FLAVOR, VISCOSITY, AND COLOR ANALYSES OF HOT AND
COLD BREAK TOMATO JUICES

A Thesis

Presented in Partial Fulfillment of the Requirements for
the Degree of Master of Science in the
Graduate School of The Ohio State University

By

Carrie Lynne Goodman, B.S.

The Ohio State University
2000

Master's Examination Committee:

Dr. Sheryl Barringer, Adviser

Dr. Grady Chism

Dr. David Min

Approved by

A handwritten signature in cursive script that reads "Sheryl Barringer". The signature is written in black ink and is positioned above the printed name and title.

Adviser
Department of Food Science
and Nutrition

ABSTRACT

Two methods are used commercially to produce tomato juice: hot break and cold break. "Hot" typically refers to a chopping temperature of 85-90°C which causes inactivation of enzymes important to flavor and viscosity. Pectinmethylesterase and polygalacturonase break down pectin in tomato tissue. By inactivating these enzymes in the hot break process, a more viscous product can be achieved. Conversely, lipoxygenase initiates the creation of important flavor compounds, and when it is inactivated in the hot break, the product lacks flavor. "Cold" refers to a temperature below 70°C to increase enzyme activity. This is an advantage for flavor, but a disadvantage for viscosity. The objective of this study is to compare the consumer preference, flavor volatiles, color, and viscosity of hot and cold break tomato juice. Fifty pound (22.68 kg) batches of tomatoes were chopped and allowed to sit for various time intervals to simulate the cold break process. This allowed enzyme activity before inactivation in the tubular heat exchanger at 93°C. Zero minutes was the hot break process, and 2-24 min were the cold break process. The sensory evaluation of freshness and overall liking was conducted with a panel of 78 consumers. Solid phase

microextraction and gas chromatography were used to identify volatile flavor compounds in tomato products. The Hunter Colorimeter was used for color analysis, and a buret method was used for viscosity. Consumer preference, volatile analysis, color, and viscosity were conducted in order to determine which time interval would produce the optimum tomato juice product. The sensory panel rated hot break significantly less fresh and liked it significantly less than the 7 and 15 min cold break while a 17 min holding time was too long and produced paint off-flavors. Hexanal concentration increased significantly from hot break (0 min) to 24 min. Total lipoxygenase-initiated volatiles (hexanal, cis-3-hexenal, trans-2-hexenal, and cis-3-hexenol) increased from hot break to cold break which is a function of holding time. There was a significantly higher amount of total lipoxygenase-initiated volatiles in juice than in retorted juice, sauce, or retorted sauce. No overall difference in color was found between time intervals. Hot break was significantly more viscous than the cold break. The cold break process can be used to produce a premium flavored tomato juice product.

Dedicated to my mother for her love and support
as we took this journey together and to my grandfather who was
our inspiration every step of the way.

ACKNOWLEDGMENTS

I wish to express sincere appreciation to my adviser, Dr. Sheryl Barringer, for offering me the opportunity to work with her and tomatoes. Her advice and hands-on guidance were unmatched as I made my way through this unforgettable experience.

I thank Dr. Mike Mangino for taking me into his lab when I came up with this grad school idea. Without him, this thesis may not have been possible. I am grateful to Drs. Chism and Min for their expert suggestions and feedback while on my committee. Special thanks go to Dr. David Francis for supplying the tomatoes and to Dr. Winston Bash and Gary Wenneker for their assistance in the tomato processing. Thanks to Dr. Jim Harper for the use of his gas chromatograph and to Susan Fawcett for conducting the trained sensory panel on my tomato juice.

I sincerely thank Josh for his support and for putting up with me during this. Without his understanding, my tough times would have been a lot tougher.

Some say you meet your lifetime friends while in college. I am grateful to the ones I met, Courtney and Peggy, for keeping me sane as we went through

this together. And, thanks to Julie and Dave for being my friends and keeping laughing when I needed it most.

Thanks to Dad, Nancy, Nick, and Megan for their love, the weekly laughs, and the visits that reminded me that some of the best parts of life are the good times with your family.

I am grateful to John for his support and for being there for my mom. Finally, I would like to thank all of my family and friends who, whether they realize it or not, have each helped me along the way.

VITA

September 28, 1976

Born – Chillicothe, Ohio

1998

B.S. Food Science, The Ohio State University

1998 – present

Graduate Teaching and Research Associate,
The Ohio State University

FIELDS OF STUDY

Major Field: Food Science and Nutrition

TABLE OF CONTENTS

	<u>Page</u>
Abstract	ii
Acknowledgments	v
Vita	vii
List of Tables	xi
List of Figures	xiii
Chapters:	
1. Introduction.....	1
2. Literature Review	3
2.1 Tomato Juice	3
2.2 Break Temperature	4
2.3 Color	5
2.4 Viscosity	10
2.4.1 Definitions	11
2.4.2 Viscometers Used for Tomato Juice	12
2.4.3 Factors Affecting Viscosity of Tomato Products	14
2.4.4 Pectic Enzymes	18

2.5 Sensory Evaluation	21
2.5.1 Sensory Attributes.....	24
2.4.2 Types of Sensory Tests	25
2.4.3 Sensory Tests Used in This Study.....	27
2.4.4 Sensory Evaluation of Tomato Products.....	28
2.4.5 Statistical Definitions	29
2.4.6 Statistical Analysis of Sensory Evaluation	30
2.6 Volatile Flavor Analysis	31
2.6.1 Important Tomato Flavor Compounds	32
2.6.2 Solid Phase Microextraction (SPME).....	39
2.6.3 SPME on Tomato Products.....	44
3. Materials and Methods	45
3.1 Tomatoes	45
3.2 Small-Scale Hot Break	45
3.3 Small-Scale Cold Break	46
3.4 Procedure for Large Scale Study.....	46
3.5 Sauce Samples.....	47
3.6 Canning and Retorting.....	48
3.7 Sensory Evaluation	48
3.8 SPME/GC	49
3.9 Compound Identification.....	51

3.10 Viscosity	52
3.11 Color	53
3.12 Color Triangle Test	53
3.13 Statistical Significance.....	54
4. Results and Discussion	55
4.1 Sensory Evaluation	55
4.2 Volatile Flavor Analysis	59
4.3 Viscosity	68
4.4 Color	69
4.5 Color Triangle Test.....	71
4.6 Overall Implications.....	74
List of References	75
APPENDIX A: Sensory Evaluation Sheet.....	84
APPENDIX B: Color Triangle Test Evaluation Sheet.....	88
APPENDIX C: Triangle Test for Difference Table.....	90
APPENDIX D: Statistical Analyses	92
APPENDIX E: Chromatograms.....	101

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 Synthetic mixture that closely matches the aroma of sliced, fresh ripe tomato (Buttery 1993)	33
2.2 Synthetic mixture that closely matches the aroma of tomato paste (Buttery 1993)	37
2.3 Available SPME fiber coatings (Shirey 1998)	42
4.1 Consumer rating of tomato juice samples held for 0-17 min before enzyme inactivation	56
4.2 Color triangle test data	72
4.3 <i>L</i> , <i>a</i> , and <i>b</i> values for the two juice samples closest in hue angle to the sample with hue angle 22.08°	74
D.1 Single factor ANOVA of the consumer panel's rating of overall liking (Heinz 9423 tomato juice)	93
D.2 Single factor ANOVA of the consumer panel's rating of freshness (Heinz 9423 tomato juice)	94
D.3 Single factor ANOVA of hexanal concentration for various hold times (Heinz 9423 tomato juice)	95
D.4 Single factor ANOVA of hexanal concentration for various hold times (Ohio 8245 tomato juice)	96
D.5 Single factor ANOVA of trans-2-hexenal concentration for various hold times (Ohio 8245 tomato juice)	97

D.6	Single factor ANOVA of hexanal concentration throughout processing (Heinz 9423 tomato juice)	98
D.7	Single factor ANOVA of trans-2-hexenal concentration throughout processing (Heinz 9423 tomato juice)	98
D.8	Single factor ANOVA comparing viscosity of cold break hold times between cultivars	99
D.9	T-test assuming equal variances comparing hot and cold break tomato juice viscosity	99
D.10	Single factor ANOVA comparing color data of various tomato cultivars	100

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
2.1	Chemical structures of lycopene and β -carotene 7
2.2	The most prevalent monomeric unit of a high-methoxyl pectin (BeMiller and Whistler 1996) 19
2.3	The demethylation reaction catalyzed by pectinmethylesterase (Sajjaanantakul and Pitiifer 1991) 20
2.4	Polygalacturonase hydrolyzes the α -1,4-glycosidic bond between the anhydrogalacturonic acid units (Whitaker 1996) 21
2.5	Summary of proposed pathways for the formation of C-6 and C-9 aldehydes and alcohols from plant lipids (Galliard and others 1977) 34
2.6	Schematic drawing of SPME fiber assembly (Shirey 1998) 40
2.7	Schematic drawing of SPME fiber holders (Shirey 1998) 41
2.8	Schematic of Carboxen/PDMS-coated fiber (Shirey and others 1999) 43
4.1	Peak in tomato leaf aroma, paint aroma, and paint flavor as detected by the train sensory panel (Heinz 9423 tomato juice) (Fawcett 1999) 58
4.2	Concentrations of hexanal, cis-3-hexenal, and trans-2-hexenal for various hold times (Heinz 9423 tomato juice) 60
4.3	Hexanal concentration for various hold times (Ohio 8245 tomato juice) 61

4.4	Cis-3-hexenal and trans-2-hexenal concentrations for various hold times (Ohio 8245 tomato juice)	62
4.5	Effect of processing on hexanal concentration (Heinz 9423 tomato juice)	64
4.6	Effect of processing on trans-2-hexenal concentration (Heinz 9423 tomato juice)	65
4.7	Effect of processing on total lipoxygenase-initiated volatiles: hexanal, cis-3-hexenal, trans-2-hexenal, and cis-3-hexenol (Heinz 9423 tomato juice)	66
4.8	Decrease in viscosity of tomato juice with longer hold times	69
4.9	Color of hot and cold break tomato juice	71
E.1	Tomato juice with saturated calcium chloride added after 3 min hold time	102
E.2	Tomato juice with saturated calcium chloride added after 25 Min hold time	103
E.3	Hot break tomato juice (Heinz 9423)	104
E.4	Hot break retorted tomato juice (Heinz 9423)	105
E.5	Hot break tomato sauce (Heinz 9423)	106
E.6	Hot break retorted tomato sauce (Heinz 9423)	107
E.7	24 min hold time tomato juice (Heinz 9423)	108

CHAPTER 1

INTRODUCTION

Two methods are used commercially to produce tomato juice: hot break and cold break. "Hot" typically refers to a chopping temperature of 85-90°C which causes inactivation of enzymes important to flavor and viscosity.

Pectinmethylesterase and polygalacturonase break down chains of pectin in tomato tissue. By inactivating these enzymes in the hot break process, a more viscous product can be achieved (Bel-Haj 1981; Fito and others 1983), which is usually desirable. Conversely, lipoxygenase is the initiating enzyme involved in the creation of important fresh flavor compounds through the breakdown of unsaturated fatty acids, and when it is inactivated in the hot break, the product lacks flavor.

"Cold" refers to a temperature below 70°C to increase enzyme activity. A characteristic of the cold break process is a decrease in viscosity. Advantages of cold breaking over hot breaking are that the final product is said to have a more natural color and a fresher flavor (Gould 1992), but in contrast, Fonseca and Luh (1976) found that aroma and flavor were rated better for tomato juice preheated

at a higher temperature. The hot break method is used to produce the majority of tomato products to maintain a high viscosity. However, an increase in the use of the cold break method should produce tomato products with a fresher flavor.

Fresh tomato flavor can be closely duplicated with just ten compounds (Buttery 1993): cis-3-hexenal, trans-2-hexenal, cis-3-hexenol, 6-methyl-5-hepten-2-one, hexanal, methyl salicylate, 3-methylbutanal, 2-isobutylthiazole, β -ionone, 1-penten-3-one. The majority of this fresh flavor is generated by enzyme activity, and the hot break process causes enzyme inactivation that prevents flavor production.

Lipoxygenase contributes significantly to characteristic tomato flavor and is inactivated by the hot break method. The C6 aldehydes produced by the lipoxygenase breakdown of fatty acids (hexanal, cis-3-hexenal, trans-2-hexenal, hexanol, cis-3-hexenol, and trans-2-hexenol) are typically associated with a "fresh" or "green" note in tomato flavor (Galliard and others 1977). Since cold break speeds enzyme activity, it should produce a premium flavor juice that consumers will prefer to hot break juice. This study evaluates consumer preference of hot and cold break tomato juice made from two different tomato cultivars, and uses a volatile flavor analysis to explain these results. In addition, this work compares color and viscosity of hot and cold break juice made from four cultivars.

