D respectively (Figure 3). The slightly greater $\tan\delta$ observed at increased temperatures for the CaCl_2 treatment may be due to its increased ion conductivity relative to the other treatments. The $\tan\delta$ values observed suggest that diced tomatoes treated as described above are suitable for microwave heating.

Penetration depth decreased with increasing temperature for all treatments (Figure 4). The penetration depth arises essentially from ϵ'' , which causes power dissipation in the material (Meredith, 1998). At heat treatment temperatures used in this study, CaCl_2 treated samples showed a slightly lower depth penetration than the other treatments which were similar to each other. Decreased depth penetration was most likely due to the observed increased in ϵ'' for the CaCl_2 treatment relative to the other treatments.

Microbial analyses

No observable growth was detected for aseptically packaged diced tomato samples after 72 h incubation on PCA, DTA or VRB media. Lack of observable growth suggests that commercial sterility was achieved. Aseptic bags incubated at 37 °C for three weeks did not change in volume, reiterating that commercial sterility was achieved.

Temperature Profile

Typical time temperature profiles for the inlet and exit streams of each heating section and the exit stream of the hold tube are located in Figures 5 and 6. The time-temperature history revealed that a minimum heat treatment of 95, 94, 93 and 93°C for 3 minutes was delivered to treatments A, B, C and D respectively.

Commercial sterility refers to the absence of disease causing microorganisms, toxic substances and spoilage causing microorganisms capable of multiplying under normal nonrefrigerated conditions of storage and distribution (David *et al.*, 1996). *Bacillus coagulans* is the major spoilage organism in canned tomatoes and has been reported to germinate and grow at a pH as low 4 (Palop *et al.*, 1999). Germination and growth of this organism has been shown to increase the pH of tomato juice from 4.5 to 5.07 after 6 days of incubation at 35 °C (Anderson, 1984). This is very dangerous as it is well know that *Clostridium botulinum* spores are capable of germination and growth at pHs greater than 4.6. In tomato products, spoilage is also commonly caused by non-spore forming aciduric bacteria (Denny, 1997). These bacteria are readily destroyed by processes in which temperatures of at least 85 °C are achieved (Barringer, 2004). The targeted time-temperature

profile (96 °C for 3 min) was based on current industry recommendations for diced tomatoes. This temperature profile is not intended to inactivate spores. Therefore it is important to note that while the targeted heat treatment was achieved, treatments A, B and C may be at risk of spoilage by *Bacillus coagulans* as their pH is close to or greater than 4.0 (Table 2).

pH, °Brix, Drained weight

The pH, °Brix and drain weight values for each treatment are reported in Table 2. The initial pH of the tomatoes was 4.43 ± 0.02 . The final pH after processing for each treatment was slightly higher than their respective target pH. Processed diced tomato pH was 4.35, 3.97, 3.96 and 3.92 for treatments A, B, C and D respectively. pH values for treatments B and C were not significantly ($p > 0.05$) different from each other but were significantly ($p < 0.05$) higher than the pH of treatment D.

°Brix was 4.75, 5.02, 4.90 and 4.98 for treatments A, B, C, and D respectively. °Brix of treatment A was significantly ($p < 0.05$) lower than all other treatments. Treatment C was significantly ($p < 0.05$) higher than A, and significantly ($p < 0.05$) lower than B and D which were similar to each other ($p > 0.05$). °Brix, is a measure of soluble solids content, such as sugars and organic acids, in the juice fraction of a product. Polygalacturonase (PG) is an enzyme which cleaves α 1-4 linkages of the galacturonic backbone of pectic substances. Pressy and Avants (1982) demonstrated that PG activity will result in galacturonic acid accumulation in the juice fraction of tomato tissue treated with this enzyme. Although one could speculate that the observed °Brix differences in treatments were due to differences in accumulated galacturonic acid in the juice, it is unlikely that this was the case. Galacturonic

acid accumulation in the juice would be in minute quantities and mostly likely below the detectable limits of the equipment used for °Brix determinations. Differences were more likely a result of CA concentration. CA, an organic acid, was added to treatments in quantities in which $A < C < B = D$. This addition scheme matches the observed °Brix trend of $A < C < B = D$.

Drain weight percentages for all treatment were not significantly ($p > 0.05$) different from each other. USDA standards for Grades of Canned Tomatoes, Grade A or U.S. Fancy canned tomatoes must have a drain weight greater than 66% (Barringer, 2004). According to Barrett *et al.* (1998), drain weight measurements are relatively gross indicators of textural properties of diced tomatoes which assess weight loss of the product following handling or processing. “High drain weight values are indicative of tissue moisture retention, juiciness, and relative greater firmness” (Barrett *et al.*, 1998). According to this *single* USDA standard, all processed treatments were of excellent quality. These observations are perplexing however because it is commonly thought that Ca^{2+} addition enhances drain weight values. This was not the case in our study. Ca^{2+} treated samples showed significantly greater firmness ($p < 0.05$) than non-calcium treated samples (which will be illustrated in the next section), yet all treatments had the same drain weight values. Our results suggest that neither Ca^{2+} addition nor pH differences effect the drain weight of the product. Thus, drain weight assessment may not be a good indicator of textural quality.

Firmness

The highest peak force values and total work load (Table 3) were significantly ($p < 0.05$) lower in non-calcium treated samples (A and B) than those for Ca^{2+} treated samples (C and D). Treatments without Ca^{2+} were not significantly ($p > 0.05$) different from each other nor were the Ca^{2+} treated samples significantly ($p > 0.05$) different from each other. These results suggest that different degrees of acidification using CA did not have an effect on firmness but that the addition of 0.02% w/w Ca^{2+} did. The results also suggest that $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ performs as well as CaCl_2 at the 0.02% w/w Ca^{2+} level in texture firmness retention. Our findings in this study may be beneficial for the diced tomato industry as it suggests that replacement of CaCl_2 with $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ in diced tomato products may be feasible.

Ascorbic acid

The AA retention was 63, 67, 56 and 52 for treatments A, B, C and D respectively (Table 4). In non-calcium treated samples, treatment B showed slightly greater AA retention than treatment A. It is well known that heat enhances the rate of AA degradation. Although heat must have played a substantial role in AA degradation for all treatments, the observed difference in AA retention between A and B may be due to the fact that treatment B had a pH (3.97) lower than the $\text{pK}_{\text{a}1}$ (4.04) of AA whereas A had a pH (4.35) greater than AA's $\text{pK}_{\text{a}1}$. It is likely that treatment A would have had more of the monoanion form of AA than B. The fully protonated and monoanion forms of AA are less susceptible to oxidation

than the ascorbate dianion (Gregory, 2008). Thus, greater oxidative degradation of AA in treatment A is likely.

Both Ca^{2+} treated samples had lower AA retentions than non-calcium treated samples. These differences in AA retentions may be due to a greater incorporation of air in the product during processing. During processing, foam formation was observed during the mixing of all treatments. Although foam formation was not measured, Ca^{2+} treated samples seemed to produce substantially greater amounts of foam than non-calcium treated samples. It is well known that the rate of AA degradation is enhanced in the presence of oxygen. It is likely that greater oxidative degradation was the cause of observed differences in AA retention between Ca^{2+} treated samples and non-calcium treated samples.

According to Barringer (2004), vitamin C content of commercially processed tomatoes is reduced by 45%. This would imply that only non-calcium treated samples had better AA retention than traditionally processed products. It is important to note however that to make any conclusions regarding which processing technique is better, a side by side study should be conducted.

Color

Diced tomato color was evaluated before and after processing (Table 5). The most noticeable difference was the observed decrease in a^* values for all treatments after processing. In the CIE L^* a^* and b^* color space, a^* represents color ranging from green (negative values) to red (positive values). A decline in positive a^* value suggests a loss of red pigment. In tomatoes, lycopene is responsible for the red color (Clinton *et al.*, 1996).

The decrease in a^* was greatest for diced tomatoes in treatment C followed by treatments A, D and B respectively. It has been demonstrated that temperatures between 90 and 150 °C caused degradation of total lycopene content in tomato puree (Shi *et al.*, 2007). Ax *et al.* (2003) found that lycopene destabilization was about three times higher in the presence of oxygen in an emulsion than that in an oxygen free system. As discussed previously, air incorporation into the system was problematic for all treatments but was most prominent for calcium treated samples. This change in a^* contributed to the significant ($p < 0.05$) decrease in overall color change as indicated by the $L^*(a^*/b^*)$ parameter (Figure 7).

2.5 Conclusion

Diced tomatoes treated with or without Ca^{2+} are suitable materials for microwave heating applications. The use of CaCl_2 as a firming agent in diced tomatoes will cause an increase in diced tomato dielectric loss factor whereas $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ will not at 0.02% w/w levels. Additionally, $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$ is as effective a firming agent as CaCl_2 at the 0.02% Ca^{2+} level. Acidification with citric acid does not significantly affect diced tomato dielectric properties. AA retention was greater for tomato product at a pH of 3.9 than that at pH 4.3. Furthermore, decreased a^* values were evident in all treatments. Future works should employ the use of a defoaming agent to reduce air incorporation in calcium treated diced tomatoes.

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Table 1. Percentage citric acid needed to obtain desired pH in whole pack tomatoes*

| Starting pH | % Citric acid to reduce pH to | | |
|-------------|-------------------------------|-----|-----|
| | 4.1 | 4.0 | 3.9 |
| 4.6 | 0.3 | 0.4 | 0.5 |
| 4.4 | 0.2 | 0.3 | 0.4 |
| 4.2 | 0.1 | 0.2 | 0.3 |
| 4.0 | - | - | 0.1 |

*Table was adapted from Gould 1992

Table 2. pH, °Brix, and drain weight for processed diced tomato treatments

| Treatment | pH | °Brix | Drain weight |
|------------------------|-------------|--------------|---------------------|
| A (pH 4.3) | 4.35 ± 0.02 | 4.75 ± 0.04 | 71% ± 2.35 |
| B (pH 3.9) | 3.97 ± 0.02 | 5.02 ± 0.02 | 69% ± 3.22 |
| C (CaCl ₂) | 3.96 ± 0.01 | 4.90 ± 0.00 | 70% ± 1.02 |
| D (CaL ₂) | 3.92 ± 0.01 | 4.98 ± 0.02 | 70% ± 1.19 |

Table 3. Textural properties of processed diced tomato treatments

| Treatment | Absolute peak force (N/100 g drained material) | Total Work (N.s) |
|------------------------|---|-----------------------------|
| A (pH 4.3) | 47.15 ± 6.67 | 384.71 ± 53.37 |
| B (pH 3.9) | 47.37 ± 4.38 | 385.36 ± 27.53 |
| B (CaCl ₂) | 108.34 ± 9.70 | 956.90 ± 89.35 |
| D (CaL ₂) | 105.31 ± 12.89 | 899.34 ± 34.72 |

Table 4. AA before and after processing

| Treatment | Raw (mg/100 g fw) | Processed (mg/100 g fw) | Percent Retention |
|------------------------|------------------------------|------------------------------------|------------------------------|
| A (pH 4.3) | 0.14 ± 0.007 | 0.09 ± 0.004 | 63 |
| B (pH 3.9) | 0.14 ± 0.008 | 0.09 ± 0.003 | 67 |
| C (CaCl ₂) | 0.17 ± 0.001 | 0.09 ± 0.003 | 56 |
| D (CaL ₂) | 0.15 ± 0.009 | 0.08 ± 0.006 | 52 |

Table 5. L*a*b* of diced tomato treatments before and after processing

| Treatment | Stage | L* | a* | b* |
|------------------------|--------------|--------------|--------------|--------------|
| A (pH 4.30) | raw | 27.81 ± 0.88 | 16.49 ± 1.10 | 11.60 ± 0.11 |
| | processed | 27.63 ± 0.05 | 13.45 ± 0.51 | 12.62 ± 0.05 |
| B (pH 3.90) | raw | 28.32 ± 0.31 | 15.87 ± 0.11 | 11.55 ± 0.13 |
| | processed | 27.85 ± 0.06 | 13.92 ± 0.17 | 12.83 ± 0.08 |
| C (CaCl ₂) | raw | 27.38 ± 0.08 | 17.22 ± 0.34 | 11.56 ± 0.02 |
| | processed | 27.18 ± 0.08 | 12.94 ± 0.38 | 12.37 ± 0.13 |
| D (CaL ₂) | raw | 28.42 ± 0.40 | 16.48 ± 0.09 | 12.54 ± 0.10 |
| | processed | 27.12 ± 0.10 | 14.45 ± 0.42 | 12.95 ± 0.23 |

