UNDERSTANDING THE SENSORY CHARACTERISTICS OF FRESH AND PROCESSED TOMATOES USING DESCRIPTIVE SENSORY ANALYSIS

by

PAIRIN HONGSOONGNERN

B.S., Khon Kaen University, Thailand, 1999
M.S., University of Minnesota, 2003

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Food Science Institute
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

Abstract

Three studies, using descriptive sensory analysis with highly trained panelists, were conducted to better understand the sensory characteristics of fresh and processed tomatoes.

A "green" note often has been described as part of tomato flavor and is noted in many fruits, vegetables, grains and processed products. Thus, the first study developed a sensory lexicon for green characteristics in foods. The lexicon, consisting of 17 sensory attributes, was used to characterize sensory properties of 22 chemicals potentially associated with green odor. Green characteristics can be differentiated as green-unripe, green-peapod, green-grassy/leafy, green-viney and green-fruity. Additional attributes that are important in various green characteristics included musty/earthy, pungent, bitter, sweet and floral. Various chemicals were described as green at different concentrations. Green-grassy/leafy was the most common characterizing green attribute of many of the chemicals studied. Changing the concentrations of the chemicals resulted not only in changing the intensity of the attributes, but it also altered the sensory profile of many of the chemicals.

A sensory lexicon for describing tomatoes also was developed. A variety of fresh tomatoes, processed tomatoes, and tomato-based products such as ketchup and pasta sauce were used to create the lexicon. The characteristics of tomatoes can be described using 33 aroma, flavor and texture attributes. Some characteristics were common across all or most fresh and processed tomatoes. However, reducing the number of attributes may be possible for certain studies because some attributes were appropriate only for fresh or processed tomatoes, not both.

A third study determined the sensory characteristics of five tomato types, including newer and older cultivars that varied in their physical traits and primary use. The impacts of processing on the sensory quality of tomato products were investigated, with juice (minimal processing) and paste (higher level of processing) being made from the cultivars. Fresh tomatoes differed significantly because of cultivar and ripening stage differences. Fresh tomatoes differed considerably from processed tomatoes. A low processing level intensified some key aroma and flavor attributes, but differences in flavor attributed to cultivar became minimal after a higher

degree of processing. Textural differences among cultivars after processing were more pronounced than flavor differences.

UNDERSTANDING THE SENSORY CHARACTERISTICS OF FRESH AND PROCESSED TOMATOES USING DESCRIPTIVE SENSORY ANALYSIS

by

PAIRIN HONGSOONGNERN

B.S., Khon Kaen University, Thailand, 1999
M.S., University of Minnesota, 2003

A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Food Science Institute
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

Approved by:

____

Major Professor
Edgar Chambers IV

Abstract

Three studies, using descriptive sensory analysis with highly trained panelists, were conducted to better understand the sensory characteristics of fresh and processed tomatoes.

A "green" note often has been described as part of tomato flavor and is noted in many fruits, vegetables, grains and processed products. Thus, the first study developed a sensory lexicon for green characteristics in foods. The lexicon, consisting of 17 sensory attributes, was used to characterize sensory properties of 22 chemicals potentially associated with green odor. Green characteristics can be differentiated as green-unripe, green-peapod, green-grassy/leafy, green-viney and green-fruity. Additional attributes that are important in various green characteristics included musty/earthy, pungent, bitter, sweet and floral. Various chemicals were described as green at different concentrations. Green-grassy/leafy was the most common characterizing green attribute of many of the chemicals studied. Changing the concentrations of the chemicals resulted not only in changing the intensity of the attributes, but it also altered the sensory profile of many of the chemicals.

A sensory lexicon for describing tomatoes also was developed. A variety of fresh tomatoes, processed tomatoes, and tomato-based products such as ketchup and pasta sauce were used to create the lexicon. The characteristics of tomatoes can be described using 33 aroma, flavor and texture attributes. Some characteristics were common across all or most fresh and processed tomatoes. However, reducing the number of attributes may be possible for certain studies because some attributes were appropriate only for fresh or processed tomatoes, not both.

A third study determined the sensory characteristics of five tomato types, including newer and older cultivars that varied in their physical traits and primary use. The impacts of processing on the sensory quality of tomato products were investigated, with juice (minimal processing) and paste (higher level of processing) being made from the cultivars. Fresh tomatoes differed significantly because of cultivar and ripening stage differences. Fresh tomatoes differed considerably from processed tomatoes. A low processing level intensified some key aroma and flavor attributes, but differences in flavor attributed to cultivar became minimal after a higher

degree of processing. Textural differences among cultivars after processing were more pronounced than flavor differences.