CHAPTER 2

LITERATURE REVIEW

2.1 Tomato Juice

The tomato (*Lycopersicon esculentum*) is the world's second largest vegetable crop with production over 70 million tons in 1993 (Hayes and others 1998). Tomatoes may be consumed fresh or as processed products such as tomato juice that can be concentrated to sauce and paste. According to Hayes and others (1998), tomato juice refers to the juice from whole crushed tomatoes from which the skins and seeds have been removed and which has been subject to fine screening, and is intended for consumption without dilution or concentration. The major quality parameters for tomato products, including juice, are color, viscosity, and flavor (Hayes and others 1998).

2.2 Break Temperature

The two methods used commercially to produce tomato juice are hot break and cold break. "Hot" typically refers to a chopping temperature of 85-90°C which causes inactivation of enzymes important to viscosity and flavor. "Cold" refers to a temperature below 70°C to increase enzyme activity. Moresi and Liverotti (1982) describe the breaking process as chopped tomatoes being pumped through a heat exchanger that has been preheated to the desired temperature (depending on hot or cold break). A hot break juice typically has a higher consistency due to the retention of pectin while cold break has a lower viscosity because pectic enzymes (pectin methylesterase and polygalacturonase) remain active and break down pectin (Luh and Daoud 1970; Shomer and others 1984). Flavor is also affected by these processing techniques. Lipooxygenase is an enzyme in the tomato that aids in the generation of flavor compounds from fatty acids and remains active longer in the cold break process. Hot break inactivates this enzyme early and therefore lacks fresh tomato flavor. Gould (1992) stated that the advantages to hot break are a greater yield and a more viscous product that does not separate upon standing. According to Hayes and others (1998), the advantages of cold breaking over hot breaking are as follows:

- The juice is less likely to foul heat exchangers and evaporators due to the lower gross viscosity.

- The juice is easier to pump due to a low serum viscosity.
- Higher final concentrations of tomato paste are possible.
- The final product has more natural color and a fresher tomato flavor.

The breaking process is usually varied to fit the intended use of the tomato product. For instance, with tomato paste, if the final paste should have a high viscosity for use in pizza sauce or ketchup, a hot break process is used. A cold break treatment might be selected for a paste to be diluted for tomato juice and vegetable beverages (Morris 1991).

2.3 Color

The human eye consists of focusing and sensitive elements. The focusing elements are the cornea, pupil, lens, and the vitreous humor while rods and cones are sensitive. Rods are affected by small amounts of light thus being responsible for the ability to see by moonlight and starlight. Cones provide day vision and perception of colors. Found mostly in the center of the retina, cones are directly connected to the brain where images are received and interpreted. Color perception of tomato products by the human eye has some limitations including the eye's inability to determine small color differences in a nonhomogeneous surface and eye fatigue. However, subjective color determination by the human eye can provide meaningful results. (Gould 1992)

Consumers look for tomato products to be of a good, bright red color and free from black specks, insects, or other foreign matter (Ranken and Kill 1993). The red color of the tomato forms during ripening when chlorophyll is destroyed and lycopene and other carotenoids are synthesized (Yang 1986). The pigments of major importance to overall tomato color are: alpha-carotene, beta-carotene, gamma-carotene, delta-carotene, lycopene, and 22 xanthophylls (Gould 1992) (Fig 2.1). These carotenoids occur naturally in small globules suspended in the tomato pulp. In addition, differences in carotene content have been correlated with differences in tomato variety (Ellis and Hammer 1943). Lycopene makes up about 83% of the total pigment present in tomatoes and is subject to degradation during processing (Hayes and others 1998).

temperature increases. The formation of brown pigments due to Maillard reactions can occur in processed tomato products and depends on the amount of sugar and amino acids present along with pH and the time and temperature of processing (Thakur and others 1995). In addition, color loss in tomato juice is accelerated by high temperature storage (Gould 1978).

Specific varieties and maturities of tomatoes have been shown to affect the color relationship of the raw product to the finished product in the manufacture of tomato juice (Davis and Gould 1955). Increasing the size of the screen openings of the juice finisher increases color retention. Reducing heat sterilization treatments by lowering pH would also reduce color loss in tomato juice, but may adversely affect the flavor quality (Kattan and others 1956).

According to Hayes and others (1998), there are four main color measurement methods: The Munsell Spinning Disk Colorimeter, tristimulus color meters, reflectance spectrophotometers, and the Lovibond Tintometer. The Munsell Spinning Disk Colorimeter and the Lovibond Tintometer are subjective methods using the human eye. The tristimulus color meters and reflectance spectrophotometers are objective (Gould 1983; Goose and Binstead 1973). There are a number of problems with using the human eye to evaluate color as it can fatigue quickly. Therefore, a tristimulus color meter may be used to imitate the human eye's response to color. The Hunter and Gardner instruments are tristimulus color meters. The principle of these color meters is that a

standard light source is shone at an angle of 45° onto the sample and the light reflected perpendicular to the sample is split into three beams. Each beam is passed through a red, green, or blue glass filter and measured by a specific photocell. Before use the color meter is calibrated against standard black, gray, and white tiles (Hayes and others 1998). The Hunter and Gardner instruments generate L , a , and b values.

- L is the visual lightness of the sample on a scale of 0 to 100 (0 = perfect black, 100 = perfect white, 50 = medium gray).
- a is the redness/greenness of the sample. Positive values are red, negative values are green, and zero is gray.
- b is the yellowness/blueness of the sample. Positive values are yellow, negative values are blue, and zero is gray.

The a and b values coincide with the red-yellow ratio, indicating the color of redness of tomatoes (Bontovits 1981) making the a/b ratio a common color measurement. There are different classes of tomato products based on this ratio (Bontovits 1981):

- Class I tomato pastes, juice, sauce, *etc.*, have a/b values of 2.0 or above.
- Class II tomato pastes have 1.8-1.99 a/b ratio.
- Class III tomato products have 1.60-1.79 a/b values.
- Between 2.2-2.4 a/b ratio were classed as extra

- Between 2.4-2.6 a/b ratio as super extra

The hue angle has replaced the a/b ratio as the most common way to report tomato color results. A more suitable measure of color can be obtained by the calculation of hue angle (McGuire 1992). The hue angle is defined as the angle between the hypotenuse and the a-axis (x-axis). It is calculated from the arctangent of $b/a \times 57.3$ (degrees). The color of the fruit may be interpreted from the hue angle as follows (McGuire 1992):

- 0° = red-purple
- 90° = yellow
- 180° = bluish green
- 270° = blue

The USDA has Quality Grade Standards for tomato juice where Grade A is 26-30 points, Grade C is 23-25 points, and Grade D is 0-22 points (Gould 1993).

2.4 Viscosity

According to Gould (1992), viscosity is a measure of the resistance offered by a fluid to relative motion of its parts or the ratio of resistance to shear to rate of shear. Viscosity or consistency is one of the most important factors to be considered in determining the overall quality and acceptability of many tomato products (Thakur and others 1995; Gould 1992). Organoleptic qualities of tomato juice, puree, and paste depend on their low consistency, and products

with low consistency may be sold at lower prices or even graded unacceptable (Thakur and others 1995). Consumers may view viscosity as cohesiveness, smoothness, or the degree of gelling and firmness and probably evaluate consistency of tomato products second only to color (Gould 1992).

The consistency of tomato juice follows Grade A and Grade C standards. Grade A juice “flows readily and has a normal amount of insoluble tomato solids in suspension with little tendency to settle out,” and Grade C juice “flows readily and has a normal amount of insoluble tomato solids in suspension with no marked tendency to settle out” (Gould 1993). The USDA has no guidelines for the consistency of tomato paste or puree in the Quality Grade Standards; however, standards have been established for the measurement of the consistency of ketchup and tomato sauce using a Bostwick Consistometer (Hayes and others 1998).

2.4.1 Definitions

Newtonian Liquid

A liquid in which resistance to shear is directly proportional to rate of shear. An example is water (Gould 1992).

Non-Newtonian Liquid

A liquid in which resistance to shear is not linearly related to rate of shear. Examples include ketchup and cream style corn (Gould 1992).

Gross Viscosity

This term refers to the viscosity of whole tomato juice (Hand and others 1955).

Serum Viscosity

This is defined as the tomato juice freed of suspended particles (Hand and others 1955).

Apparent Viscosity

This is a measure of the viscosity that must be related to a particular rate of shear for non-Newtonian substances (Gould 1992).

Shear Stress

This is the stress applied tangential to the plane along which the force acts. It is expressed as force per unit area.

Shear Rate

This term refers to the velocity gradient established in a fluid as a result of applied stress. It is expressed as reciprocal second.

2.4.2 Viscometers Used for Tomato Juice**Efflux Tube or GOSUC Consistometer**

This viscometer consists of a blown glass reservoir sloped into a 2-mm orifice on the efflux and a $\frac{3}{4}$ - inch orifice at the top, which allows pouring the sample into the reservoir through a funnel or filling the reservoir vacuum. A

piece of rubber tubing is attached to a metal plug with a 2-mm precision-bore orifice. This allows flow to be stopped by a pinch clamp. The time is recorded in seconds it takes a volume of tomato juice to go through the tube. (Gould 1992)

USDA Viscometer

This is a four-part assembly of a funnel, a rubber hose, a pinchcock to stop juice flow, and a metal precision tube at the end of the rubber hose. This apparatus is attached to a ring stand, and the time it takes in seconds for 200 mL of tomato juice to go through the funnel is recorded. Standardization is done by adjustment of the rubber tubing or orifice.

Capillary Viscometer

The cup of this viscometer is a Lucite tube with a Lucite plug on the bottom that is sloped at an angle to the opening. A Pyrex tube is inserted into the opening. The glass tube is vertically enclosed in a chrome-plated brass tube having a sleeve of Tygon between the glass and outer brass covering. A stopwatch is used to time (in seconds) the efflux of sample to a standardized mark. (Gould 1992)

Stormer Viscometer

Consistency is measured by recording the time required for a definite number of revolutions of a rotating cylinder immersed in a sample placed in a test cup. The temperature of the sample is maintained by keeping it in a water

or oil bath (Gould 1992). Kluter (1959) found problems with this when measuring tomato juice as a certain weight is required to drive the rotor.

Others

The Brookfield Viscometer and Gardner Mobilometer could be used to measure tomato juice viscosity; however, they are best used on more viscous materials than tomato juice (Gould 1992).

2.4.3 Factors Affecting Viscosity of Tomato Products

According to Hayes and others (1998), there are five main factors affecting the consistency of tomato products:

1. Compositional differences between cultivars
2. Compositional variation of a cultivar at different stages of maturity
3. The total solids content and insoluble solids content
4. The particle size distribution and particle shape of the insoluble material
5. The break temperature

According to Xu and others (1986), the different characteristics of tomato varieties have a significant influence on the viscosity of tomato products. One of the most important factors affecting viscosity of unconcentrated tomato juice or pulp is the cultivar used (Gould 1978). The type and range of solids found in the tomato vary with variety/cultivar, maturity of the tomato at harvest, areas of production, and/or cultural conditions and practices during production such as,

irrigation and/or water stress (Gould 1992). According to Hayes and others (1998), it takes about 12 days for tomatoes to ripen. During this time protopectin is converted to soluble pectin by the enzyme protopectinase, and the pectin binds the cells together less firmly. If tomatoes are allowed to grow past maturity, the pectin itself is broken down into soluble compounds by the pectic enzymes polygalacturonase (PG) and pectin methylesterase (PME), and the fruit becomes soft and mushy (Gould 1983).

Total solids and water make up the composition of the tomato, and portions of the water and total solids are removed during concentration. Some concentrated tomato products are made with solids in excess of 40% or 40° Brix. These solids are often diluted to give juice or sauce (Gould 1992). Total solids test is the best way to measure tomato quality; however, this test is time consuming and is typically not used in industry. Other components of the total solids are measured instead, such as degree Brix (Gould 1992). A refractometer gives the reading in degree Brix which is soluble solids in the tomato. The refractometer measures the speed of light passing through a substance compared to the speed of light passing through air (Gould 1992).

According to Kertesz (1951), the consistency of tomato juice depends on two major factors: (1) the quantity, average size, and size distribution of the suspended particles; and (2) the viscosity of the serum. In addition, Tanglertpaibul and Rao (1987) stated that particle size distribution is a major

contributor to the viscosity of tomato juice. Xu and others (1986) said that rheological behavior is affected by particle size distribution. The quantity, configuration, and characteristics of the suspended particles influence the viscosity of the product (Hand and others 1955; Robinson and others 1956; Luh and others 1954). It is widely recognized that elongated particles have a greater effect on viscosity than do spherical particles (Hand and others 1955). The average size and size distribution of the suspended particles partly determine whether, upon standing, the tomato juice shows any serum separation (Kertesz 1951). Particles in the suspended tissue tend to increase their water-holding capacity as their size is reduced from 20 mesh to about 100 mesh in the hydrated condition (Kertesz 1951).