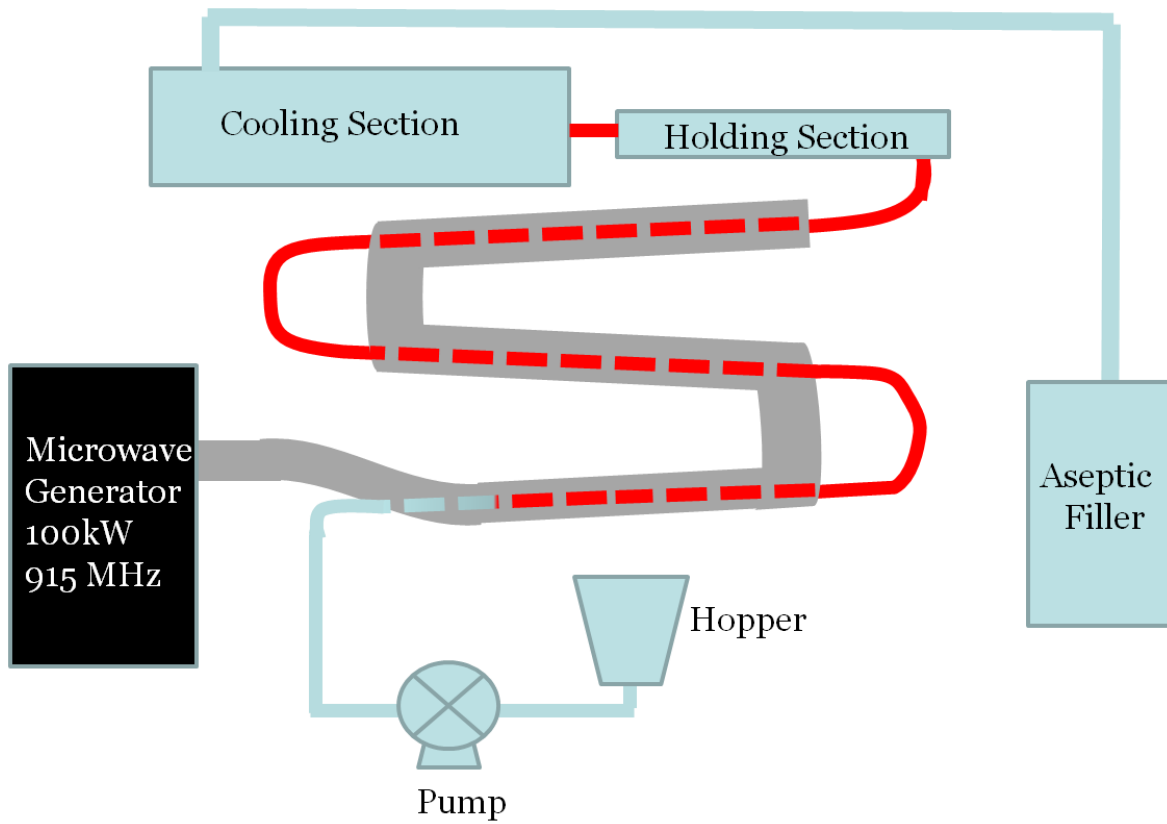


Figure 1. Schematic diagram of the continuous flow microwave system

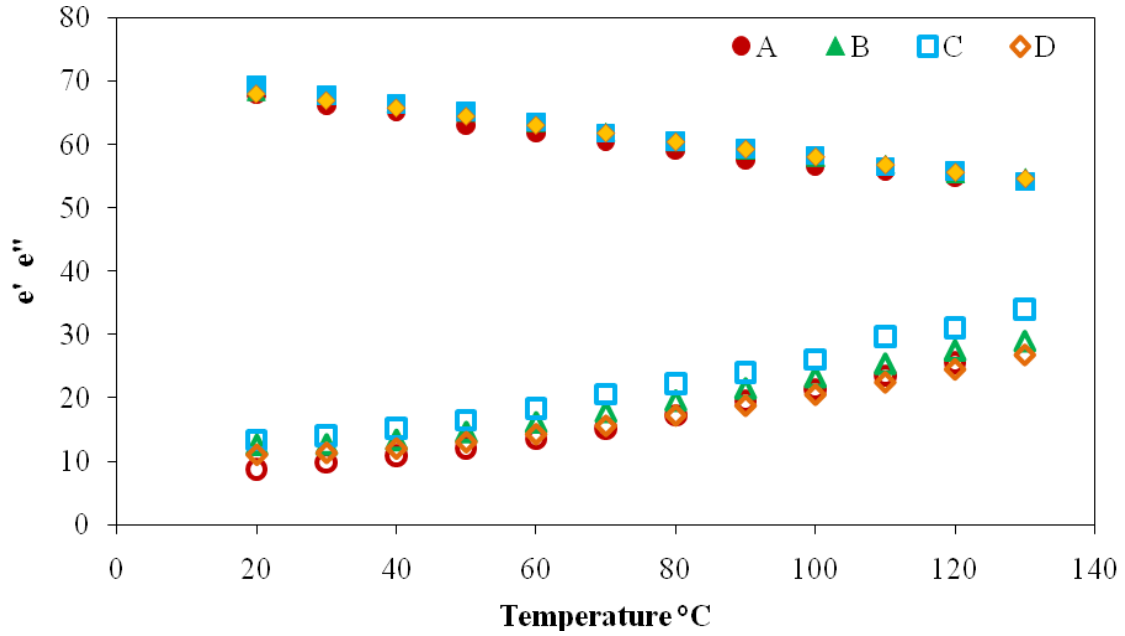


Figure 2. Dielectric constant (closed symbols) and loss factors (open symbols) for diced tomato treatments with respect to temperature for pH 4.3(A) or 3.9(B) and treated with CaCl_2 (C) or Calcium lactate (D)

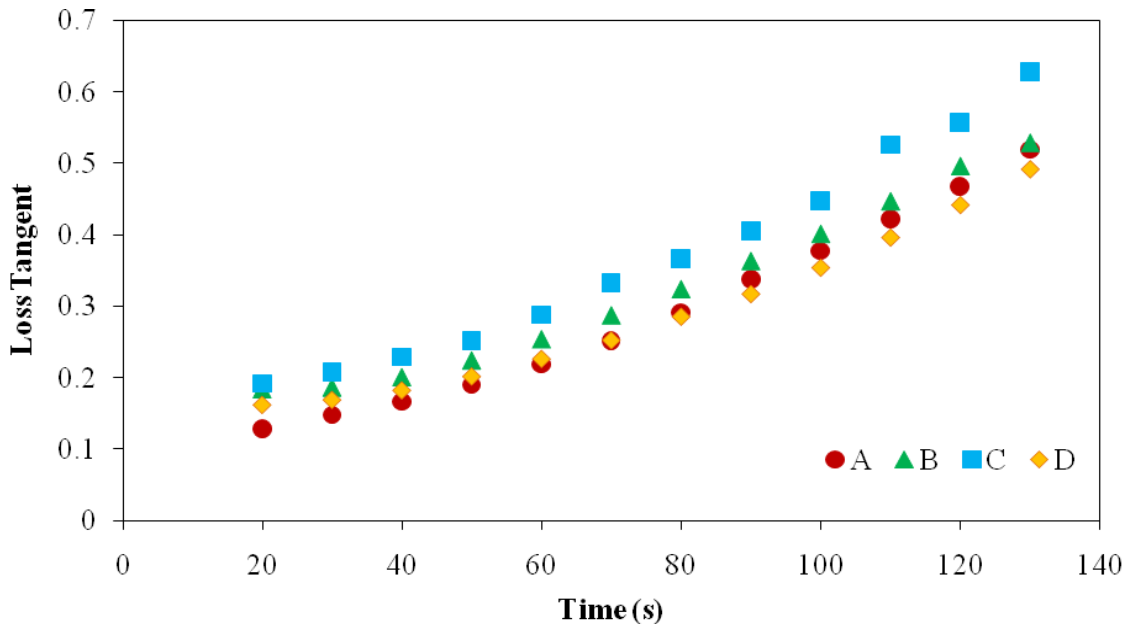


Figure 3. Loss tangent for diced tomato treatments with respect to temperature for pH 4.3(A) or 3.9(B) and treated with CaCl_2 (C) or Calcium lactate (D)

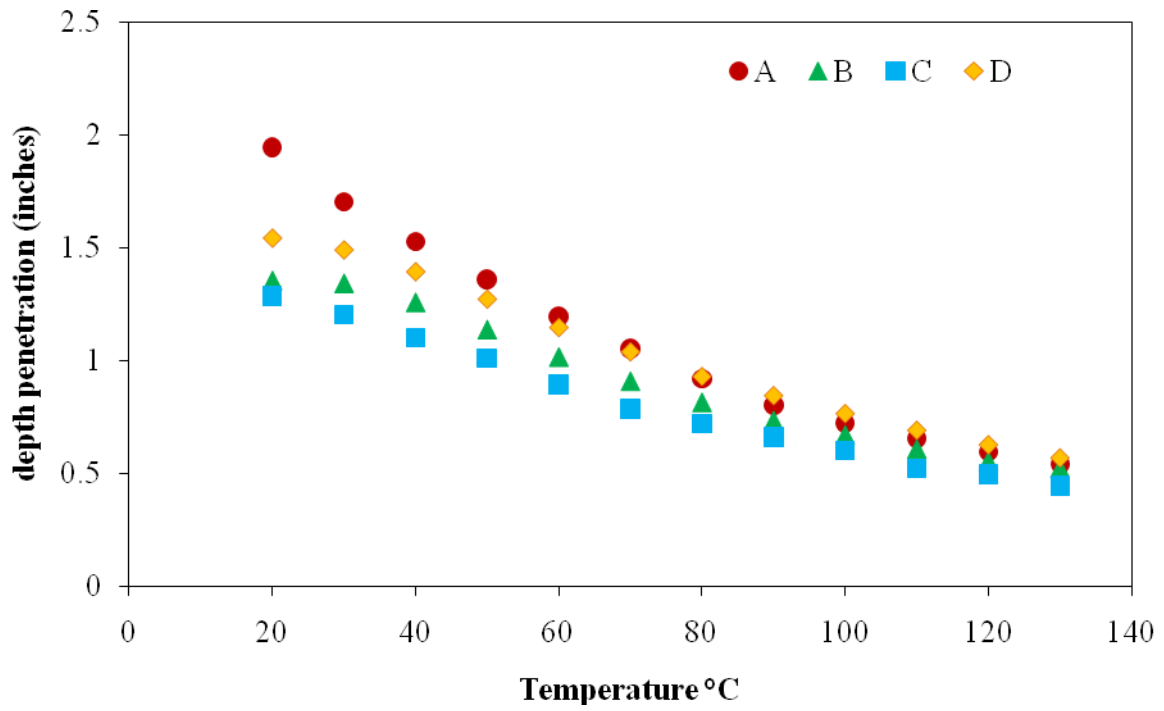


Figure 4. Depth penetration with respect to temperature for diced tomatoes acidified to pH 4.3(A) or 3.9(B) and treated with CaCl_2 (C) or Calcium lactate (D)