The finisher speed (rpm) and screen size also affect particle size and thus affect viscosity (Tanglertpaibul and Rao 1987). At higher operating speeds there is an increase in the number of particles produced, and the particles tend to be more elongated giving tomato juice a higher viscosity (Hand and others 1955). Samples observed under a microscope indicated that tomato products finished with a screen with large holes did not consist of uniformly large particles but rather of a mixture of small particles along with suspended shreds of tissue (Kattan and others 1956). Tanglertpaibul and Rao (1987) suggest that the influence of screen size be explained with the notion that small screens reduce

the size of particles and remove some of the larger particles. Small, suspended particles give a higher consistency due to the larger surface area.

Homogenization is typically used for cold break tomato juice to reduce the settling and give a thick-bodied juice (Gould 1992). Particles often change shape during homogenization of tomato juice as it changes the configuration of the cell walls (Thakur and others 1995). Particles change shape and get smaller as the cells are forced through a small opening (pressurized homogenization). These linear shaped cell walls exert more resistance to flow, resulting in an increase in the viscosity of homogenized tomato juice (Luh and others 1954). This increase in consistency is due to reduced particle size, changed shape, and increased surface area of the particles due to homogenization (Thakur and others 1995).

Break temperature during processing greatly influences the viscosity of tomato products. The highest break temperature produces tomato products of highest viscosity (Xu and others 1986). Bel-Haj (1981) showed that a break temperature of 200°F (93°C) gave a juice with higher viscosity than juice made at a break temperature of 175°F (79°C) or 150°F (66°C). This occurs because of the greater degree of inactivation of the pectic enzymes polygalacturonase and pectin methylesterase (Luh and Daoud 1970). Pectin retention is highest at a high break temperature, and more pectin results in more bound water in the cell wall material, which could explain why these hot break products have a high flow resistance (Xu and others 1986). A cold break tomato juice has a low

consistency due to the activity of these pectic enzymes and gives greater serum separation (Shomer and others 1984). Fonseca and Luh (1976) stated that there is a direct correlation between break temperature and the quality of tomato juice. They found cold break treatments to result in a lower total pectin and serum viscosity than hot break in canned tomato juice (Fonseca and Luh 1976). Consumers can detect this viscosity difference. Many taste panels have been conducted with the average consumer to determine their sensitivity to gross viscosity of tomato juice. Hand and others (1955) used triangle testing with one of three samples differing in gross viscosity by 25%. They found that their taste panel was able to make a significant number of correct selections of like and unlike samples.

2.4.4 Pectic Enzymes

A heavier bodied, more homogeneous tomato juice is obtained by the hot break process because heat destroys the pectic enzymes and allows more efficient extraction of pectin (Gould 1992). Pectin is found in the cell walls and intercellular layers of all land plants. In all natural pectins, some of the carboxyl groups are in the methyl ester form. The principal key feature of all pectin molecules is a linear chain of (1 → 4)-linked α -D-galactopyranosyluronic acid units (Whitaker 1996) (Fig 2.2).

Figure 2.2: The most prevalent monomeric unit of a high-methoxyl pectin (BeMiller and Whistler 1996)

Pectic enzymes break down chains of pectin. Tomatoes have unusually high levels of enzymes that attack pectins (Buescher and Tigchelaan 1975; Tucker and Robertson 1980). Pectin methylesterase (pectinesterase or PME) and polygalacturonase (PG) are two pectic enzymes found in higher plants and microorganisms (Whitaker 1996).

Pectin methylesterase is comparatively heat-resistant in tomatoes. Above 60°C PME is gradually inactivated, but for rapid inactivation of the enzyme as required in tomato processing, a temperature above 80°C is needed (Kertesz 1951). PME is usually present in abundance in tomato fruit tissue before softening takes place (Van Buren 1991). PME hydrolyzes the methyl ester bond of pectin to give pectic acid and methanol (Whitaker 1996). Pectin methylesterase has considerable qualitative specificity toward these methyl esters (Kertesz 1951). Methanol is a major product of the action of PME on pectin (Sajjaanantakul and Pitifer 1991) (Fig 2.3).

Figure 2.3: The demethylation reaction catalyzed by pectinmethylesterase (Sajjaanantakul and Pitifer 1991)

PG catalyzes the hydrolytic cleavage of the O-glycosyl bond of α -D-(1 $\rightarrow$ 4)-polygalacturonan. Polygalacturonase enzymes increase in tomatoes during ripening (Van Buren 1991). Endo-PG proceeds in random degradation, and exo-PG hydrolyzes bonds at the end of the polymer (Whitaker 1996) (Fig 2.4).

Figure 2.4: Polygalacturonase hydrolyzes the α -1,4-glycosidic bond between the anhydrogalacturonic acid units (Whitaker 1996)

It is debated whether plants possess both polymethylgalacturonases (act on pectins) and polygalacturonases (act on pectic acid), since pectin methylesterase in the plant quickly converts pectin to pectic acid. However, Buescher and Tigchelaan (1975) and Tucker and Robertson (1980) and Dey and Brinson (1984) found that both endo- and exo-polygalacturonases exist in the tomato along with pectin methylesterase. The action of PG results in hydrolysis of pectic acid, leading to important decreases in texture of some raw foods, such as tomatoes (Whitaker 1996).

2.5 Sensory Evaluation

Sensory evaluation has been defined as "a scientific discipline used to evoke, measure, analyze, and interpret reactions to those characteristics of foods

and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing” (IFT 1981). Pangborn (1964) traced the history of systematic sensory analysis and found it was based on wartime efforts to provide acceptable food to American troops and on the development of the triangle test in Scandinavia. The chain of sensory perception has three steps according to Meilgaard and others (1991): (1) the stimulus hits the sense organ and is converted to a nerve signal which travels to the brain (2) the brain organizes and integrates the incoming sensations into perceptions and (3) a response is formed based on the subject’s perceptions. According to Meilgaard and others (1991), sensory tests can provide data showing the worth of a commodity or even its acceptability. The principal uses of sensory testing are in quality assurance, product development, and research (Meilgaard and others 1991). The Sensory Evaluation Division of the Institute of Food Technologists (1981) has a more specific list of the most commonly occurring industrial applications of sensory evaluation:

- **New product development** – provides needed information to the product developers on the sensory quality and acceptability of experimental prototype samples.
- **Product matching** – uses sensory testing to verify that there is no difference between the experimental product and the standard.

- **Product improvement** – improvement is measured using difference tests to determine whether an experimental product is different from a control or affective tests to see if experimental sample is liked more than the control.
- **Process change** – sensory evaluation is used to determine if a process change would maintain or improve the quality of a product.
- **Cost reduction and/or selection of a new source of supply** – uses sensory testing to evaluate whether a lower-priced ingredient or process will affect quality of the product.
- **Quality control** – these tests are used during production, distribution, and marketing to ensure that the end product is as good as the standard.
- **Storage stability** – tests are used to ensure product stability during distribution, warehousing, and retailing.
- **Product grading or rating** – requires an accurate classification of samples according to grade standards defined for the product.
- **Consumer acceptance and/or opinions** – tells product developers whether the product can be marketed or needs improvement.
- **Consumer preference** – tells which products consumers prefer over others.

- **Panelist selection and training** – trained panels offer specific, important information to product developers, and the selection of appropriate panelists for a trained panel is imperative for valid data collection.
- **Correlation of sensory with chemical and physical measurements** – relates chemical or physical methods to the human senses.

2.5.1 Sensory Attributes

According to Meilgaard and others (1991), humans typically perceive attributes of a food in the following order:

- Appearance
- Odor/aroma/fragrance
- Consistency and texture
- Flavor (aromatics, chemical feelings, taste)

Appearance is usually the only attribute by which consumers choose to purchase or consume a food product. Characteristics to consider when describing appearance are color, size and shape, surface texture, clarity, and carbonation (Meilgaard and others 1991). The odor of a food or product is determined when its volatiles are sniffed through the nose, enter the nasal passage, and are perceived by the olfactory system (Meilgaard and others

1991). Aroma is the odor of a food material while fragrance is the odor of a perfume or cosmetic. Consistency or viscosity of a liquid is evaluated by the sensory panelist by the way it feels in their mouth. According to Meilgaard and others (1991), texture can be defined as the sensory manifestation of the structure of products in terms of their reaction to stress and tactile feel properties. Flavor, as an attribute to foods, beverages, and seasonings, has been defined as "the sum of perceptions resulting from stimulation of the sense ends that are grouped together at the entrance of the alimentary and respiratory tracts" (Amerine and others 1965).

2.4.2 Types of Sensory Tests

There are two main types of sensory tests: analytical tests (with sub-categories (a) discriminative and (b) descriptive) and affective tests (IFT 1981). Analytical tests use trained panels to evaluate differences or similarities, quality and/or quantity of sensory characteristics of a product while affective tests use consumer (untrained) panels to evaluate preference and/or acceptance and/or opinions of a product (IFT 1981). There are, of course, many different types of tests within these two major categories. Within analytical discriminative tests, there are difference tests that determine whether differences exist between samples, and sensitivity tests that measure panelists' ability to detect sensory

characteristics (IFT 1981). Types of difference tests include (Meilgaard and others 1991; IFT 1981):

- Paired comparison
- Duo-trio
- Triangle
- Ranking
- Rating difference/scalar difference from control
- Simple difference test
- Similarity testing

Sensitivity tests include threshold and dilution tests. Analytical descriptive tests measure qualitative and/or quantitative characteristics, and test examples include (IFT 1981):

- Attribute rating
 - Category scaling
 - Ratio scaling (magnitude estimation)
- Descriptive analysis
 - Flavor profile analysis
 - Texture profile analysis

- Quantitative descriptive analysis

Lastly, affective tests consist of (IFT 1981):

- Paired preference
- Ranking
- Rating
 - Hedonic (verbal or facial) scale
 - Food action scale

2.4.3 Sensory Tests Used in This Study

Rating (line scaling) and triangle testing were used in this study. When using a line scale, panelists rate the intensity of a given attribute by marking on a horizontal line the area corresponding to the amount of the perceived stimulus (Meilgaard and others 1991). The lines are typically 15 cm or 6 in. long with “anchors” at both ends with the left anchor representing zero amount of the attribute and the right being a strong level of the attribute or, in some cases, opposite stimuli are used for the anchors (Meilgaard and others 1991). The marks made by the panelists are measured, and these numbers are used for the statistical analysis. Intensity can be more accurately measured because there are no “favorite numbers” used by panelists (Meilgaard and others 1991).

Triangle testing can be administered for difference or similarity between two products. A triangle test for difference was used in this study. Typically 20 to 40 panelists are used for a triangle test, but fewer can be used if the difference is easy to see (Meilgaard and others 1991). The correct number of correct responses is counted, and a table is used for statistical interpretation. When administering a triangle test, samples should be given simultaneously if possible and controlled lighting may be necessary to reduce any color variables (Meilgaard and others 1991). Triangle testing is statistically more efficient than the paired comparison or the duo-trio tests (Meilgaard and others 1991). However, Meilgaard and others (1991) suggest that the triangle test is not affective with products with sensory fatigue, carryover, or adaptation, and with panelists who feel that evaluating three samples is confusing.

2.4.4 Sensory Evaluation of Tomato Products

Tomato flavor, as well as that of other fruits and vegetables, is a function of both taste (sugars and acids) and aroma (volatile compounds) (Malundo and others 1995). Many researchers have correlated taste and aroma components of the tomato to sensory evaluation. Kader and others (1978) found significant correlations between titratable acidity and sensory panel scores of sourness while Watada and Aulenbach (1979) saw a relationship between measures of titratable acidity and sensory perception of acidity. Results determined by Bisogni and

others (1976) showed correlations between soluble solids content and sweetness, flavor, and overall quality. Malundo and others' (1995) results showed that sugar and acid concentrations did not significantly influence descriptive sensory ratings for fresh tomato impact which they attributed to a function of volatile-compound concentrations. Stevens and others (1977) had similar findings in that sugars and acids were not related to the "tomato-like" flavor of fresh tomatoes. Kader and others (1978) concluded that reducing sugars can be highly correlated with sweetness and that "tomato-like" flavor is a complex characteristic and cannot be due to only a few components. Stevens and others (1979) reported that differences in the "tomato-like" flavor are related to variations in aroma which can be attributed to volatile compounds.

2.4.5 Statistical Definitions

Population

A population is the entire collection of elements of interest.

Sample

This is a subset of the elements of a population.

Experimental Design

This is a plan of action developed by a researcher before a study begins to address all factors involved for collecting valid statistical conclusions.