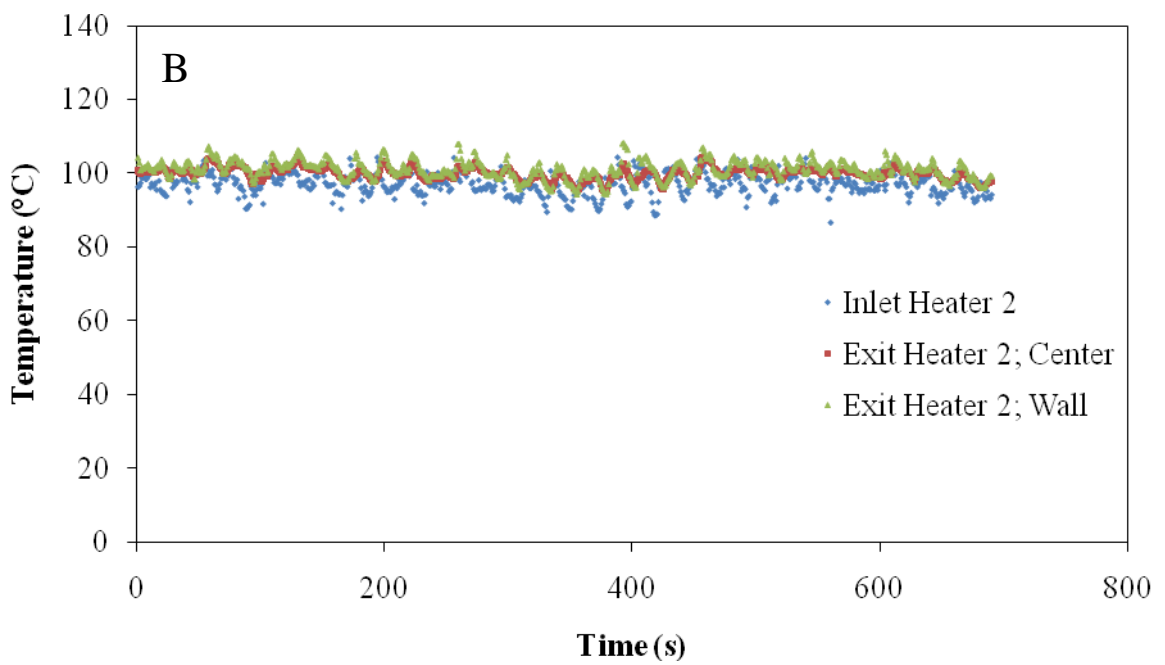
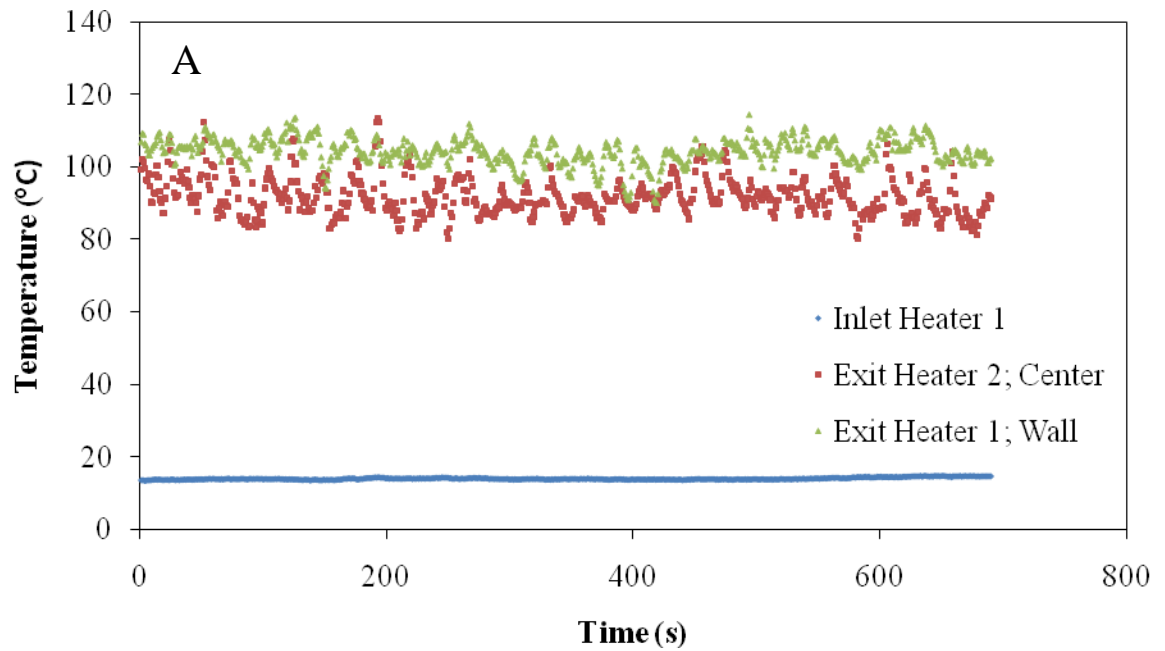


Figure 5. Typical time temperature history for inlet and exit streams of the first (A) and second (B) heating sections

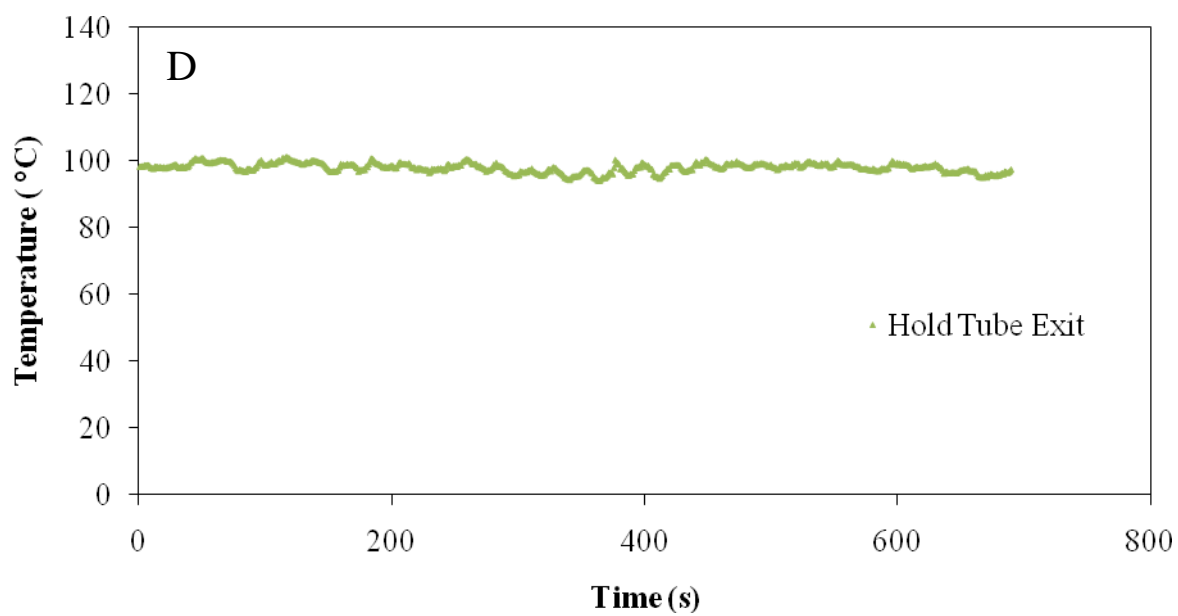
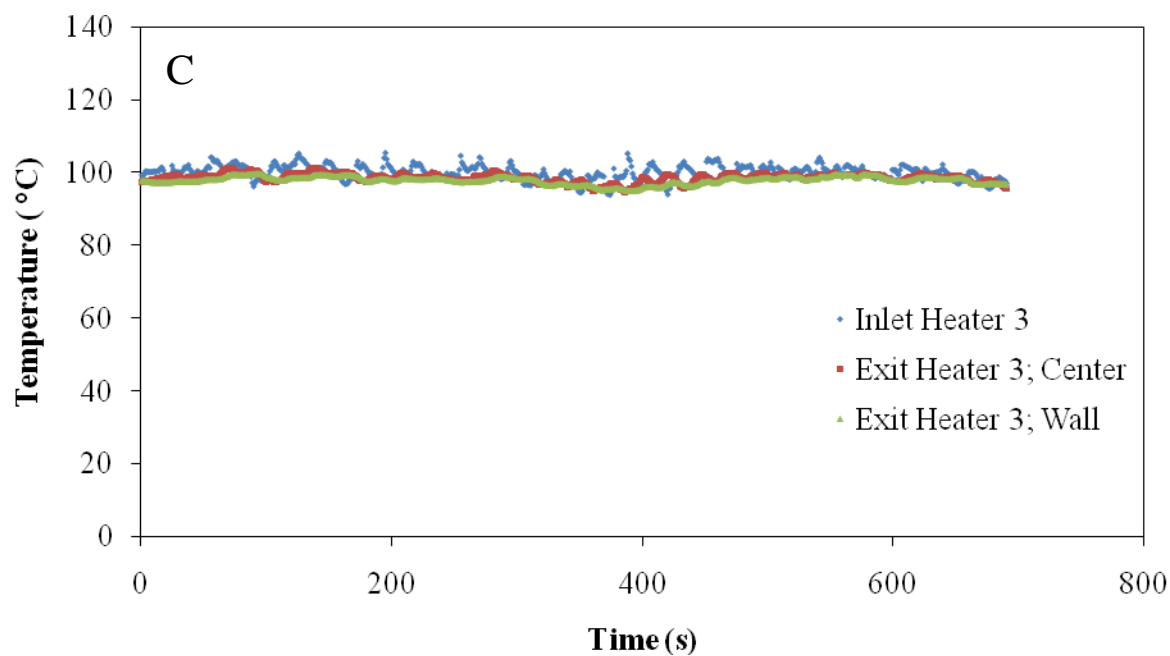


Figure 6. Typical time temperature history for inlet and exit streams of the third heating section (A) and hold tube exit (B)

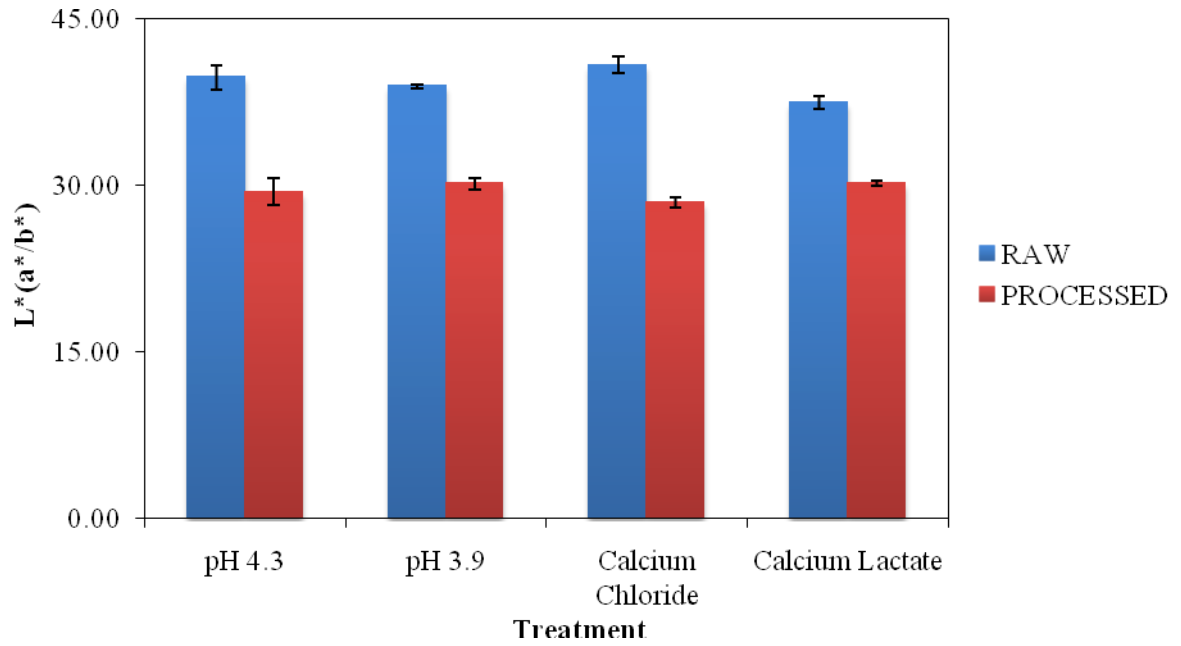


Figure 7. L*(a*/b*) before and after processing

Chapter 3

Quality and Consumer Acceptance of Continuous Flow Microwave Sterilized Tomato Based Salsa

3.1 Abstract

Incidences of foodborne outbreaks associated with consumption of fresh tomato salsas have doubled in the past decade. A fresh-tasting tomato salsa which has been processed to commercial sterility may be a suitable and safer option for consumers. The objectives of this study were to process tomato salsa to commercial sterility utilizing a continuous flow microwave (CFM) system followed by aseptic packaging and determine its quality and consumer acceptance. Formulated salsa, acidified to pH 3.7, was heated to a minimum temperature of 91°C for 3 minutes in a 100 kW CFM system operating at 915 MHz. Heated salsa was cooled to 40°C and aseptically packaged. Dielectric constant (ϵ') and loss factor (ϵ'') of a formulated raw salsa were determined. Processed salsa was analyzed after 3 and 56 days at 4°C and 56 days at 37 °C for microbial growth, ascorbic acid, drain weight, and texture. Consumer acceptance and attribute diagnostics were evaluated after 56 days of storage using a 9-point hedonic scale.