F-statistic

$$F = \frac{\text{total variance (if only between-treatments effects)}}{\text{total variance (if only within-treatments or error effects)}}$$

2.4.6 Statistical Analysis of Sensory Evaluation

According to Meilgaard and others (1991), "the goal of applied statistics is to draw some conclusion about a population based on the information contained in a sample from that population." This discussion does not include all of the statistical techniques used in sensory evaluation; however, the methods used in this work are outlined. For instance, there are many experimental designs and ways of interpreting them. A randomized (complete) block design is used if the number of samples is small enough that sensory fatigue is not a concern.

Panelists are the "blocks" and samples are the "treatments", and each panelist evaluates (by rating or ranking) all of the samples (complete block) (Meilgaard and others 1991; O'Mahony 1986). Samples are presented to the panelists in a randomized order, using all possible orders to assure complete randomization (Meilgaard and others 1991).

Rating data from a randomized (complete) block design are analyzed by analysis of variance (ANOVA). According to Meilgaard and others (1991), "the null hypothesis is that the mean ratings for all of the samples are equal versus the alternative hypothesis that the mean ratings of at least two of the samples

are different.” If the value of the calculated F-statistic is greater than the critical value of F, then the null hypothesis is rejected favoring the alternative hypothesis. When the alternative hypothesis is accepted, a multiple comparison can be used to determine which samples have significantly different average ratings (Meilgaard and others 1991). Fisher’s least significant difference (LSD) for randomized (complete) design is:

$$LSD = t_{\alpha/2, df_E} \sqrt{2MS_E/b}$$

Where b is the number of blocks (panelists) in the study and $t_{\alpha/2, df_E}$ is the upper- $\alpha/2$ critical value of a t-distribution with df_E degrees of freedom, and MS_E is the mean square for error from the ANOVA (Meilgaard and others 1991).

2.6 Volatile Flavor Analysis

Flavor quality of fruits and vegetables is a combination of an impression on the tongue (taste), mainly determined by the acid-sugar ratio, and an impression in the nasal passage (aroma) due to the volatile organic compounds (Dirinck and others 1977). Of taste and aroma analyses, aroma is the most difficult to perform. Many volatile components are responsible for the aroma of a food substance. These volatiles are present in small quantities making their separation and identification complicated, and high volatility of some aroma compounds makes them extremely difficult to quantify (Baldwin and others 1991; Nelson and Hoff 1969). Many fruits and vegetables, including tomatoes,

generate some of their important flavor volatiles when they are eaten or macerated adding to the complexity of the volatile analysis (Galliard and others 1977). Flavor quality evaluation should concentrate on the study of the volatile components, which determine aroma. In addition, it is important to isolate a representative volatile mixture that we would unconsciously send to the nose while eating (Dirinck and others 1977).

2.6.1 Important Tomato Flavor Compounds

Volatile compounds that characterize fresh tomato flavor are derived from fatty- and amino-acid metabolism and breakdown of carotenoids (Buttery and others 1971, 1988; Petro-Turza 1987). Knowledge of the identities of the components that are responsible for tomato flavor is important for the control of flavor, both in fresh and processed products (Buttery and others 1971). The volatile compounds of fresh tomatoes and tomato products have been studied extensively, and approximately 400 have been identified (Buttery and others 1990).

Of those 400 volatiles identified, only a few have been singled out as playing an important part in fresh tomato aroma (Buttery and others 1971, 1987, 1988; Petro-Turza 1987). Buttery (1993) suggests that fresh tomato flavor can be closely duplicated with just ten compounds (Table 2.1).

Compound	Concentration (ppm)
Cis-3-hexenal	3.5
Cis-3-hexenol	1.5
Hexanal	0.6
1-penten-3-one	0.2
3-methylbutanal	0.2
Trans-2-hexenal	0.16
6-methyl-5-hepten-2-one	0.1
Methyl salicylate	0.05
2-isobutylthiazole	0.01
β -ionone	0.01

ppm = parts per million

Table 2.1: Synthetic mixture that closely matches the aroma of sliced, fresh ripe tomato (Buttery 1993)

Many volatile components increase during ripening along with increased lycopene synthesis (Baldwin and others 1991). Some of the most important tomato flavor compounds are generated from the breakdown of fatty acids, mainly linolenic and linoleic acids (Fig 2.5). Lipoxygenase is a key enzyme involved in this degradation. Volatile molecules derived from the activity of

lipoxygenase and other cleaving enzymes during tomato maceration are recognized as important factors in determining tomato flavor quality (Gray and others 1999).

Figure 2.5: Summary of proposed pathways for the formation of C-6 and C-9 aldehydes and alcohols from plant lipids (Gaillard and others 1977)

The major tomato volatiles resulting from enzymatic breakdown of linolenic and linoleic acids are known to be hexanal and cis-3-hexenal (Chung and others 1983). These C6 aldehydes are typically associated with a "fresh" or "green" note in tomato flavor (Galliard 1977). Hexanal is an aldehyde important

to fresh tomato flavor that is reported to be a major component of tomato odor based on calculated odor units (ratio of concentration of the compound divided by its threshold concentration) (Buttery and others 1987). Hexanal is said to have a "green, fatty" flavor (Baldwin and others 1991). According to Buttery (1993), cis-3-hexenal is the most important aroma compound in fresh tomatoes. Cis-3-hexenal is important to fresh tomato flavor by contributing a "green, leafy, herbaceous" aroma with very natural character (Heath 1978). It has also been described as a flavor similar to that of green beans (Hoffman 1961). Guadagni and others (1972) found that, when rated by an untrained sensory panel, cis-3-hexenal and mixtures containing this compound rated in a category "between moderately similar and very similar to fresh tomato aroma." Buttery and others (1971) observed that cis-3-hexenal in dilute water solution (1 ppm) exuded an odor similar to that of a freshly cut green tomato. However, cis-3-hexenal is unstable to both heat and acidity and is easily isomerized to trans-2-hexenal (Gray and others 1999; Buttery and Ling 1993; Chung and others 1983). Buttery (1993) found that cis-3-hexenal decreased from 12,000 ppb in fresh tomato to 0.7 ppb in tomato paste, thus categorizing it as a fresh tomato compound. Seck and others (1976) found a decrease or disappearance of fresh tomato volatile components in commercial tomato juice, especially cis-3-hexenal. In order to observe and isolate a maximum amount of cis-3-hexenal, the enzymes causing extensive changes must be inactivated (Buttery, 1993). This could be

accomplished with heat; however, concentrations of fresh tomato volatiles, including cis-3-hexenal, would be decreased. Buttery (1993) found that sodium chloride caused some enzyme deactivation, but saturated calcium chloride was more efficient. An equal volume of pureed tomato to saturated calcium chloride solution is best as direct addition of solid calcium chloride can cause boiling of the tomato blend. Trans-2-hexenal has similar flavor effects to cis-3-hexenal, but they are less intense and less fresh “green” in character (Kazeniak and Hall 1970).

In addition, cis-3-hexenol, 6-methyl-5-hepten-2-one and 2-isobutylthiazole are important components of fresh tomato flavor (Chung and others 1983). Pyne and others (1965) found that cis-3-hexenol contributed a significant “green” note to tomato flavor. Kazeniak and Hall (1970) reported that 2-isobutylthiazole had a spoiled, vine-like, slightly horseradish-type flavor, and 6-methyl-5-hepten-2-one had a fruit-like aroma.

Cooked, or processed, tomato flavor has been studied by many researchers. Buttery (1993) suggests seven compounds to create synthetic tomato paste aroma (Table 2.2).

Compound	Concentration (ppb)
Dimethyl sulfide	2000
3-methylbutyric acid	2000
Eugenol	100
1-nitro-2-phenylethane	70
3-(methylthio)propanal	30
3-methylbutanal	24
β -damascenone	14

ppb = parts per billion

Table 2.2: Synthetic mixture that closely matches the aroma of tomato paste (Buttery 1993)

Hydrolysis of tomato glycosides yields β -damascenone and 3-methylbutyric acid as major volatile products in processed tomato products. Ginnette and others (1963) experimented with tomato products and found that many tomato volatiles were lost in the process of making concentrates. Typically, a decrease in low-boiling components and some middle to high-boiling components is observed with an increase in processing degree (Chung and others 1983). The amounts of volatile compounds, especially those that

contribute to the fresh, "green" flavor of tomatoes, are very low in processed, canned tomato juices (Kazeniak and Hall 1970). Chung and others (1983) studied the "heated odor" of different volatile tomato fractions. They found that the basic, phenolic, and acidic fractions had a "burnt, medicinal or ground roasted soybean-like and rancid or sweat-like odor." Miers (1966) found large amounts of hydrogen sulfide and dimethyl sulfide in processed, canned tomatoes and juices. These compounds are important to the "heated" or "cooked" odor of tomatoes (Nelson and Hoff 1969; Miers 1966). The formation of dimethyl sulfide during heat processing of tomato products is mainly due to the degradation of the S-methylmethionine sulfonium ion (Chung and others 1983). Linalyl acetate was reported to be one of the major components of tomato paste (Sieso and Crouzet 1977). In addition, 2-acetylpyrrole and 2-formylpyrrole have a characteristic burnt odor making them important to the heated aroma of tomato puree and paste (Kazeniak and Hall 1970). These pyrroles are likely to be formed by the Maillard reaction during heat processing. Chung and others (1983) reported that the relative amount of 2-isobutylthiazole, a fresh tomato component, decreased in tomato puree and paste. This decrease is said to have an important impact on the aroma of tomato products. Chung and others (1983) did not detect 2-methylpyrazine and dimethylpyrazine in fresh tomatoes and their juices, but they were recovered in purees and pastes.

2.6.2 Solid Phase Microextraction (SPME)

SPME is a rapid, solventless volatile sampling technique developed at the University of Waterloo (Ontario, Canada) in 1993. This technique requires no elaborate equipment and is also low cost and portable (Bazemore and others 1999). Only a small amount of sample is necessary, and no organic solvents are needed. SPME contains a fused silica fiber with an outer coating of polymeric organic liquid or solid (Zhang and Pawliszyn 1993). The basis of the technology is the partitioning process of the analyte between the sample and fiber coating (Song 1998). The 1cm length polymer-coated fiber is attached to a needle or rod. The rod and fiber are placed inside of an outer needle. The inner rod is glued to a color-coded hub that can be attached to a plunger. The plunger moves the fiber through a hollow needle for adsorption and desorption (Fig 2.6). There are two types of syringe-like holders for SPME fibers, manual and automated. The assemblies are basically the same except that the manual holder contains a spring to keep the fiber in the retracted position when not in use (Fig 2.7). In addition, fibers made for use with automated holders can be used with the manual holder, but not vice versa.

SPME Fiber Assembly Detail (Manual)

Figure 2.6: Schematic drawing of SPME fiber assembly (Shirey 1998)

SPME Holders

Figure 2.7: Schematic drawing of SPME fiber holders (Shirey 1998)

When the fiber is in the retracted position, the needle can be pierced through the septum of the vial and the fiber exposed to the headspace or directly immersed in the sample (Shirey 1998).

After retracting the fiber, the needle is then placed into a gas chromatograph (GC) injector, and the fiber is exposed. Here the adsorbed analytes are thermally desorbed and transferred to the GC column (Supelco 1998b). Desorption from an SPME fiber depends on the analyte's boiling point, the thickness of the coating on the fiber, and the temperature of the injection port (Supelco 1998b). SPME is a simple technique; however, consistent

sampling time and other parameters are essential to reproducible data collection. It is also important to make sure other parameters are consistent such as vial size, sample volume, and the depth at which the fiber is immersed in the sample (Supelco 1998a). SPME has compared favorably in tests against the more traditional purge-and-trap sample collection methods and concentration devices (Song 1998).

There are many types of SPME fiber coatings available (Table 2.3).

Non-polar fibers	Polar Fibers	Bi-Polar Fibers
Polydimethylsiloxane (PDMS) 100 μ m	85 μ m Polyacrylate (PA)	65 μ m PDMS-DVB (also in Stableflex™)
Polydimethylsiloxane (PDMS) 30 μ m	65 μ m Carbowax®-divinylbenzene (CW-DVB)	75 μ m Carboxen™-PDMS
Polydimethylsiloxane (PDMS) 7 μ m	50 μ m CW-Templated resin (CW-TPR) – HPLC	50/30 μ m DVB-Carboxen-PDMS StableFlex

Table 2.3: Available SPME fiber coatings (Shirey 1998)

Of these fiber types, some are absorbent (PDMS and PA) and some are adsorbent (PDMS-DVB, CW-DVB, Carboxen-PDMS, and DVB/Carboxen-PDMS). Liquid phases typically extract by absorption, or partitioning. The analytes can move freely in and out of the phase. The coating thickness is the major way to

retain analytes; therefore, for an effective extraction of volatile analytes, a thick coating is required (Shirey 1998). Adsorption occurs when fibers physically trap or chemically bond analytes (Shirey 1999). Shirey (1999) found that in all cases tested, the adsorbent fibers outperformed the absorbent fibers for the extraction of small analytes, and Carboxen dominated in adsorption capability. Carboxen and DVB both have pores that trap volatile analytes and retain them. These porous components are suspended in a PDMS or a CW phase. Carboxen is a carbon molecular sieve made of a mixture of micro, meso, and macro pores making it ideal for extracting small and medium sized molecules (Shirey 1999) (Fig 2.8).

Carboxen/PDMS Fiber

Figure 2.8: Schematic of Carboxen/PDMS-coated fiber (Shirey and others 1999)

The disadvantage of Carboxen is that molecules of molecular weight larger than 200 are not easily desorbed and may be permanently retained (Shirey and others 1999). However, for small to medium analytes, Carboxen/PDMS fiber showed responses more than 100 times greater than for any other fiber (Supelco 1999c). PDMS/DVB has proven to be a more universal coating with affinity for a variety of solvents (Supelco 1999b).

2.6.3 SPME on Tomato Products

Little research has been reported on the use of SPME to analyze tomato flavor volatiles due to the recent development of this technology. However, Song and others (1998) used a PDMS/DVB SPME fiber to identify volatiles from a fresh tomato. They found hexanal, trans-2-hexenal, and 2-methylbutanol to be the most abundant compounds in the study. 6-methyl-5-hepten-2-one, linalool, 1-penten-3-one, methyl salicylate, and heptanal were also detected. In addition, researchers at Supelco (1999a) used a 50/30 μm DVB/Carboxen/PDMS Stableflex™ fiber to analyze tomato paste. They identified a wide range of flavor compounds, from aldehydes to acids, including dimethyl sulfide, linalool, and phenylethyl alcohol.

CHAPTER 3

MATERIALS AND METHODS

3.1 Tomatoes

Tomatoes were purchased from local grocery stores for the small-scale studies, and large amounts were grown in Fremont, Ohio and obtained from Dr. David Francis from the Horticulture Department for the large-scale analysis in late August 1999. Tomatoes for the large-scale analysis were cultivars Ohio 7983 from plots 633-670, Ohio 9442 from plots 615-665, Heinz 9423 from plots 630-659, and Ohio 8245 from plots 623 and 648. Tomatoes were stored at room temperature upon receipt for 24 hours before processing.

3.2 Small-Scale Hot Break

For preliminary gas chromatography work, small-scale hot break juices were prepared. To prepare 2 L of juice, 15 tomatoes of average size (approximately 225 g each) were used. Each tomato was heated whole in the microwave on high or full power at 900 w (R-5A87/97, Sharp, Mahwah, NJ) 2.5 min with 15 sec additional heating intervals, depending on the size of the

tomato, until heated throughout. Tomatoes were cut into quarters, and pureed in a blender (54100R, Hamilton Beach/Proctor Silex, Inc., Glen Allen, VA) for 30 sec. Juice was strained with a wire mesh screen strainer with an opening of 2000 μm .

3.3 Small-Scale Cold Break

For preliminary gas chromatography work, small-scale cold break juices were prepared. To prepare 2 L of juice, 15 tomatoes were cut into pieces, and pureed in a blender (54100R, Hamilton Beach/Proctor Silex, Inc., Glen Allen, VA) for 30 sec. Puree was allowed to sit for 15 min, and 400 mL was poured into each beaker. Two beakers at a time were heated in the microwave (R-5A87/97, Sharp, Mahwah, NJ) for 2 min 45 sec. Juice was strained with a wire screen strainer.

3.4 Procedure for Large Scale Study

Approximately 300 lbs (136.7 kg) of tomatoes for each cultivar were made into juice in the Hot Break System with chopper and tubular heat exchanger. Tomatoes were chopped and held for 0-24 min to develop various amounts of volatiles before entering the heat exchanger set at 200°F (93°C) where they were heated for approximately 2 min to inactivate the enzymes. Zero minutes is the hot break and 2-24 min are the cold break samples. Typically, the cold break

process uses a lower temperature in the heat exchanger than the hot break. The same temperature was used for both methods in this study so that the hold time would be the variable instead of the temperature. With hold time as the variable, there would be no difference in flavor volatile profile due to heat destruction by breaking at different temperatures. The finisher with a screen size of ½ in. (1.27 cm) diameter removed peel and seeds to make juice, which was caught in buckets and canned.

A rotary evaporator (Buchi, Flawil, Switzerland) was used to make sauce from the juice at 0, 2, 8, and 17 min time intervals. Sauce and juice samples were retorted and stored in the refrigerator. Juice samples not retorted were frozen and used for sensory evaluation.

3.5 Sauce Samples

A glass rotary evaporator (Buchi, Flawil, Switzerland) was used to make sauce from tomato juice. A volume of 500 mL of juice was used for each run. The temperature of the water bath was set, and when the desired temperature of 60°C was reached, the sample was lowered into the water bath. The condenser was turned on, and the round bottom flask was rotated at maximum speed for 30 min to decrease liquid volume from 500 mL to 150 mL. A mark at exactly 350 mL was made on the globe collecting the water to be sure that 350 mL was removed. The rotary evaporator was attached to cold water flowing

through a condenser. All sauce samples were reconstituted back to 5.2° Brix to be compared with juice samples during the volatile flavor analysis.

3.6 Canning and Retorting

Tomato juice and reconstituted sauce were filled into 300 X 407 cans coated on the inside with fruit enamel for acid-type products and sealed with a can closer. Cans were processed in a still retort at 220°F (104°C) for 20 min with a 30 min cool cycle. The cans were refrigerated to minimize flavor loss during storage.

3.7 Sensory Evaluation

A sensory evaluation sheet was created with six-inch lines for freshness and overall liking for each of four samples (Appendix A). Personal information and freshness ranking were on the second page along with a series of questions regarding preference of tomato products and how often the panelists consumed them. Each panelist had consumed “tomato sauce as on spaghetti or pizza” at least once a month. This showed that they were familiar with tomato products.

The 0, 2, 8, and 17 min time interval tomato juice samples from Heinz 9423 and 0, 2, 7, and 15 min for Ohio 8245 were used and assigned random numbers. The first panel with Heinz 9423 consisted of 78 consumers, 60% female and 40% male, who were in the age range of 23-67. The second test

used Ohio 8245 juice and had 79 panelists, 51% female and 49% male, whose age ranged from 19 to 60. Samples were served in labeled cups with water and unsalted crackers. These panelists evaluated likeness and freshness by marking the line in the area of best fit between the two extremes. The panelists also ranked the juices from most fresh to least fresh. Marks made by the panelists for liking and freshness were measured, and these measurements and ranking numbers were entered into a spreadsheet where a single factor analysis of variance (ANOVA) and Fisher's least significant difference (LSD) for randomized (complete) block design were performed.

In addition, a trained sensory panel was conducted by Susan Fawcett (1999) on all time intervals of the Heinz 9423 juice. The panel evaluated many attributes including tomato leaf aroma, paint aroma, and paint flavor.

3.8 SPME/GC

10 mL clear, glass sample vials (3-3105, Supelco, Bellefonte, PA) were sonicated with a mild glassware detergent and rinsed with distilled water. 5 mL of tomato juice or reconstituted sauce and a magnetic stir bar were placed in each vial. The vials were sealed with regular seals and 20 mm viton septa (3-3146-U, Supelco, Bellefonte, PA) to be used with SPME and GC that had been baked in an oven at 150°C for three hours to drive off any extraneous siloxane volatile compounds. Any samples that could not be run the same day they were

prepared were stored at -80°C. Samples were thawed for approximately 30 min prior to analysis by SPME/GC.

Samples were magnetically stirred for 10 min.

Carboxen/polydimethylsiloxane (Carboxen/PDMS) SPME fiber (5-7318, Supelco, Bellefonte, PA) for a manual holder (5-7330-U, Supelco, Bellefonte, PA) was used. The fiber was conditioned at 285°C for 30 minutes. The fiber was then exposed to the headspace of the sample for 20 min at room temperature. The SPME fiber was injected into the GC, where it remained through the duration of the run, with the injector temperature set at 265°C.

The GC analysis was conducted on a Hewlett Packard GC 5890 Series II (Hewlett Packard, Palo Alto, CA) with nitrogen as the carrier gas at 60 psi. A Hewlett Packard Free Fatty Acid Phase (FFAP) capillary column at 25m long X 0.32mm inner diameter X 0.52 μ m film thickness (19091F-112, Hewlett Packard, Palo Alto, CA) was used. The temperature program held at 35°C for 4 min, ramped 3°/min to 83°C, then increased 20°/min to 150°C and held for 2 min. The total run is 25.35 min.

According to Buttery (1993), 3-pentanone, 2-octanone, and anethole are adequate internal standards for tomato volatile analysis. The 3-pentanone covers most C5 compounds, 2-octanone covers middle range compounds, and anethole covers higher boiling point compounds. These internal standards were used initially in this study. However, when added in such small amounts,

preliminary results showed they were not as consistent as 6-methyl-5-hepten-2-one when using SPME. Therefore, 6-methyl-5-hepten-2-one was chosen as the internal standard.

Immediately following this run, another run was executed with the injector temperature at 280°C to clean off any peaks remaining on the fiber. The program started at 35°C, held for four minutes, ramped 10°C per minute to 150°C, and held for four minutes. The total run time was 19.5 minutes.

Samples were analyzed to determine presence and concentration of hexanal, cis-3-hexenal, trans-2-hexenal, and cis-3-hexenol using 6-methyl-5-hepten-2-one as the internal standard. GC tests include fresh juice, retorted juice, sauce, and retorted sauce for each available time interval for Heinz 9423, and fresh juice for Ohio 8245 was also analyzed.

Results were analyzed by dividing the peak areas for hexanal, cis-3-hexenal, and trans-2-hexenal by an internal standard, 6-methyl-5-hepten-2-one. A single factor ANOVA was used on all hold times with Fisher's LSD to determine significant differences in compound concentrations between hold times.

3.9 Compound Identification

Buttery and others' (1987) method was used to determine retention times for cis-3-hexenal and trans-2-hexenal. Saturated calcium chloride solution was prepared by adding 74.5 g of calcium chloride to 100 mL room temperature

water. Tomatoes were stored for at least one week at room temperature to promote maximum volatile production. Approximately 33.3 g from each of three tomatoes was cut to make a 100 g sample. The sample was then mixed in a chopper (LT-206, House & Home/Wholesale Merchandisers, Inc., Grand Rapids, MI) for 30 sec. The sample was held 3 min to obtain maximum cis-3-hexenal or 25 min to create a decrease in cis-3-hexenal and an increase in trans-2-hexenal (Buttery 1993). After holding, 100 mL of the saturated calcium chloride solution was added to the 100 g tomato mixture to inactivate lipoxygenase and other enzymes. The sample was mixed again for 10 sec. These 3 min and 25 min samples were analyzed by solid phase microextraction and gas chromatography to determine retention times for cis-3-hexenal and trans-2-hexenal. They were 7.6 min for cis-3-hexenal and 10.3 min for trans-2-hexenal.

The other volatile retention times were identified by injecting pure standards into the GC. The identities of these fresh compounds were confirmed by GC/MS (5970 Series Mass Selective Detector, Hewlett Packard, Palo Alto, CA) and retention times include 5.6 min for hexanal, 15.6 min for 6-methyl-5-hepten-2-one, and 17.7 min for cis-3-hexenol.

3.10 Viscosity

An efflux tube was used to measure viscosity. A 500 mL buret (03-789-5B, Fisher, Chicago, IL) was fit with rubber tubing (approximately one inch) to

hold a 1 mm bore glass tip (03-875, Fisher, Chicago, IL) and filled with juice. The time was measured in seconds that it took for 300 mL of juice (from 400 mL to 100 mL lines on the buret) to go through the tip. Each time interval was measured in triplicate for each of three cultivars (Ohio 9442, Heinz 9423, and Ohio 8245). Data were analyzed by single factor ANOVA and Fisher's LSD, and a two-sample t-test assuming equal variances was used for hot break (0 min) versus cold break (2-24 min) comparisons.

3.11 Color

Tomato juice samples were filled into an optical cuvette for use with the Hunter Spectrocolorimeter (SN-7789, Ultrascan, Hunter and Associates, Reston, VA). The colorimeter was calibrated with white, black, and gray tiles before use. The instrument read the reflectance of the sample, and L , a , and b values were given. The hue angle ($\arctangent$ of $b/a \times 57.3$) was reported. All samples were measured in triplicate. Data were analyzed by single factor ANOVA and Fisher's LSD, and a two-sample t-test assuming equal variances was used for hot break (0 min) versus cold break (2-24 min) comparisons.