ϵ' decreased from 73 at 20 °C to 59 at 130 °C and ϵ'' increased from 30 at 20 °C to 78 at 130 °C. Microbial growth was below detectable limits for PCA, VRB and DTA media indicating that commercial sterility was achieved. Ascorbic acid retention was 72% and 66% for 3 and 56 days after processing respectively. Drain weight was 77% and did not change significantly during storage ($P > 0.05$). Highest peak force value for texture was 90 N/100 g of drained salsa and did not change significantly during storage ($P > 0.05$). Average overall consumer liking was 7.3. Consumer liking of appearance, overall texture, tomato texture, and flavor were 7.7, 6.9, 6.7, and 7.2 on average respectively. Average perceived fresh flavor intensity was 7.2.

These results suggest that use of a CFM system followed by aseptic packaging can produce a commercially sterile tomato salsa that is fresh-tasting and perceived favorably by consumers after 56 days of storage at 4°C. Substitution of fresh tomato salsas for one that is commercially sterile, such as the one produced in this study, would reduce incidences of foodborne outbreaks associated with its consumption.

Keywords: microwave processing, salsa, consumer acceptance

3.2. Introduction

Consumption of fresh refrigerated salsa is a potential health hazard. Incidences of foodborne outbreaks associated with the consumption of fresh salsa have doubled during the decade between 1998 and 2008 compared with that from the years between 1984 and 1998 (Preidt, 2010). Contaminated cilantro, green onions, and jalapeño and Serrano peppers associated with salsa preparations have been indicted as the cause of outbreaks of *Salmonella* serotype Thompson, Hepatitis A, and *Salmonella* serotype Saintpaul respectively over the past decade (Campbell *et al.*, 2001; Jungk, 2008; Wheeler *et al.*, 2005). Consumption of raw tomatoes alone has also been the cause of outbreaks of *Shigella flexneri* Serotype 2a and *Salmonella spp.* (Reller *et al.*, 2006; Cummings *et al.*, 2001; Green *et al.*, 2008). Fresh salsa contaminated with *Salmonella enteritis* by a food handler was the cause of an outbreak in 2002 (Beatty *et al.*, 2009). Ma *et al.* (2010) found that tomato based salsas inoculated with pathogenic *Salmonella spp.* were able to support the survival of these pathogens, depending on the salsa formulation. Their study found that freshly prepared salsas formulated with lime juice but without fresh garlic supported the survival and growth of *Salmonella spp.* Fresh refrigerated salsas currently comprise seven to eight percent of the total salsa market in the U.S. (Chang, 2009). As consumer demand for fresh, high quality foods increases, it is likely that the market share for fresh refrigerated salsas will increase. Consequently, so too will outbreaks associated with its consumption unless appropriate safety measures are implemented.

A fresh tasting tomato based salsa which has been processed to commercial sterility may be a suitable and safer alternative for consumers who prefer fresh refrigerated salsa.

As a commercially sterile food, this type of product would have the benefit of having a shelf life that is substantially longer than fresh refrigerated salsas not only on a food safety basis but also on a sensory quality basis. Texture contributes to the overall sensory quality of a food product. Tomatoes contain endogenous textural degrading enzymes including polygalacturonase (PG). PG enzymes cleave the α 1-4 linkages of the galacturonic backbone of pectic substance which contribute to the structure and ultimately the textural integrity of a plant cell. Unless these enzymes are inactivated, such activity will result in the destruction of textural integrity. Loss of textural integrity in the components of fresh refrigerated salsa will reduce sensory quality of the product.

Enzymatic inactivation and microbial destruction can be achieved through thermal processing. Excessive thermal treatments of food products in conventional canning processes result in degradation of color, flavor, texture, and nutrients (David *et al.*, 1996). In aseptic processing, a product with microbial destruction identical to that achieved in conventional canning, which is also of high quality, can be achieved due to the use of high temperatures for short periods of time. Use of microwaves in thermal processing is advantageous due to rapid heat penetration of foods and improved nutrient retention (Fu, 2004). Continuous flow microwave heating of foods is an emerging technology. Its rapid heating of foods lends itself well to aseptic processing technologies. The objectives of this study were to process a tomato-based salsa to commercial sterility using a continuous flow microwave system, followed by aseptic packaging and to evaluate its quality and consumer acceptance.

3.3 Methods and Materials

Chemicals

Analytical grade metaphosphoric acid and L-Ascorbic acid were obtained from Sigma-Aldrich (St. Louis, Mo., U.S.A.).

Salsa Ingredients

A complete list of ingredients used in the salsa formulation and respective manufacturer information is located in Table 1.

Salsa Preparation

Roma tomatoes, white onions, green bell peppers and jalapeño peppers were stored for 24 h at 4 °C then diced to 1/2", 1/4", 1/4", and 1/8" cubes respectively (Urschel, Model RA-D, Chalfont, Pa., U.S.A.). Parsley, cilantro, salt, sugar, onion powder, garlic powder, cayenne pepper, chipotle chili powder and citric acid were manually combined with the lime juice and tomato paste until evenly distributed. Paste mixture was diluted with tomato puree. Tomato puree was prepared by pulverizing Roma tomatoes in a hammer mill (FitzMill, Model D, Chicago, Ill., U.S.A.) with #5 screen, set to low speed. Diced tomatoes were gently mixed into the tomato puree mixture until evenly distributed. Raw salsa was processed immediately.

Microwave Processing

A schematic of the microwave system is presented in Figure 1. Raw salsa was processed in a 100 kW continuous flow microwave system (UltrAseptics Inc., Raleigh, N.C., U.S.A.) operating at 915 MHz. Microwaves, generated by a magnetron, were delivered to

the salsa during its passage through three segments of microwave-transparent tubes located within rectangular waveguides in an axial traveling-wave like structure. In this system, the propagating waves travel concurrently with the flow of product. Pipes containing product pass through the waveguides at three sections to yield three heating areas. Within these sections, pipes are composed of a high purity alumina ceramic-reinforced PTFE to allow for microwave penetration of the food product.

Salsa was pumped through the system at a rate of 5.68 L/min using a positive displacement pump (Model A7000, Marlen Research Corp., Overland Park, Kans., U.S.A.). The salsa was heated by controlling the power of the system, which varied from 40 to 45 kW. The targeted minimum heat treatment was 96 °C for 3 minutes. Heated salsa was cooled using a tubular heat exchanger to 40 °C then aseptically packaged in aluminum-polyethylene laminated bags (Scholle Corp, Chicago, Ill., U.S.A.) using a bag-in-box aseptic filler unit (Model PT A.F., Astepo, Parma, Italy). Temperature of the product was monitored by Type T thermocouples (OMEGA Engineering, Inc., Stamford, Conn., U.S.A.) positioned at the inlet and exit of the applicator and the exit of the hold tube. Two 150 lb batches of salsa were processed. Aseptic bags of processed salsa were stored at 4 or 37 °C until analyzed.

Analyses

Homogenization of samples

For dielectric and pH analyses, salsa was homogenized in an Oster blender (Model 6872) set to puree speed for 30 seconds.

Dielectric Analysis

Dielectric properties of raw homogenized salsa were measured under static conditions using an open-ended coaxial probe (Model HP 85070B Agilent Technologies, Palo Alto, Calif., U.S.A.) connected to a network analyzer (Model HP 8753C, Agilent Technologies). Calibration of the network analyzer was achieved by leaving the probe in contact with ambient air ($22\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$), metal, and deionized water. Dielectric properties were measured between 20 and 130 °C at 10 °C intervals and at frequencies from 300 to 3000 MHz with an increment of 5 MHz. The variable step size for temperature increment was chosen in order to determine the dielectric properties at sterilization temperatures. Homogenized salsa was placed in a pressurized cylindrical cell (inner diameter 35 mm and height 36.5 mm) and heated in an oil bath (Model RTE-111, Neslab Instruments Inc., Newington, N.H., U.S.A.) to attain the testing temperature.

Microbial Analyses

Duplicate samples for each batch of processed salsa were aseptically plated on plate count agar (PCA), violet red bile agar (VRB) and dextrose tryptone agar (DTA). Samples were plated using a spiral microplater (Autoplate 4000, Exotech Inc., Gathersburg, Md., U.S.A.). PCA and VRB plates were incubated at 37 and 55 °C in aerobic and anaerobic atmospheres. DTA plates were incubated at 37 and 55 °C in an anaerobic atmosphere only. All plates were incubated for 72 hours. Additionally, two aseptically packaged bags of the processed salsa (one from each batch) were incubated at 37 °C for three weeks.

Physical assessments for quality

Drain weight, pH and °Brix measurements. Drain weight was determined based on the procedure recommended for diced tomatoes by the California League of Food Processors Diced Tomato Committee (CLFP, 2011). Approximately 100 ounces of processed salsa at room temperature was allowed to drain for 2 minutes on a #8 sieve, for which one side was tilted two inches higher than the other. Percent drain weight was calculated according to the following equation:

$$\% \text{ Drain Weight} = (\text{Drained Tomato Weight}) \times 100 / \text{Net Weight}$$

Measurements for pH values were obtained before and after processing (Accumet AR50 pH meter, Fisher Scientific). °Brix was determined for the salsa's juice using a hand held refractometer (Model A727275, ATAGO USA, Inc.).

Ascorbic acid.

Sample preparation: 1:10 dilutions of homogenized raw and processed salsa were prepared using 5% metaphosphoric acid. Diluted samples were tissuezimed (Type SDT-1810, Tekmar Co., Cininnati, Ohio, U.S.A.) for one minute and stored at -80 °C until analysis. For analysis, samples were thawed and filtered through glass wool. One ml aliquots of filtered samples were centrifuged in a microcentrifuge 210A (Model CO210, Denville Scientific, Metuchen N.J., U.S.A.) at 10,000 rpms for 10 minutes then analyzed by HPCL.

HPLC: For ascorbic acid (AA) quantification, centrifuged samples were stored in amber vials and placed in the sample tray set at a temperature of 6 °C with a light-proof covering. Samples (20 ml) were injected onto a 3 mm reverse phase column (4.6_150 mm) (Bondapack-NH₂ Z-module cartridge, Waters Associates, Milford, Mass.) and were separated at 35 °C under isocratic conditions with an eluent flow rate of 1.2 ml/min. The mobile phase consisted of aqueous 0.005M KH₂PO₄ and acetonitrile (30:70 v/v). Peaks were monitored at 242 nm by a UV 6000 LP Diode Array Detector. Standard solutions with concentrations from 0 to 10 mg/ml were used for the calculations. The R² of the standard curve was greater than 0.99 with the intercept forced through zero. ThermoQuest Chromatography Data Acquisition Software version 4.1 was used to collect and process the data.

Texture firmness measurements. Texture of processed salsa was measured using a TA-XT2 Texture Analyzer (Texture Technologies, Scarsdale, N.Y., U.S.A.) equipped with a 25 kg load cell, back extrusion rig (TA-94) and plunger with 45mm disk attachment. For analysis, at ambient temperature was drained in a #8 sieve, for 3 minutes. 100 g of drained salsa was compressed to 30% of original height at a rate of 1 mm/s. Six replicates of each batch of salsa were analyzed.

Sensory Analyses

A consumer acceptance panel was conducted using 76 salsa consuming, untrained panelists. Panelists were solicited from the campus of North Carolina State University via

flyers and email. Samples used for sensory analysis had been maintained in storage for eight weeks at 4 °C. Panelists were given 2-ounce portions of salsa (4 °C) in a 4-ounce clear portion container with lid and provided with Tostitos bite-sized plain tortilla chips if desired. Panelists were first asked to taste the salsa and rate their degree of overall liking on a 9-point hedonic scale (1=extremely dislike, 5=neither like nor dislike, 9=extremely like). Panelists were then asked to rate their degree of liking for appearance, overall texture, texture of the tomato component and flavor using a 9-point hedonic scale (1=extremely dislike, 5=neither like nor dislike, 9=extremely like). Using a 5-point Just-About-Right scale (1=too soft, 3=just about right, 5=too firm) panelists were also asked to assess how they felt about the overall firmness of the salsa and the firmness of the tomato component. To assess perceived fresh flavor intensity, panelists were asked to rate the intensity of the salsa's fresh flavor using a 9-point hedonic scale (1=not at all fresh, 5=somewhat fresh, 9=very fresh). Finally, panelists were asked whether or not they would purchase this product if it were available.

3.4 Results and discussion

Dielectric properties

The dielectric properties of the salsa at 915 MHz with respect to temperature are shown in Figure 2. The dielectric constant (ϵ') decreased from 73 at 20 °C to 59 at 130 °C and dielectric loss factor (ϵ'') increased from 30 at 20 °C to 78 at 130 °C. The observed trends for ϵ' and ϵ'' are consistent with findings for tomatoes, bell peppers, jalapeños and onions by Kumar *et al.*, (2008). The dielectric constant of food relates to the ability of the material to store electrical energy. ϵ' is affected by the relaxation time of polar molecules in

the material such as water (Ryynänen, 1995) and Brownian movement under static conditions (Tang, 2005). Reduced relaxation time decreases its contribution to dielectric constant values. Increased temperatures cause increased Brownian movement which in turn decreases the static dielectric constant (Tang, 2005). The dielectric loss factor relates to a material's ability to convert stored energy into heat and is influenced by ionic conductivity. The increasing ϵ'' may be explained by increasing ionic conductivity within the salsa as temperatures increase. Ionic conduction is dependent on the mobility of ions within a material matrix. Viscosity of a fluid is temperature dependant (Bourne, 2002). Decreased viscosity would allow for greater ion mobility and ultimately greater contribution to ϵ'' . Notably, the loss factor becomes larger than the dielectric constant between 100 and 110°C. This could be due to predominance of ionic conduction at higher temperatures. The loss tangent at 915 MHz increased from 0.41 at 20 °C to 1.32 at 130 °C (Figure 3). The high loss tangent value of the formulated salsa suggests that it is a good candidate for processing in a continuous flow microwave system as it has the ability to convert the stored microwave energy into heat.

Microbial

No observable growth was detected after 72 h incubation on PCA, DTA or VRB media. Lack of observable growth suggests that commercial sterility was achieved. Aseptic bags incubated at 37 °C for three weeks did not change in volume which confirms that commercial sterility was achieved, providing further evidence that commercial sterility was achieved.

Temperature profile

The recorded temperatures for the inlet and outlet streams of the first, second and third heating sections as well as the exit of the hold tube are presented in Figures 4 and 5. Salsa entered the system at around 14.4 °C and exited the hold tube at 94 – 106 °C. In the first heating section, salsa temperatures increased from about 14.4 °C at the inlet to between 67 and 125 °C at the exit. In the second heating section, inlet temperatures ranged from 67 to 112 °C and exited at temperatures between 91 and 108 °C. In the third heating section, inlet temperatures ranged from 94 and 110 °C. Salsa exited the hold tube at 94 – 106 °C. The salsa spent an estimated 40 s in each of the heating sections. The total time spent in the system from the entrance of the first heating section to the exit of the hold tube was about 4.5 minutes.

A minimum heat treatment of 91 °C for 3 minutes was achieved. For high acid foods, thermal heat treatments target degradative enzymes and microorganisms such as yeasts, molds, and bacterial spores. For foods with a pH of 3.7 and below, processes are designed for the control of non-spore forming bacteria, yeasts and molds. In tomato products, spoilage is commonly caused by non-spore forming aciduric bacteria (Denny, 1997). These bacteria are readily destroyed by processes in which temperatures of at least 85°C are achieved (Barringer, 2004). Thus, it is likely that commercial sterility was still achieved.

To maintain a long shelf life, endogenous polygalacturonase (PG) should be inactivated to below appreciable levels. PG enzymes are cell wall degrading enzymes found in tomatoes and bell peppers (Anthon, 2002; Priya Sethu, 1996) and are more heat resistant than other endogenous enzymes such as pectinmethylesterase and peroxidase. PG is

responsible for cleavage of the α 1-4 linkages in the galacturonic backbone of pectic substances. In tomatoes, two isozymes of PG exist; of which PG 1 is more heat resistant than PG2 (Anthon, 2002). Anthon and others found that PG 1 enzymes required temperatures greater than 85 °C for a significant rate of destruction in tomato juice. Their study determined the D-value for PG 1 to be 16.1 min at a reference temperature of 90 °C and z-value of 7.7 °C. Lopez *et al.* (1997) determined PG 1 D-values to be 15.9 min at 86 °C and 0.46 at 95.4 °C in tomato extracts at pH 4. Their reported z-value was 5.6 °C. Values reported by Lopez *et al.* were used to determine what was the probable log reduction achieved in the delivered thermal treatment since their values were determined for a system with a pH similar to ours. To determine the possible log reduction the following equations were used:

$$D = D_{ref} 10^{\frac{T_{ref}-T}{z}}$$

Using the new D-value:

$$\text{Observed process time} / D_{new} = \text{delivered log reduction}$$

Where T = temperature (°C)

Based on the above formulas, it was determined that the observed process was capable of delivering a minimum PG 1 log reduction of 1.07. This reduction may be underestimated however. The salsa formula contained onions and garlic, the juices of which have been reported to markedly reduce PG activity (Al-Jasim *et al.*, 1973). Furthermore, much of the material experienced temperatures greater than 105 °C during processing, which would have greatly reduced the PG 1 activity.

pH, °Brix, Drained weight

The pH, °Brix and drain weight values of the salsa after 3 and 56 days of storage at 4 and 37 °C are reported in Table 2. The final pH of the processed salsa was 3.7 showing that the product may be classified as a high acid food. The pH of the salsa did not change significantly ($p > 0.05$) over time nor was it affected by storage temperature. Some bacteria and molds have the ability to utilize acids during growth phase causing a rise in pH. *Bacillus coagulans*, a major spoilage organism in canned products, has been shown to increase the pH of tomato juice from 4.5 to 5.07 after 6 days of incubation at 35 °C (Anderson, 1984). Odlaug *et al.* (1979) demonstrated that tomato juice inoculated with *Aspergillus gracilis*, isolated from a can of spoiled tomatoes, caused an increase in pH from 4.6 to > 6.2 after 25 days at 32 °C allowing for the growth of *Clostridium botulinum* spores. Conversely, lactic acid bacteria utilize sugars and produce acids during growth causing a pH depression. Lack of a significant pH change in the salsa samples over time is indicative that no microbial growth occurred and that commercial sterility was achieved.

°Brix of the salsa was 8.20 ± 0.01 3 days after processing and did not change significantly ($p > 0.05$) during storage at either temperature. °Brix, often referred to as soluble solids, is a percentage of the soluble compounds, such as sugars and organic acids, present in the liquid fraction of a product. Changes in soluble solids content could indicate significant deterioration of the product, but this was not the case in our study.

Drain weight percentages of the salsa were 77% after 3 and 56 days of storage at 4 °C and 76% after 56 days at 37 °C. According to Barrett *et al.* (1998), drain weight measurements are relatively gross indicators of textural properties of diced tomatoes which

assess weight loss of the product following handling or processing. “High drain weight values are indicative of tissue moisture retention, juiciness, and relative greater firmness” (Barrett *et al.*, 1998). Negligible differences in drain weight percentages due to storage time and temperature suggest minimal decomposition of fruit/vegetable pulp, due to enzymatic degradation, occurred and that the applied process may yield salsa of good storage stability.

Ascorbic acid

AA retention 3 days after processing was 72%, and declined significantly ($p < 0.05$) after 56 days of storage at 4 and 37 °C to 66 and 50% respectively (Table 3). These results were expected. AA is easily degraded by heat and oxygen. In aseptically packaged foods AA degradation will follow both aerobic and anaerobic pathways. During processing, degradation was most likely due to combined heat and oxygen exposure. Any air incorporated into the feed stream will accelerate the degradation rate. During storage, oxygen incorporated into the system will become dissolved oxygen in the aseptic pouch. Initially, aerobic degradation of AA will predominate. Once residual oxygen has reached equilibrium, anaerobic pathways will predominate. Heat will enhance anaerobic degradation rates and thus it is not surprising that the lowest level of AA was observed in samples stored at 37 °C.

Texture firmness

Highest peak force values for 100g drained salsa after 3 and 56 days of storage at 4 and 37 °C are illustrated in Figure 6. Highest peak force values for salsa stored for 3 and 56

days at 4 °C were not significantly ($p > 0.05$) different but were significantly ($p < 0.05$) lower for salsa stored at 37 °C. Texture degradation observed in processed fruits and vegetables during storage may be due to depolymerization of pectic substances located in the middle lamella which line parenchyma cells within the fruit tissue. Residual enzymatic activity or acid hydrolysis at high storage temperatures can cause depolymerization of pectic substances (Anthon *et al.*, 2002; DeMann, 1982). As stated previously, PG is the main endogenous texture degrading enzyme in tomatoes. It is thought that the delivered heat treatment may have reduced PG activity by at least 1.07 logs. Therefore, it is likely that residual activity was present in the samples. PG activity increases with increasing temperature. This could explain the loss of firmness observed in samples stored at 37 °C. Additionally, heat promotes the depolymerization of pectic substances (Bourne, 1983). Heating of fruits in acidic conditions causes hydrolysis of pectic substances (DeMann, 1982). With a pH of 3.7 some acid hydrolysis could have occurred during storage at 37 °C. These results suggest that salsa quality may be maintained during storage at 4°C for at least two months but may degrade during longer storage times and at elevated temperatures.

The number of peak force responses (Table 4) recorded during back extrusion compression was significantly ($p < 0.05$) lower for samples stored for 53 days at both temperatures than that for 3 days after processing. The number of peak force responses for samples stored for 53 days at both temperatures were not significantly ($p > 0.05$) different from each other. Differences in the number of peak force responses may be due to loss of turgor pressure within plant cell tissue during storage. Turgor pressure is the hydrostatic pressure within the cell and is responsible for the perceived crispness of fruits and

vegetables. As a cell is crushed, the pressure is released causing a spike in force which can be detected by the instrumentation. Loss of turgor pressure during storage is most likely a result of cell wall deterioration caused by enzymes or loss of the physiological processes which maintain turgor pressure. Thus, although stored salsa retained overall firmness for at least two months, loss of crispness, contributed by turgor pressure, occurred during storage.

Sensory

The average consumer liking scores for overall liking and liking of appearance, overall texture, tomato component texture, and flavor are shown in Table 4. Overall, the salsa product was received favorably by panelists. The average overall liking score was 7.3. Average liking scores for appearance, overall texture, tomato component texture and flavor were 7.7, 6.9, 6.7, and 7.2 respectively. Although average liking scores for overall texture and tomato component texture were lower than appearance and flavor liking scores, the difference was not significant ($p > 0.05$).