3.12 Color Triangle Test

Tomato juice (Campbell's, Camden, New Jersey) was purchased at a local supermarket. Red food coloring was added to several samples of the

juice to produce different hue angles that were in the range of the tomato juice made in this study. A sensory evaluation sheet for the color evaluation by triangle tests (picking the odd sample) was created (Appendix B) to determine at which hue angle panelists could tell a difference. Samples closest in hue angle, furthest in hue angle, and those in between were paired for the test and given randomly selected sample numbers. There were 77 panelists in the first test and 76 in the second. Standardized lighting was not used in the first test, but a MacBeth Executive Daylight Lamp (110 volts, 650 watts, 74261, MacBeth, Newburgh, New York) was used the second time. Correct responses were counted and data were analyzed with the Triangle Test for Difference Table (Meilgaard and others 1991) (Appendix C).

3.13 Statistical Significance

A p-value of less than 0.05 was considered significant for all analyses of variance and t-tests in the study.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Sensory Evaluation

"Tomato-like" flavor is a complex characteristic and cannot be due to just a few components (Kader and others 1978). Differences in "tomato-like" flavor among individual fruits can be attributed to variations in aroma which is made up of volatile compounds (Stevens and others 1979).

Tomatoes contain lipoxygenase that converts linoleic and linolenic acids partially to hydroperoxy isomers that may be cleaved to produce volatile carbonyl compounds (Galliard and others 1977). One of these volatile compounds is hexanal which has been reported to be important to fresh tomato aroma (Baldwin and others 1991) by contributing a "green, fatty" flavor. In sensory panels cis-3-hexenal and samples containing this component were rated in a category between moderately similar and very similar to fresh tomato aroma (Guadagni and others 1972). Cis-3-hexenal is said to have a "green, leafy, herbaceous" aroma (Heath 1978) and is easily converted to trans-2-hexenal

(Buttery and others 1971). Trans-2-hexenal is also an important component of fresh tomato flavor and has similar aroma effects as cis-3-hexenal, but they are less intense and less fresh “green” in character (Kazeniak and Hall 1970). The creation of these volatile, fresh tomato components affects consumers’ perceptions of tomato juice.

	Heinz 9423		Ohio 8245	
	Freshness	Overall Liking	Freshness	Overall Liking
most	8 min	8 min	15 min ^a	15 min ^a
	2 min	0 min	7 min ^{ab}	7 min ^{ab}
	0 min	2 min	2 min ^{bc}	2 min ^{bc}
least	17 min	17 min	0 min ^c	0 min ^c

*time intervals with the same letter are not significantly different

Table 4.1: Consumer rating of tomato juice samples held for 0-17 min before enzyme inactivation

Overall, cold break was rated as fresher and liked more by the consumer panel than hot break for the two cultivars examined (Table 4.1). A trained sensory panel also evaluated all time intervals of juice from the Heinz 9423

cultivar. They found that "tomato leaf aroma" peaked at the 11 min time interval (Fawcett 1999) (Fig 4.1). "Tomato leaf aroma" may describe cis-3-hexenal which, according to Buttery (1993), should be at peak concentration around 3-8 min. Only four representative time intervals (0, 2, 8, and 17 min) were chosen for the consumer panel to avoid consumer fatigue. Therefore, the 11 min time interval was not evaluated by the consumer panel. However, the closest time interval was at 8 min, and this was found freshest and most liked by the panel (Table 4.1).

The trained panel also detected a paint aroma and flavor that peaked at 17 min in Heinz 9423. The paint aroma and flavor are not desirable and are likely lipid oxidation off-flavors. This explains the 17 min time interval being the least fresh and least liked by the consumer panel. The oxidation path would continue to create more rancid or painty flavors. Therefore, holding too long could create a problem for the flavor of a cold break tomato juice. Fresh volatiles such as trans-2-hexenal may continue to increase (Buttery 1993); however, the paint aroma and flavor are also increasing which render the sample least liked and least fresh. Beyond 17 min the paint aroma and flavor decreased as the highly reactive aldehydes responsible for these flavors react with others compounds making the aroma decrease.

Results from the consumer panel who evaluated 0, 2, 7, and 15 min hold times of Ohio 8245 juice also showed that cold break provides a fresher tomato

flavor. The panel liked the samples in order of increasing hold time; therefore, the longer the samples were held, the more liked and fresher they were up to 15 min (Table 4.1). The 15 min time interval was significantly fresher and liked more than hot break and the 2 min time interval. The 7 min time interval was also significantly fresher and liked more than the hot break sample. Therefore, activating lipoxygenase and holding produced a better flavor than the hot break method.

Figure 4.1: Peak in tomato leaf aroma, paint aroma, and paint flavor as detected by the trained sensory panel (Heinz 9423 tomato juice) (Fawcett 1999)

4.2 Volatile Flavor Analysis

Lipoxygenase is an enzyme that contributes significantly to characteristic tomato flavor. This enzyme forms a stereospecific complex with linoleic or linolenic acid and produces a free radical at the ω -8 position (Axelrod 1975). A hydroperoxide is formed and dissociates from the enzyme. Other enzymes cleave the hydroperoxy isomers resulting in C6 aldehydes (hexanal and cis-3-hexenal) typically associated with a "fresh" or "green" note in tomato flavor (Galliard and others 1977). Isomerases convert cis-3-hexenal to trans-2-hexenal, a compound also important to fresh tomato flavor (Kazeniak and Hall 1970). Corresponding alcohols (hexanol, cis-3-hexenol, and trans-2-hexenol) are created by alcohol oxidoreductase activity on these aldehydes (Stone and others 1975). These C6 aldehydes and alcohols were the main focus of this study, with the exception of hexanol and trans-2-hexenol, which were not detected. These volatiles will be referred to as lipoxygenase-initiated volatiles because lipoxygenase is the first enzyme involved in the reaction. The concentrations of these lipoxygenase-initiated products increased with increasing hold time.

Hexanal showed a significant increase when hot break (0 min) was compared to cold break (2-24 min) for Heinz 9423 (Fig 4.2). Each cold break hold time contained a significantly higher concentration of hexanal than hot break.

Cis-3-hexenal concentration increases very rapidly once the tomato fruit is macerated and reaches a maximum in about 3-8 minutes (Buttery 1993). After reaching the maximum, there is a gradual loss due to isomerization to trans-2-hexenal and reductase conversion to cis-3-hexenol (Buttery and Ling 1993). However, there was no overall significant difference in cis-3-hexenal or trans-2-hexenal concentration in this study when hot break (0 min) was compared with cold break (2-24 min) for Heinz 9423 juice (Fig 4.2).

Figure 4.2: Concentrations of hexanal, cis-3-hexenal, and trans-2-hexenal for various hold times (Heinz 9423 tomato juice)

There was an overall significant difference in hexanal concentration (Fig 4.3) and trans-2-hexenal concentration (Fig 4.4) for Ohio 8245 juice when hot break (0 min) was compared to cold break (2-20 min) juice. No significant difference was observed in cis-3-hexenal content over the time intervals for Ohio 8245 tomato juice (Fig 4.4).

Figure 4.3: Hexanal concentration for various hold times (Ohio 8245 tomato juice)

Figure 4.4: Cis-3-hexenal and trans-2-hexenal concentrations for various hold times (Ohio 8245 tomato juice)

Typically, the amounts of volatile components in headspace gas decrease with an increase in processing temperature (Chung and others 1983). A single factor ANOVA and Fisher's LSD was completed on the concentrations of hexanal, cis-3-hexenal, and trans-2-hexenal for Heinz 9423 raw juice, retorted juice, sauce, and retorted sauce. Hexanal concentration was significantly higher in raw juice than in retorted juice, sauce, or retorted sauce, and higher in retorted juice than in sauce or retorted sauce (Fig 4.5). In addition, the raw juice contained a

significantly higher concentration of trans-2-hexenal than in retorted juice, sauce, or retorted sauce (Fig 4.6). No difference was found in cis-3-hexenal concentration between raw juice, retorted juice, sauce, and retorted sauce.

Total volatile products initiated by lipoxygenase activity on unsaturated fatty acids include hexanal, cis-3-hexenal, trans-2-hexenal, and cis-3-hexenol. Hexanol and trans-2-hexenol are also lipoxygenase-initiated products but were not detected in this study. After completing a single factor ANOVA and Fisher's LSD on Heinz 9423 raw juice, retorted juice, sauce, and retorted sauce for these lipoxygenase-initiated volatiles, it was found that raw tomato juice contains significantly more of these fresh tomato volatiles than retorted juice, sauce, or retorted sauce (Fig 4.7). In addition, there are significantly more of these volatiles in retorted juice than in sauce or retorted sauce.

These C6 aldehydes are generally absent in heat-processed products (Galliard and others 1977). Typically, a decrease in low-boiling components and an increase in middle to high-boiling components are observed with increasing processing degree (Chung and others 1983). It has been reported that a commercial tomato juice shows a decrease or disappearance of the volatile components of fresh tomato aroma, especially cis-3-hexenal (Sieso and Crouzet 1977).

For this study, cold break juice and retorted juice had significantly more lipoxygenase-initiated volatiles than hot break juice. However, there was no

significant difference between the hot and cold break sauce and retorted sauce. Therefore, by the time juice has been concentrated to sauce, all of the flavor advantages of cold break juice may have been lost, unless a better evaporator is used than the one in this study.

Figure 4.5: Effect of processing on hexanal concentration (Heinz 9423 tomato juice)

Figure 4.6: Effect of processing on trans-2-hexenal concentration (Heinz 9423 tomato juice)

Figure 4.7: Effect of processing on total lipoxigenase-initiated volatiles: hexanal, cis-3-hexenal, trans-2-hexenal, and cis-3-hexenol (Heinz 9423 tomato juice)

Tomatoes contain a complex mixture of volatiles at low concentrations that makes quantitative analysis difficult (Baldwin and others 1991). Buttery (1993) reported that quantitative analysis of volatile components in a vegetable or fruit is not as straightforward as the analysis of a mixture of volatiles in solvent because the concentrations in the fruit or vegetable may be affected considerably by the type of isolation method used. In addition, these volatiles are often present in extremely small quantities that complicate their separation

and identification (Nelson and Hoff 1969). Quantitative analysis was difficult in this study and had a considerable amount of variability. Other researchers have noted this difficulty in quantitative analysis. Nelson and Hoff (1969) reported that the high volatility of many aroma compounds and the great dilution at which they occur make the aroma fractions extremely difficult to quantitize. Tomatoes, like many other plant foods, generate some of the volatile flavor compounds when the fruit is eaten, and this adds to the complexity of the quantitative analysis (Linforth and others 1994). Buttery and others (1971) found that because of its instability, it is difficult to get an accurate analysis of the relative amount of cis-3-hexenal as it occurs in the tomato.

Kazeniak and Hall (1970) observed large variations in their quantitative analysis of the aldehydes and alcohols among different varieties of tomatoes which coincides with this study. A carboxen/PDMS fiber was used for this work, and Bazemore and others (1999) also used this fiber for their study of orange juice. They reported that poor replication may have been partly due to incomplete desorption of analytes from the fiber because components larger than C12 have been reported to be retained strongly on the carboxen/PDMS fiber surface and are not easily desorbed (Shirey 1998). In addition, Arthur and others (1992) suggest the use of a chromatographic autosampler with slight modifications for reproducible SPME data. The GC used in this analysis did not

have an autosampler; however, the use of one may have improved reproducibility.

4.3 Viscosity

Hot break juice (0 min) had a significantly higher viscosity than cold break juice (2-20 min) for all of the cultivars tested (Fig 4.8). Fito and others (1983) reported that when using the "hot" method, the temperatures are high enough for pectolytic enzyme inactivation, and this leads to a concentrate of greater viscosity. However, the "cold" method has no such enzyme inactivation, so the pectins are partly degraded, and the resulting concentrate has a lower viscosity. The apparent viscosity for hot break extracted tomato juice is considerably higher than cold break (Molwane and Gunjal 1985). In addition, break temperature during processing greatly influences the viscosity of tomato products, and pectin retention is highest at a high break temperature (Xu and others 1986).

One of the most important factors affecting viscosity of unconcentrated tomato juice or pulp is the cultivar used (Gould 1992). Comparing cold break time intervals for each cultivar, both Heinz 9423 and Ohio 9442 were significantly different from Ohio 8245 but were not significantly different from each other (Fig 4.8).

Figure 4.8: Decrease in viscosity of tomato juice with longer hold times

4.4 Color

No overall significant difference was found between hot break (0 min) and cold break (2-24 min) juice (Fig 4.9). This is due to the fact that a true cold break was not conducted. The same temperature in the heat exchanger was used for both hot and cold breaks in order to have only time as a variable. Typically, with the lower processing temperature in the cold break, there is a difference in color between the two processes. One of the advantages of cold breaking over hot breaking is that the final product has more natural color

(Gould 1992). Color deterioration corresponds to two and a half color grades between the cold break and hot break tomato products (Bontovits 1981). Since heat application is the most important factor involved in loss of color during processing (Kattan and others 1956), a difference in color may not be seen in the two processes when using the same temperature.

All cultivars were statistically different from each other in color except Ohio 9442 and Ohio 8245 (Fig 4.9). It has been reported that color in the tomato is a result of the presence of carotenes and carotenol (Gould 1992), and differences in carotene content are correlated with varietal differences (Ellis and Hammer 1943).

Figure 4.9: Color of hot and cold break tomato juice

4.5 Color Triangle Test

Panelists' hue angle perception threshold fell between sample differences of 0.57° and 1.32° . A significant number of panelists gave a correct answer (detected the odd sample) for the samples with a hue angle difference of 1.32° or 2.06° . However, a significant number of correct answers was not seen for the samples with a difference of 0.57° or 0.29° (Table 4.2).

Difference in Hue Angle (Degrees)	Significance
Test 1	
0.29	5%
0.57	<10%
1.32	5%
2.06	>0.1%
Test 2	
0.07	>0.1%
0.29	<10%
0.57	<10%
1.32	1%
2.06	>0.1%

Table 4.2: Color triangle test data

For the first triangle test, standardized lighting was not used. The second test was conducted with a MacBeth Executive Daylight Lamp (110 volts, 650 watts, 74261, MacBeth, Newburgh, New York). This explains the discrepancy between the data in the first test. In the first triangle test, the panelists were

able to determine the odd sample from the pair with a difference of 0.29° , but they were not able to tell the difference between the samples with a difference of 0.57° (Table 4.2). This was not the case with the second test when standardized lighting was used. The panelists were able to detect differences sequentially until the samples with the difference of 0.29° . However, there was a pair of samples in the second test with a difference of 0.07° that does not follow the sequence by having a significant number of correct responses. This sample with hue angle 22.08° was made on a different day with a different can of juice from the other samples. The L , a , and b values were considerably different from those closest to it in hue angle (Table 4.3); therefore, it can be concluded that this sample would be a different shade of red and would be detected as the odd sample when compared with either of the other two samples in Table 4.3.

From the data collected in this triangle test regarding color perception thresholds, it can be concluded that the juices made from the different cultivars in this study are distinguishable from each other.

Hue Angle (degrees)	<i>L</i>	<i>a</i>	<i>b</i>
22.30	28.76	17.26	7.08
22.08	28.15	17.9	7.26
22.01	28.91	17.22	6.96

Table 4.3: *L*, *a*, and *b* values for the two juice samples closest in hue angle to the sample with hue angle 22.08°

4.6 Overall Implications

The cold break process produces a tomato juice which consumers rate as having a significantly improved flavor over the hot break method. The viscosity decreases when using the cold break which is an economic loss; however, a product with fresher flavor could be sold at a premium price. The optimum hold time would need to be determined since excessive time produces painty off-flavors.

LIST OF REFERENCES

Amerine MA, Pangborn RM, and Roessler EB. 1965. Principles of sensory evaluation of food. New York: Academic Press. p 399.

Arthur CL, Killam LM, Buchhoz KD, Pawliszyn J. 1992. Automation and optimization of solid-phase microextraction. Anal. Chem. 64(17): 1960-1966.

Axelrod B. 1974. Lipoxygenases. In: Whitaker JR, editor. Food related enzymes. Washington DC: American Chemical Society. p 324-348.

Baldwin EA, Nisperos-Carriedo MO, Baker R, Scott JW. 1991. Quantitative analysis of flavor parameters in six Florida tomato cultivars (*Lycopersicon esculentum* Mill). J. Agric. Food Chem. 39(6): 1135-1140.

Bazemore R, Goodner K, Rouseff R. 1999. Volatiles from unpasteurized and excessively heated orange juice analyzed with solid phase microextraction and GC-olfactometry. J Food Sci 64(5): 800-803.

Bel-Haj HM. 1981. Effect of cultivars, break temperature, pulping and extraction methods on the viscosity of tomato juice. Ph. D. Dissertation. Ohio State Univ., Columbus.

BeMiller JN, Whistler RL. 1996. Carbohydrates. In: Fennema OR, editor. Food chemistry. 3rd ed. New York: Marcel Dekker, Inc. p 216.

Bisogni, CA, Armbruster G, Brecht PE. 1976. Quality of room ripened and field ripened tomato fruits. J Food Sci 41(2): 333-338.

Bontovits L. 1981. The effect of processing technologies on colour changes in tomato. Acta Alimentaria 10(3): 215-228.

Buescher RW, Tigchelaan EC. 1975. Pectinesterase, polygalacturonase, and Cx-cellulase activity in the *rin* tomato mutant. Hort Sci. 10: 624-625.

Buttery RG. 1993. Quantitative and sensory aspects of flavor of tomato and other vegetables and fruits. In: Acree TE, Teranishi R, editors. Flavor science: sensible principles and techniques. Washington DC: American Chemical Society. p 259-286.

Buttery RG, Ling LC. 1993. Volatile components of tomato fruit and plant parts. In: Teranishi R, Buttery RG, Sugisawa H, editors. Bioactive volatile compounds from plants. San Fransisco: American Chemical Society. p 23-34.

Buttery RG, Seifert RM, Guadagni DG, Ling LC. 1971. Characterization of additional volatile components of tomato. J Agric Food Chem 19(3): 524-529.

Buttery RG, Teranishi R, Flath RA, Ling LC. 1990. Identification of additional tomato paste volatiles. J Agric Food Chem 38(3): 792-795.

Buttery RG, Teranishi R, Ling LC. 1987. Fresh tomato aroma volatiles: A quantitative study. J Agric Food Chem 35(4): 540-544.

Buttery RG, Teranishi R, Ling LC, Flath RA, Stern D. J. 1988. Quantitative studies on origins of fresh tomato aroma volatiles. J Agric Food Chem 36: 1247-1250.

Chung TY, Hayase F, Kato H. 1983. Volatile components of ripe tomatoes and their juices, purees, and pastes. Agric Biol Chem 47(2): 343-351.

Cole ER, Kapur NS. 1957. The stability of lycopene. I. Degradation by oxygen. *J Sci Food Agric* 8: 360-368.

Davis RB, Gould WA. 1955. The effect of processing methods on the color of tomato juice. *Food Tech*: 540-547.

Dey PM, Brinson K. 1984. Cell wall and fruit ripening. *Adv Carb Chem Biochem*. 42: 339-382.

Dirinck P, Schreyen L, Schamp N. 1977. Aroma quality evaluation of tomatoes, apples, and strawberries. *J Agric Food Chem* 25(4): 759-762.

Ellis GH, Hammer KC. 1943. The carotene content of tomatoes as influenced by various factors. *J Nutri* 25: 539-553.

Fawcett S. 1999. Personal communication. Borden Foods, Inc. Columbus, OH.

Fito PJ, Clemente G, Sanz FJ. 1983. Rheological behavior of tomato concentrate (hot break and cold break). *J Food Eng* 2: 51-62.

Fonseca H, Luh BS. 1976. Effect of break temperature on quality of tomato juice reconstituted from frozen tomato concentrates. *J Food Sci* 41(6): 1308-1311.

Galliard T, Matthew JA, Wright AJ, Fishwick MJ. 1977. The enzymatic breakdown of lipids to volatile and non-volatile carbonyl fragments in disrupted tomato fruits. *J Sci Food Agric* 28: 863-868.

Ginnette LF, Graham RP, Miers JC, Morgan AI. 1963. Tomato powder by foam-mat drying. *Food Tech* 17(6): 811-813.

Goose PG, Binstead R. 1964. Tomato paste, puree, juice, and powder. London: Food Trade Press.

Gould WA. 1978. Quality evaluation of processed tomato juice. J Agric Food Chem 26(5): 1006-1011.

Gould WA. 1983. Tomato production, processing and quality evaluation, 2nd ed. Westport, Connecticut: AVI Publishing.

Gould WA. 1992. Tomato production, processing & technology, 3rd ed. Baltimore: CTI Publishing. p 202-203, 254, 297-344, 359-367, 436.

Gray DA, Prestage S, Linforth RST, Taylor AJ. 1999. Fresh tomato specific fluctuations in the composition of lipoxygenase-generated C6 aldehydes. Food Chem 64: 149-155.

Guadagni DG, Buttery RG, Venstrom DW. 1972. Contribution of some volatile tomato components and their mixtures to fresh tomato aroma. J Sci Food Agric 23: 1445-1450.

Hand DB, Moyer JC, Ransford JR, Hening JC, Whittenberger RT. 1955. Food Tech May: 228-235.

Hayes WA, Smith PG, Morris AEJ. 1998. The production and quality of tomato concentrates. Critical Reviews in Food Science and Nutrition 38(7): 537-564.

Heath HB. 1978. Flavoring Materials. In: Flavor technology, profiles, products, applications. Westport, Connecticut: AVI Publishing.

Institute of Food Technologists. 1981. Sensory evaluation guide for testing food and beverage products. Food Tech 35(11): 50-59.

Kader AA, Morris LL, Stevens MA, Albright-Holton M. 1978. Composition and flavor quality of fresh market tomatoes as influenced by some postharvest handling procedures. J Amer Soc Hort Sci 103(1): 6-13.

Kattan AA, Ogle WL, Kramer A. 1956. Effect of process variables on quality of canned tomato juice. Proc Am Soc Hort Sci 68: 470-481.

Kazeniak SJ, Hall RM. 1970. Flavor chemistry of tomato volatiles. J Food Sci 35: 519-530.

Kertesz ZI. 1951. Pectic substances. New York: Interscience Publishers, Inc. p 372, 547-550.

Kluter RA. 1959. The objective measurement of tomato juice consistency. M.S. Thesis. Ohio State Univ., Columbus.

Linforth RST, Savary I, Pattenden B, Taylor AJ. 1994. Volatile compounds found in expired air during eating of fresh tomatoes and in the headspace above tomatoes. J Sci Food Agric 65: 241-247.

Luh BS, Daoud HN. 1970. Pectin and pectin enzymes in VF-145 tomatoes. Univ of California Tomato Res Prog Rep. (April 15).

Luh BS, Dempsey WH, Leonard S. 1954. Consistency of pastes and puree from Pearson and San Marzano tomatoes. Food Tech 8(12): 576-580.

MacGillivray JH. 1931. Tomato color as related to quality in the tomato canning industry. Purdue Agric Exp Stn Bull. 350.

Malundo TMM, Shewfelt RL, Scott JW. 1995. Flavor quality of fresh tomato (*Lycopersicon esculentum* Mill.) as affected by sugar and acid levels. Postharvest Biology and Technology 6: 103-110.

McGuire RG. 1992. Reporting of objective color measurements. *HortScience* 27(12): 1254-1260.

Meilgaard M, Civille GV, Carr BT. 1991. *Sensory evaluation techniques*. 2nd ed. Boca Raton, Florida: CRC Press, Inc. p 2-10, 54-55, 60-67, 237-268.

Miers JC. 1966. Formation of volatile sulfur compounds in processed tomato products. *J Agric Food Chem* 14: 419-423.

Molwane SD, Gunjal BB. 1985. Viscometric characteristics of cold-break and hot-break extracted tomato juice concentrates. *J Food Sci* 22: 353-357.

Moresi M, Liverotti C. 1982. Economic study of tomato paste production. *J Food Tech* 17: 177-192.

Morris CE. 1991. New tomato plant processes 90 tons per hour. *J Food Eng* 63(4): 136-140.

Nelson PE, Hoff JE. 1969. Tomato volatiles: effect of variety, processing and storage time. *J Food Sci* 34: 53-57.

Noble AC. 1975. Investigation of the color changes in heat concentrated tomato pulp. *J Agric Food Chem* 23(1): 48-49.

O'Mahony M. 1986. Tannenbaum ST, Walstra P, editors. *Sensory evaluation of food: statistical methods and procedures*. New York: Marcel Dekker, Inc. p 138, 153-164.

Pangborn RM. 1981. Individuality in response to sensory stimuli. In: Solms J, Hall RL, editors. *Criteria of Food Acceptance*. Zurich: Forster-Verlag. p 177.

Petro-Turza M. 1987. Flavor of tomato and tomato products. *Food Rev Int* 2: 309-351.

Pyne AW, Wick EL. 1965. Volatile components of tomatoes. *J Food Sci* 30(2): 192-200.

Ranken MD, Kill RC, editors. 1993. *Food Industries Manual*. London: Blackie Academic and Professional. p 161-164.

Robinson WB, Kimball LB, Ransford JR, Moyer JC, Hand DB. 1956. Factors influencing the degree of settling in tomato juice. *Food Tech* 10(2): 109-112.

Sajjaanantakul T, Pitifer LA. 1991. Pectinesterase. In: Walter RH, editor. *The chemistry and technology of pectin*. San Diego: Academic Press, Inc. p 135-164.

Seck S, Crouzet J, Piva MT. 1976. Influence des traitements thermiques sur la nature des constituents volatils de la tomate. *Ann Tech Agric* 25: 85-95. Cited in Sieso V, Crouzet J. 1977. Tomato volatile components: effect of processing. *J Food Chem* 2: 241-252.