Histograms for overall liking, liking of appearance and liking of flavor are presented in Figure 7. The population distributions for these histograms were left skewed. Histograms for both overall texture and tomato component liking scores revealed bimodal distributions for the population of scores (Figure 8). These bimodal distributions suggest that consumers are partial to particular textural characteristics in salsas. 62% of panelists found that the overall texture was just about right (JAR) whereas 30% and 8% found that it was either too soft or too firm respectively. 57% of panelists found that the tomato component was JAR where as 36% and 8% found that it was either too soft or too firm respectively. Since more

than 20% of the population scored overall texture and tomato component texture in non-JAR categories, it was concluded that the salsa texture was not optimal.

To determine if non-optimal textural attributes significantly impacted panelists overall liking scores a penalty analysis was performed (Table 4, Figure 9). The penalty analysis revealed that overall liking scores for non-JAR panelists were not significantly ($p > 0.05$) affected by the non-optimal texture for either overall texture or texture of the tomato component.

Panelists were asked to rate the perceived freshness in the flavor of the salsa. The average perceived freshness score was 7.2. It is well known that thermal processing induces changes in the flavor profile of foods. Processed tomato products are described as having “browned” and “cooked” flavor characteristics (Hongsoongnern *et al.*, 2007). Hongsoongnern *et al.* (2007) demonstrated that tomato products which are processed to varying degrees have distinctly different flavor profiles. The high fresh flavor scores of this study suggests that cooked flavor notes may be minimized in this type of processing due to quick temperature come up times, short hold time and rapid cooling. Thus, a commercially sterile salsa product that is also fresh tasting may be achieved in continuous flow microwave processing followed by aseptic packaging.

Finally, panelists were asked whether or not they would purchase this product if it were available in the market. 73% of panelists stated that they would purchase the product while 21% stated that they may purchase it and 5% stated they would not purchase the product.

3.5 Conclusions

Formulated salsa received a minimum heat treatment of 91 °C for 3 min. Microbial assays performed on processed salsa indicated that commercial sterility was achieved. Although AA retention declined during storage, salsa stored at 4°C showed good texture firmness, drain weight, and °Brix retention after 56 days. Panelists perceived the salsa processed in a continuous flow microwave system favorably. Non-optimal texture attributes did not significantly impact overall liking scores. The high fresh flavor scores of this study suggests that cooked flavor notes may be minimized in this type of processing. This research has demonstrated that a fresh tasting salsa which is commercially sterile can be achieved in a continuous flow microwave system followed by aseptic packaging. In light of the numerous recent foodborne illness outbreaks involving fresh salsas, the replacement of fresh salsas with one that has been processed as described above would be a viable and safer option for consumers.

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Table 1. Salsa ingredients and manufacturer information

| Ingredient | Manufacturer/Producer information |
|---------------------------------|--|
| Fresh Roma tomatoes | Patterson Farm, Inc., China Grove, N.C., U.S.A. |
| Tomato paste | Kroger CO., Cincinnati, Ohio, U.S.A. |
| Apple cider vinegar | Harris Teeter, Mathews, N.C., U.S.A. |
| Key West lime juice | Nellie and Joe's, Key West, Fla., U.S.A. |
| Fresh Vidaila onion | North Carolina Farmer's Market, Raleigh, N.C., U.S.A. |
| Fresh Green bell pepper | North Carolina Farmer's Market, Raleigh, N.C., U.S.A. |
| Fresh Jalapeno pepper | North Carolina Farmer's Market, Raleigh, N.C., U.S.A. |
| Chopped garlic | Harris Teeter, Mathews, N.C., U.S.A. Simply Organic, Frontier Natural Products CO-OP, Norway, Iowa, U.S.A. |
| Dried cilantro | |
| Dried parsley | McCormick & Co., Inc., Hunt Valley, Md., U.S.A. |
| Coarse Kosher salt | Morton International, Inc., Chicago Ill., U.S.A.) |
| Granulated sugar | Food Lion LLC, Salisbury, N.C., U.S.A. |
| Onion powder | Food Lion LLC, Salisbury, N.C., U.S.A. |
| Garlic powder | Food Lion LLC, Salisbury, N.C., U.S.A. |
| Ground cumin | McCormick & Co., Inc., Hunt Valley, Md., U.S.A. |
| Chipolte chili powder | McCormick & Co., Inc., Hunt Valley, Md., U.S.A. |
| Cayene pepper | McCormick & Co., Inc., Hunt Valley, Md., U.S.A. |
| FCC-grade anhydrous citric acid | Duda Diesel LLC, Madison, Ala., U.S.A. |

Table 2. pH, °Brix and Drain weight of Salsa after 3 and 56 days of storage at 4 and 37 °C

| Time (days) | Temperature (°C) | pH | °Brix | Drained Wt. (g) |
|--------------------|-------------------------|-------------|--------------|------------------------|
| 3 | 4 | 3.73 ± 0.03 | 8.20 ± 0.01 | 77% |
| 56 | 4 | 3.76 ± 0.04 | 8.25 ± 0.05 | 77% |
| | 37 | 3.76 ± 0.03 | 8.18 ± 0.27 | 76 % |

Table 3. AA retention in salsa after 3 and 56 days of storage at 4 and 37 °C

| Time (days) | Storage Temperature (°C) | Fresh Salsa (mg/100g fw) | Processed Salsa (mg/100g fw) | Vitamin C Retention |
|--------------------|---------------------------------|---------------------------------|-------------------------------------|----------------------------|
| 3 | 4 | 0.19 ± 0.009 | 0.14 ± 0.003 | 72% |
| 56 | 4 | - | 0.13 ± 0.009 | 66% |
| | 37 | - | 0.09 ± 0.005 | 50% |

Table 4. Highest peak force and number of peak force responses in salsa after 3 and 56 days of storage at 4 and 37 °C

| Time (weeks) | Storage Temperature (°C) | Highest Peak Force (N/100g) | Number of Peaks |
|---------------------|---------------------------------|------------------------------------|------------------------|
| 3 | 4 | 89.59 ± 5.09 | 70.67 ± 4.60 |
| 56 | 4 | 88.37 ± 11.62 | 55.5 ± 4.57 |
| | 37 | 60.26 ± 4.52 | 58.00 ± 4.45 |

Table 5. Average Consumer Liking Scores for Overall Liking and Liking of Appearance, Overall Texture, Tomato Component Texture, and Flavor

| | Overall Liking | Appearance | Texture | Tomato Component Liking | Flavor |
|-----------|----------------|----------------|----------------|-------------------------|----------------|
| | | Overall Liking | Overall Liking | | Overall Liking |
| Mean | 7.3 | 7.7 | 6.9 | 6.7 | 7.2 |
| <i>SD</i> | 1.2 | 1.2 | 1.5 | 1.8 | 1.7 |

Table 6. Mean Consumer Overall Liking Score, Percent Response and Penalty for JAR and non-JAR scores for Texture

| JAR Category | Overall Texture | | | | Tomato Component | | | |
|--------------|-----------------|------|------------|---------|------------------|------|------------|---------|
| | MEAN | SD | % Response | Penalty | MEAN | SD | % Response | Penalty |
| > JAR | 6.78 | 1.57 | 30.26 | -0.69 | 6.96 | 1.63 | 35.53 | -0.56 |
| JAR | 7.47 | 0.97 | 61.84 | | 7.52 | 0.97 | 56.58 | |
| < JAR | 8.00 | 1.26 | 7.89 | 0.53 | 7.50 | 0.55 | 7.89 | -0.02 |

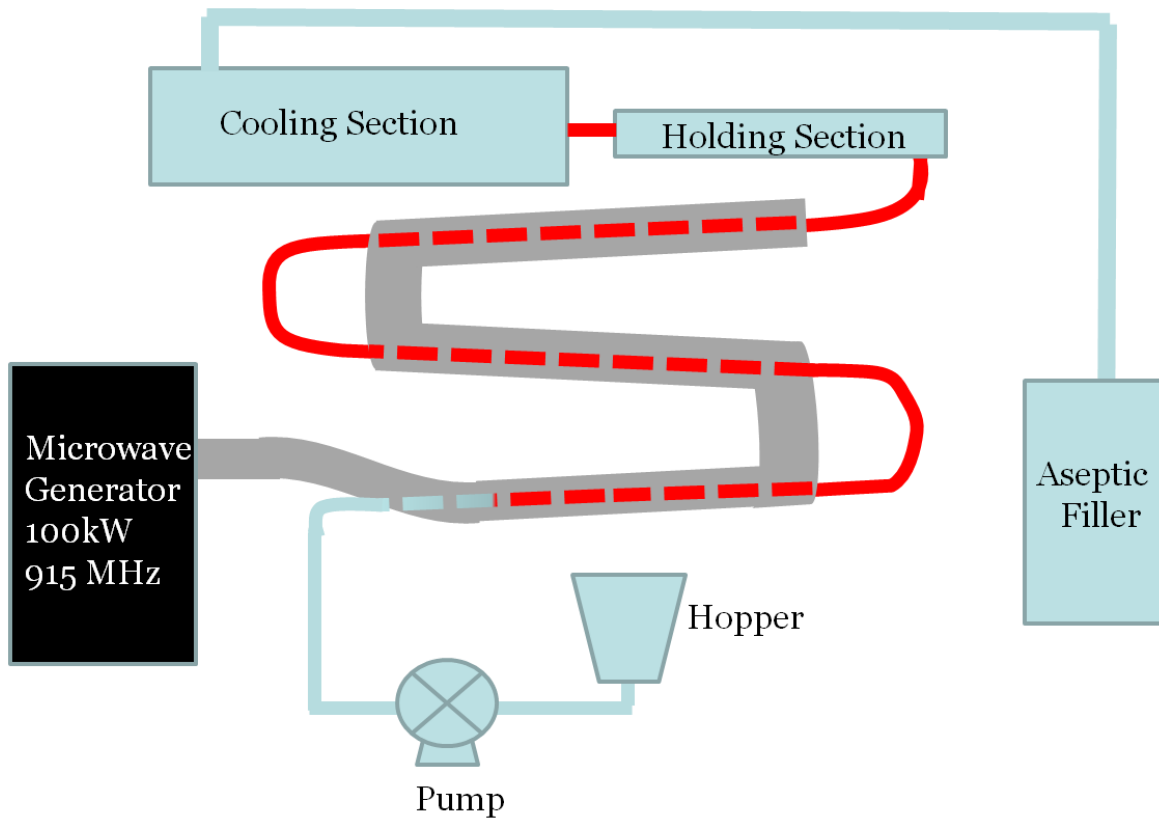


Figure 1. Schematic diagram of the continuous flow microwave system

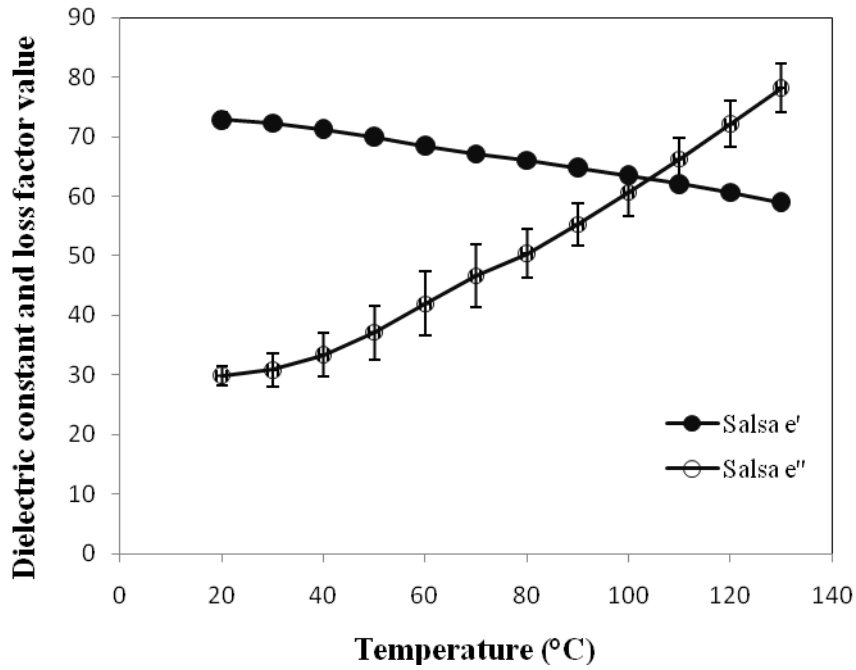


Figure 2. Dielectric constant and loss factor as a function of temperature for salsa.