Shirey RE. 1998. Analysis of flavors and food by SPME. Presentation. Supelco. Bellefonte, PA.

Shirey RE. 1999. Selecting the appropriate SPME fiber for your application needs. Presentation. Supelco. Bellefonte, PA.

Shirey RE, Mani V, Mindrup RF. 1999. Dual-layered solid phase microextraction (SPME) fibers to expand analyte range and detection limits. Presentation. Supelco. Bellefonte, PA.

Shomer I, Lindner P, Vasiliver R. 1984. Mechanism which enables the cell wall to retain homogenous appearance of tomato juice. *J Food Sci* 49: 628-633.

Sieso V, Crouzet J. 1977. Tomato volatile components: effect of processing. *J Food Chem* 2: 241-252.

Song J, Fan L, Beaudry RM. 1998. Application of solid phase microextraction and gas chromatography/time-of-flight mass spectrometry for rapid analysis of flavor volatiles in tomato and strawberry fruits. *J Agric Food Chem* 46: 3721-3726.

Stevens MA, Kader AA, Albright-Holton M, Algazi M. 1977. Genotypic variation for flavor and composition in fresh market tomatoes. *J Am Soc Hort Sci* 102: 680-689.

Stevens MA, Kader AA, Albright M. 1979. Potential for increasing tomato flavor via increased sugar and acid content. *J Am Soc Hort Sci* 104: 40-42.

Stone EJ, Hall RM, Kazeniac SJ. 1975. Formation of aldehydes and alcohols in tomato fruit from U-¹⁴C-labeled linolenic and linoleic acids. *J Food Sci* 40: 1138-1141.

Supelco. 1998a. Solid phase microextraction: solventless sample preparation for monitoring flavor compounds by capillary gas chromatography. Bulletin 869A. Bellefonte, PA.

Supelco. 1998b. Solid phase microextraction: theory and optimization of conditions. Bulletin 923. Bellefonte, PA.

Supelco. 1999a. Screening or quantitative determination: which SPME approach should you use? *Sample Prep Made Easy* (Spring). Bellefonte, PA.

Supelco. 1999b. The effect of sample pH on organic compound extractions by SPME. *Sample Prep Made Easy* (Fall). Bellefonte, PA.

Supelco. 1999c. How to choose the proper SPME fiber. *Sample Prep Made Easy*. (Winter). Bellefonte, PA.

Tanglertpaibul T, Rao MA. 1987. Rheological properties of tomato concentrates as affected by particle size and methods of concentration. *J Food Sci* 52(1): 141-145.

Thakur BR, Singh RK, Handa AK. 1995. Effect of homogenization pressure on consistency of tomato juice. *J Food Quality* 18: 389-396.

Tucker GA, Robertson NG. 1980. Changes in polygalacturonase isoenzymes during the 'ripening' of normal and mutant tomato fruit. *Eur J Biochem*. 112: 119-124.

Van Buren JP. 1991. Function of pectin in plant tissue structure and firmness. In: Walter RH, editor. *The chemistry and technology of pectin*. San Diego: Academic Press, Inc. p 1-22.

Watada AE, Aulenbach BB. 1979. Chemical and sensory qualities of fresh market tomatoes. *J Food Sci* 44(4): 1013-1016.

Whitaker JR. 1996. Enzymes. In: Fennema OR, editor. *Food Chemistry*. 3rd ed. New York: Marcel Dekker, Inc. p 493-496.

Xu SY, Shoemaker CF, Luh BS. 1986. Effect of break temperature on rheological properties and microstructure of tomato juices and pastes. *J Food Sci* 51(2): 399-402.

Yang SF. 1986. Fruit ripening. In: Nevins DJ, Jones AJ, editors. *Tomato biotechnology*. New York: Alan R. Liss, Inc. p 325-327.

Zhang Z, Pawliszyn J. 1993. Headspace solid phase microextraction. *Anal Chem* 65: 1843-1852.

APPENDIX A
Sensory Evaluation Sheet

Instructions:

In front of you are 4 samples of tomato juice.

Please evaluate all samples in the order listed below.

Taste the first sample, answer the questions regarding that sample by marking the line to best express your opinion of that product.

Drink the water and eat the cracker provided to rinse your mouth between samples and as needed.

Continue with the next samples in the same manner as the first.

Sample #927

Overall Liking

Freshness

Sample #833

Overall Liking

Freshness

Sample #758

Overall Liking

Freshness

Sample #536

Overall Liking

Freshness

Rank the samples from the most **fresh** to least **fresh**:

Most fresh

Least fresh

Product:

Yes No I don't know

___ ___ _____

Do you like fresh tomatoes?

___ ___ _____

Do you like tomato juice?

___ ___ _____

Do you like tomato sauce (spaghetti or pizza)?

___ ___

Have you had tomato juice in the last three months?

___ ___

Have you had tomato sauce (spaghetti or pizza)
in the last three months?

Respondent/Subject Profile:

Age_____

Gender_____

Comments:

APPENDIX B

Color Triangle Test Evaluation Sheet

Instructions: Look at the following five groups of tomato juice samples one at a time. Within each group, two samples are identical in color. Determine which is the odd/different sample.

Sets of three samples

Which is the odd sample?

549 661 161

274 253 915

746 912 425

685 448 179

266 522 614

Comments:

APPENDIX C

Triangle Test for Difference Table

Triangle Test for Difference: Critical Number (Minimum) of Correct Answers

Entries are the minimum number of correct responses required for significance at the stated significance level (i.e., column) for the corresponding number of respondents "n" (i.e., row). Reject the assumption of "no difference" if the number of correct responses is greater than or equal to the tabled value.

n	Significance level (%)				n	Significance level (%)			
	10	5	1	0.1		10	5	1	0.1
3	3	3	—	—	26	13	14	15	17
4	4	4	—	—	27	13	14	16	18
5	4	4	5	—	28	14	15	16	18
					29	14	15	17	19
					30	14	15	17	19
6	5	5	6	—	31	15	16	18	20
7	5	5	6	7	32	15	16	18	20
8	5	6	7	8	33	15	17	18	21
9	6	6	7	8	34	16	17	19	21
10	6	7	8	9	35	16	17	19	22
11	7	7	8	10	36	17	18	20	22
12	7	8	9	10	42	19	20	22	25
13	8	8	9	11	48	21	22	25	27
14	8	9	10	11	54	23	25	27	30
15	8	9	10	12	60	26	27	30	33
16	9	9	11	12	66	28	29	32	35
17	9	10	11	13	72	30	32	34	38
18	10	10	12	13	78	32	34	37	40
19	10	11	12	14	84	35	36	39	43
20	10	11	13	14	90	37	38	42	45
					96	39	41	44	48
21	11	12	13	15					
22	11	12	14	15					
23	12	12	14	16					
24	12	13	15	16					
25	12	13	15	17					

Note: For values of n not in the table compute $z = (k - (1/2)n)/\sqrt{(1/9)n}$, where k is the number of correct answers. Compare the computed value of z to the critical value of a standard normal random variable, i.e., the values in the last row of Table T4 ($z_{\alpha, n}$).

APPENDIX D
Statistical Analyses

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Hot break (0 min)	79	164.3692	2.080623	2.412534
2 min	79	188.8876	2.390982	2.382455
8 min	79	201.8503	2.555067	2.14874
17 min	79	223.0563	2.823497	2.335672

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	22.89679	3	7.632264	3.289981	0.020982	2.633548
Within Groups	723.7933	312	2.31985			
Total	746.6901	315				

Table D.1: Single factor ANOVA of the consumer panel's rating of overall liking (Heinz 9423 tomato juice)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Hot break (0 min)	79	204.6	2.589873	2.430183
2 min	79	217.0689	2.747708	2.42044
8 min	79	223.9496	2.834805	2.234172
17 min	79	261.5811	3.311153	2.384849

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	22.85296	3	7.617654	3.217715	0.023098	2.633548
Within Groups	738.6323	312	2.367411			
Total	761.4852	315				

Table D.2: Single factor ANOVA of the consumer panel's rating of freshness (Heinz 9423 tomato juice)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Hot break (0 min)	3	21.45331	7.151103	1.454979
2 min	2	34.11379	17.05689	0.59927
6 min	2	37.55654	18.77827	30.55905
8 min	3	53.81408	17.93803	20.15339
11 min	3	75.737	25.24567	11.17558
17 min	2	49.40527	24.70263	0.139111
24 min	3	90.7186	30.23953	0.240391

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	969.2363	6	161.5394	18.25377	3.97E-05	3.094613
Within Groups	97.34612	11	8.849647			
Total	1066.582	17				

Table D.3: Single factor ANOVA of hexanal concentration for various hold times (Heinz 9423 tomato juice)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Hot break (0 min)	3	40.15722	13.38574	3.241504
2 min	3	21.94222	7.314074	0.662298
6 min	3	52.13691	17.37897	77.70397
8 min	3	54.22878	18.07626	0.639328
11 min	3	14.01808	4.672693	0.061511
17 min	3	53.72035	17.90678	82.93242
24 min	3	59.93346	19.97782	3.846565

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	633.10716		105.5179	4.368298	0.010829	2.847727
Within Groups	338.175214		24.15537			
Total	971.282320					

Table D.4: Single factor ANOVA of hexanal concentration for various hold times (Ohio 8245 tomato juice)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Hot break (0 min)	3	3.612694	1.204231	0.019439
2 min	3	2.814855	0.938285	0.006838
6 min	3	5.175264	1.725088	0.07671
8 min	3	1.871217	0.623739	0.35957
11 min	3	1.230359	0.41012	0.002871
17 min	3	2.66631	0.88877	0.417593
24 min	3	3.356684	1.118895	0.045309

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	3.258394	6	0.543066	4.094938	0.013965	2.847727
Within Groups	1.856663	14	0.132619			
Total	5.115056	20				

Table D.5: Single factor ANOVA of trans-2-hexenal concentration for various hold times (Ohio 8245 tomato juice)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Retorted sauce	12	60.90255	5.075212	2.226233
Sauce	12	52.1696	4.347467	7.453406
Retorted juice	12	111.7404	9.311699	7.632142
Juice	12	158.7864	13.2322	78.53721

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	611.8994	3	203.9665	8.511992	0.000143	2.816464
Within Groups	1054.3394	44	23.96225			
Total	1666.2384	47				

Table D.6: Single factor ANOVA of hexanal concentration throughout processing (Heinz 9423 tomato juice)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Retorted sauce	12	5.216269	0.434689	0.024631
Sauce	12	3.379404	0.281617	0.033516
Retorted juice	12	3.85717	0.321431	0.002951
Juice	12	12.6928	1.057733	0.798846

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	4.711575	3	1.570525	7.305243	0.000445	2.816464
Within Groups	9.459383	44	0.214986			
Total	14.17096	47				

Table D.7: Single factor ANOVA of trans-2-hexenal concentration throughout processing (Heinz 9243 tomato juice)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Ohio 9442	18	3696.9	205.3833	18.91912
Heinz 9423	18	3665.2	203.6222	17.52183
Ohio 8245	18	3384.7	188.0389	26.05899

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	3280.6292		1640.3157	8.7351	82.56E-16	3.178798
Within Groups	1062.4995	1	20.8333			
Total	4343.1285	3				

Table D.8: Single factor ANOVA comparing viscosity of cold break hold times between tomato cultivars

	<i>Variable</i>	<i>Variable</i>
	<i>1</i>	<i>2</i>
Mean	239.6556	199.0148
Variance	381.9628	81.94581
Observations	9	54
Pooled Variance	121.2923	
Hypothesized Mean Difference	0	
Df	61	
t Stat	10.24927	
P(T<=t) one-tail	3.45E-15	
t Critical one-tail	1.670219	
P(T<=t) two-tail	6.89E-15	
t Critical two-tail	1.999624	

Table D.9: T-test assuming equal variances comparing hot and cold break tomato juice viscosity

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Ohio 7983	7	2.6877280.3839610.000748		
Ohio 9442	7	2.6066440.3723783.54E-05		
Heinz 9423	7	2.4541260.3505893.38E-05		
Ohio 8245	7	2.2983970.3283420.000132		

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.0126883		0.00422917.832072.65E-063.008786			
Within Groups	0.00569224		0.000237			
Total	0.01838	27				

Table D.10: Single factor ANOVA comparing color data of various tomato cultivars

APPENDIX E
Chromatograms

Figure E.1: Tomato juice with saturated calcium chloride added after 3 min hold time

Figure E.2: Tomato juice with saturated calcium chloride added after 25 min hold time

Figure E.3: Hot break tomato juice (Heinz 9423)

Figure E.4: Hot break retorted tomato juice (Heinz 9423)

Figure E.5: Hot break tomato sauce (Heinz 9423)

Figure E.7: 24 min hold time tomato juice (Heinz 9423)