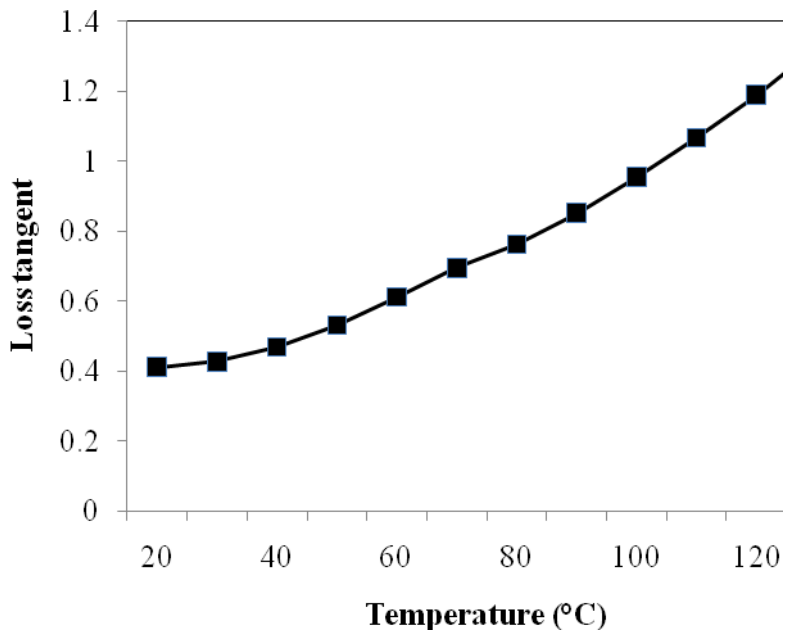


Figure 3. Loss tangent as a function of temperature for salsa.

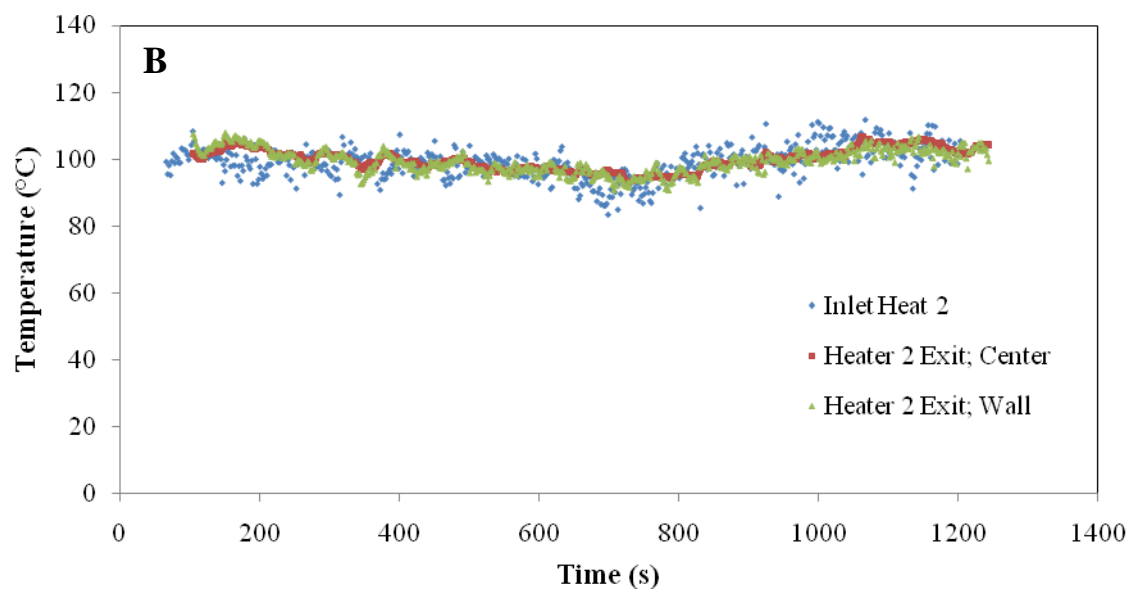
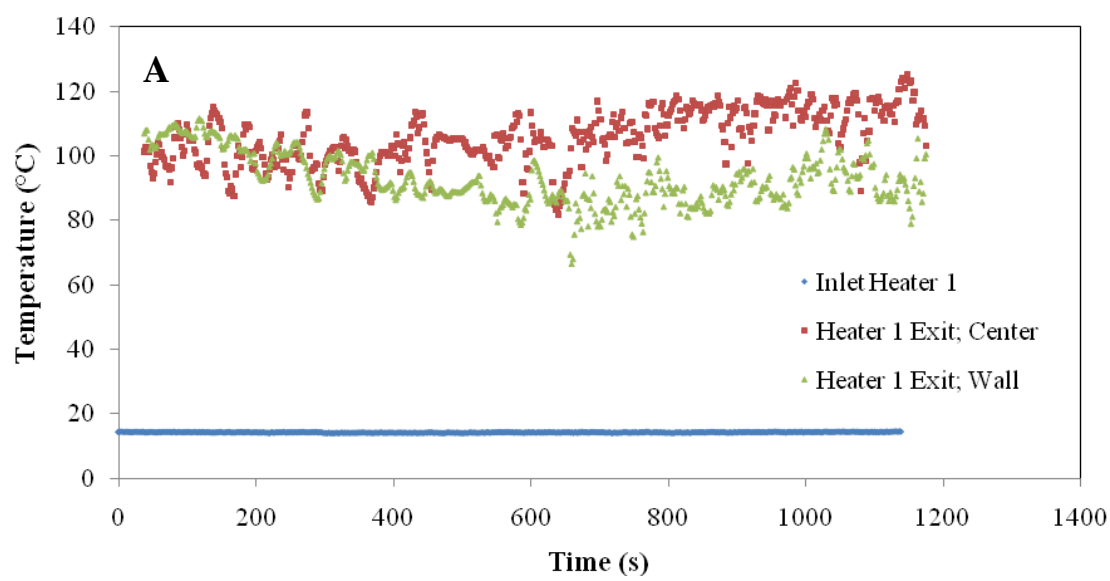


Figure 4. Typical time temperature history for inlet and exit streams of the first (A), second (B) heating sections

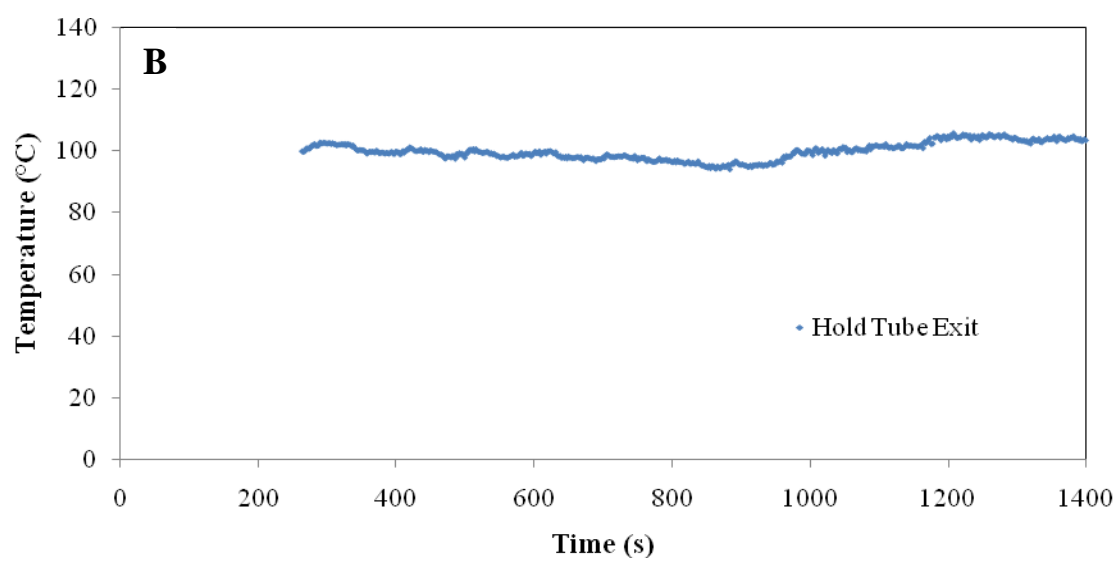
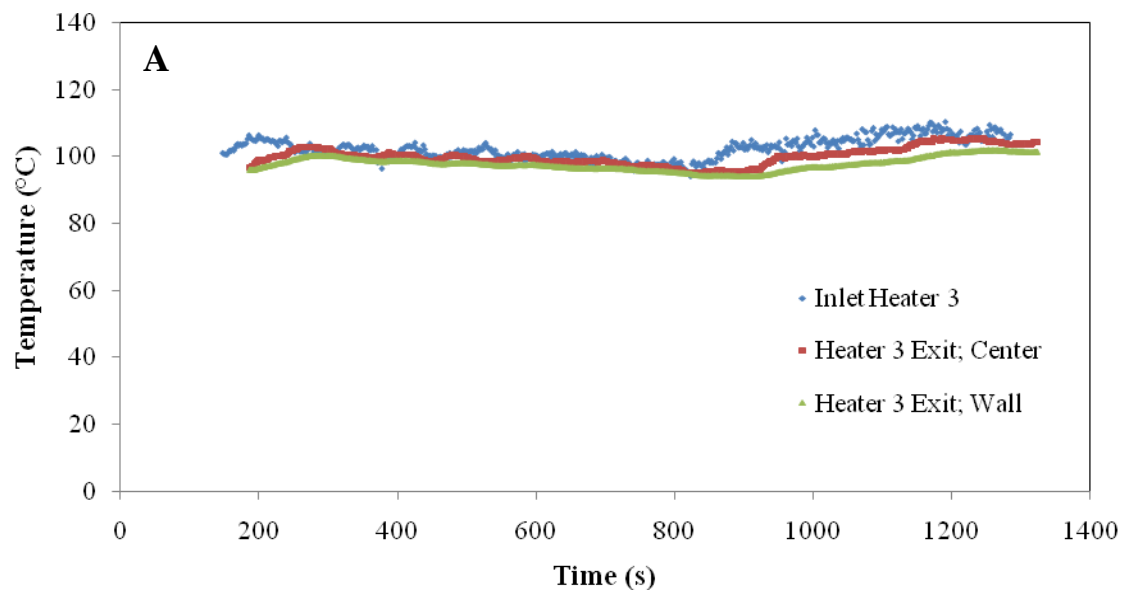


Figure 5. Typical time temperature history for inlet and exit streams of the third heating section (A) and the hold tube exit (B)

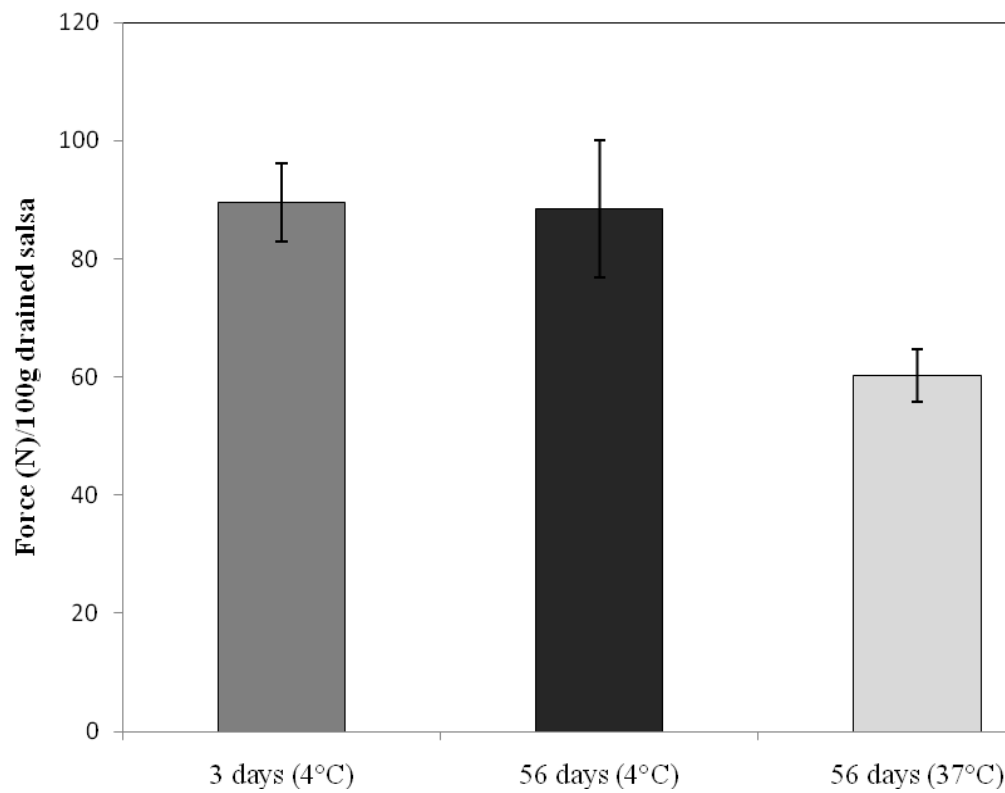


Figure 6. Highest peak force of 100g drained salsa after 3 and 56 days of storage at 4 and 37 °C

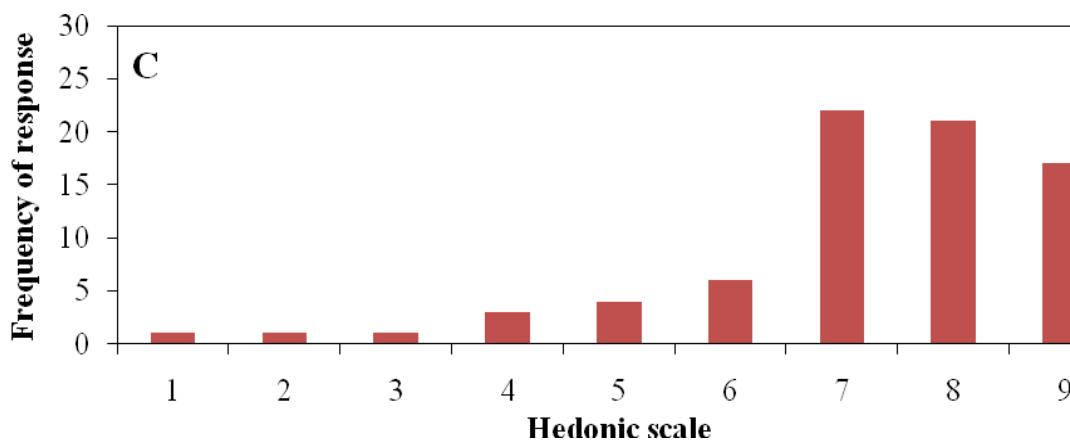
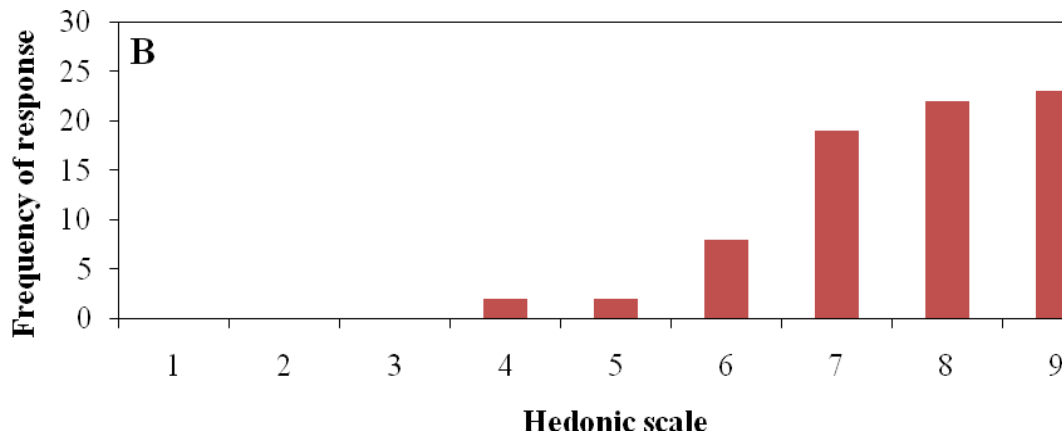
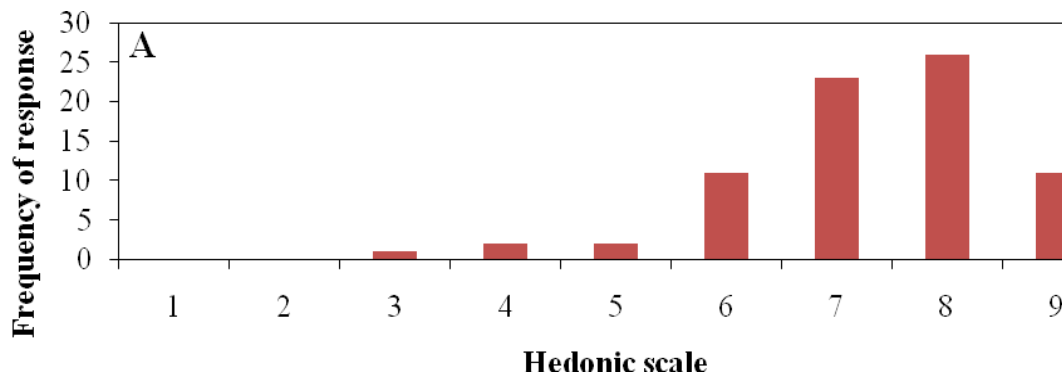


Figure 7. Histogram for consumer Overall liking (A), Liking of Overall Appearance (B), Liking of Flavor (C)

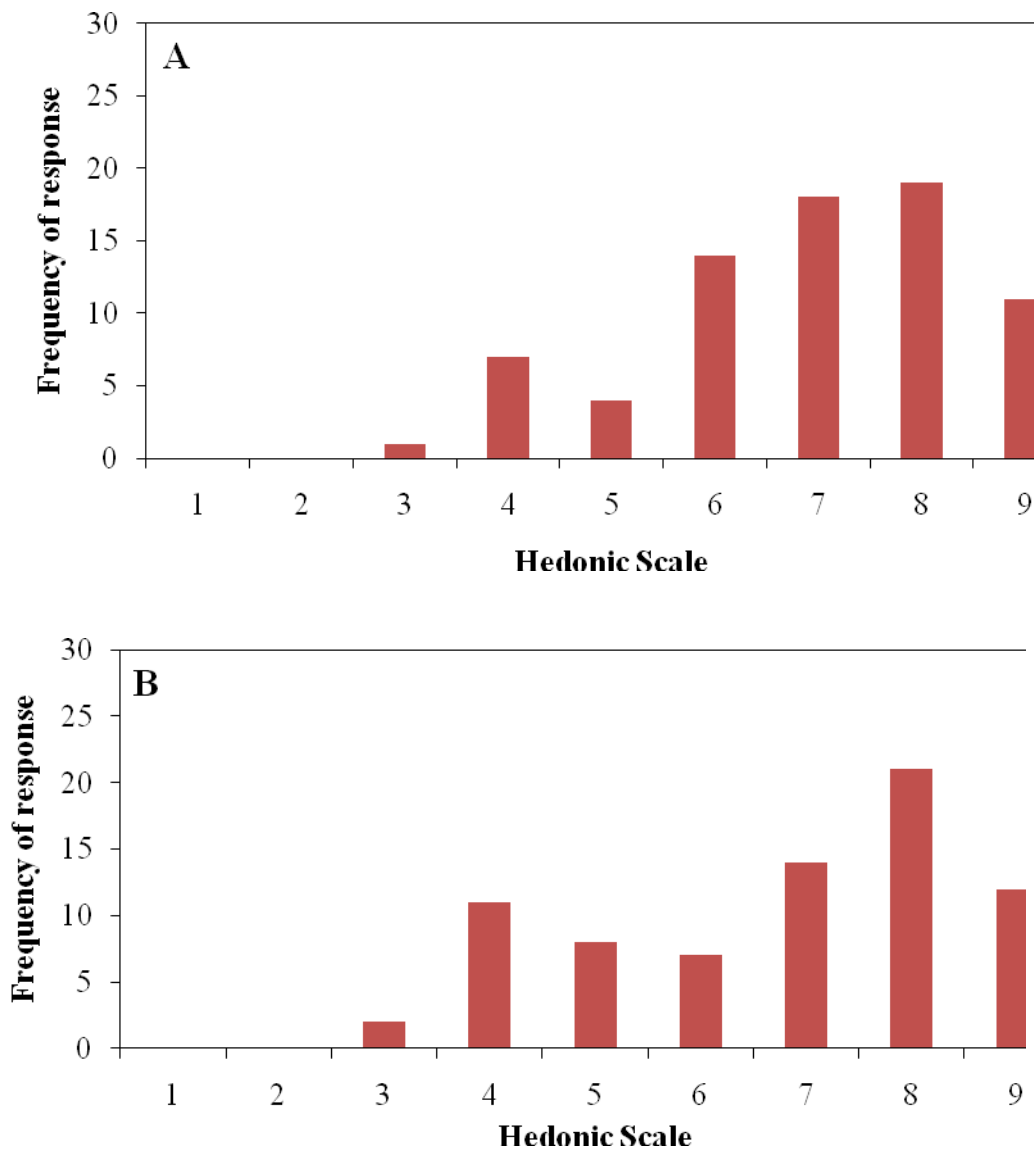


Figure 8. Histogram for consumer liking of overall texture (A) and liking of tomato component texture (B)

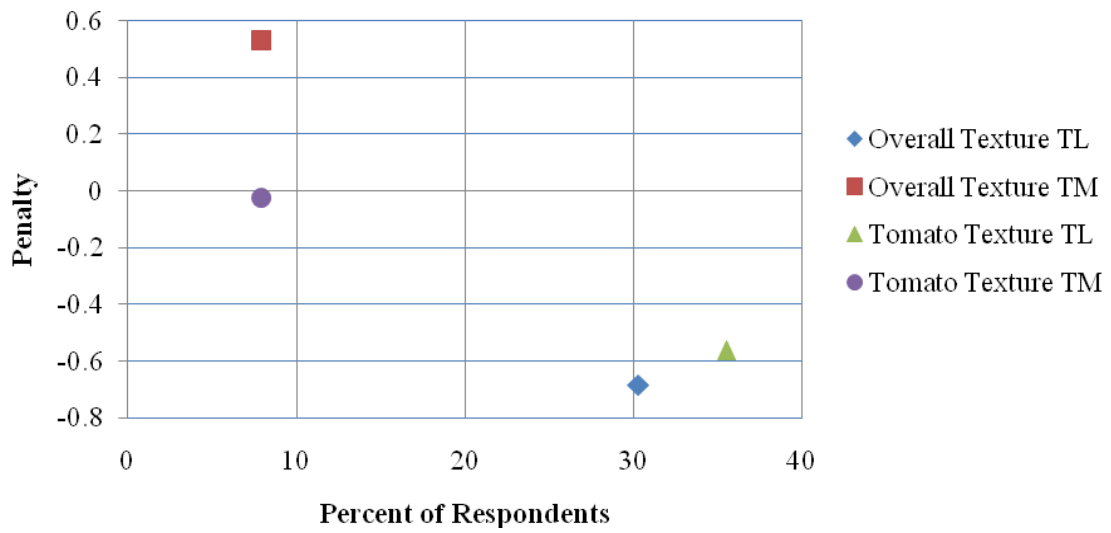


Figure 9. Penalty analysis on overall liking scores for non-JAR texture