Table of Contents

List of Figures ... xii

List of Tables ... xiii

Acknowledgements ... xv

Dedication ... xvi

CHAPTER 1 - Review of Literature ... 1

Part 1 – The Sensory Characteristic “Green” ... 2

Volatiles Contributing to Green Notes ... 2

Sensory Descriptions of Green Chemicals Used in Literature ... 3

Part 2 – The Sensory Characteristic of Tomatoes ... 4

Consumption Trends for Tomato ... 5

Factors Influencing the Increase of Tomato Consumption ... 6

1. Increasing awareness of health and nutritional needs ... 6
2. Increase in number of tomato varieties ... 7
3. Income, age, and gender ... 7

Flavor of Tomatoes ... 7

Compounds Contributing to Tomato Flavor ... 8

Volatile Compounds and Flavor of Tomatoes ... 8

Non-Volatile Compounds and Flavor of Tomatoes ... 11

Instrumental vs. Descriptive Sensory Studies on Flavor of Tomatoes ... 12

Instrumental Measurements and Tomato Flavor ... 13

Descriptive Sensory Analysis of Tomato Flavor ... 17

Relating Sensory Analysis and Instrumental Measurement of Tomato Flavor ... 22

Conclusions ... 25

References ... 26

CHAPTER 2 - Detailed Materials and Methods to a Lexicon for Green Odor and Characteristics of Chemicals Associated with Green Odor in Foods ... 38

Panelists ... 39

Samples and Sample Preparation 39
Food Products 39
Chemicals 39
Evaluation Procedure 43
Phase 1: Determining the Sensory Characteristics of "Green" 43
Phase 2: Evaluation of Various Chemicals Associated with "Green" 43
References 44
CHAPTER 3 - A Lexicon for Green Odor and Characteristics of Chemicals Associated with Green Odor in Foods 45
Abstract 46
Introduction 47
Materials and Methods 49
Panelists 49
Phase 1: Determining the Sensory Characteristics of "Green" 49
Phase 2: Evaluation of Various Chemicals Associated with "Green" 50
Chemicals 50
Sample Preparation 50
Evaluation Procedure 51
Results and Discussion 51
Phase 1: Determining the Sensory Characteristics of "Green" 51
Phase 2. Evaluation of Various Chemicals Associated with "Green" 55
Conclusions 61
References 62
CHAPTER 4 - Detailed Materials and Methods to Determining a Lexicon Describing the Sensory Flavor and Texture Characteristics of Tomatoes 65
Panelists 66
Samples and Sample Preparation 66
Evaluation Procedure 67
Lexicon Development 67
Product Evaluation 68
Data Analysis 71

References ... 72
CHAPTER 5 - A Lexicon for Texture and Flavor Characteristics of Fresh and Processed Tomatoes ... 73
Abstract ... 74
Practical Applications ... 75
Introduction ... 75
Materials and Methods ... 78
Samples ... 78
Sample Preparation ... 78
Panelists ... 79
Development and Description of the Terminology ... 79
Evaluation Procedure during Lexicon Validation ... 80
Data Analysis ... 81
Results and Discussion ... 81
Lexicon Development ... 81
Comparison of the Sensory Characteristics Established in Current Study and Previous Literature ... 86
Evaluating the Characteristics of Fresh and Processed Tomatoes ... 88
Conclusions ... 92
References ... 93
CHAPTER 6 - Detailed Materials and Methods to Sensory Characteristics of Fresh Tomatoes and the Impact of Processing on the Sensory Characteristics of Tomatoes ... 97
Plant Materials ... 98
Analytical Method ... 100
Sample Preparation ... 100
pH, Total Soluble Solids (ºBrix), Titratable Acidity (TA) and Dry Matter content ... 100
Processing of Tomato – Tomato Juice and Tomato Paste ... 101
Panelists ... 102
Descriptive Sensory Analysis ... 102

Sample Preparation 102
Evaluation Procedure 102
Data Analysis 103
References 104
CHAPTER 7 - Sensory Characteristics of Fresh Tomatoes and the Impact of Processing on the Sensory Characteristics of Tomatoes 105
Abstract 106
Introduction 107
Materials and Methods 108
Tomatoes 108
Postharvest Treatments 108
Preparation of Tomato Juice and Paste 109
Compositional Analyses 109
Descriptive Sensory Analysis 110
Statistical Analysis 111
Results and Discussions 111
Compositional Analyses 111
Sensory Characteristics of Fresh Tomatoes 115
Sensory Characteristics of Tomato Juice and Paste 124
Comparing Sensory Characteristics of Fresh and Processed Tomatoes 127
Conclusions 130
References 131
Appendix A - Descriptive Sensory Analysis for Green Odor in Foods and Chemicals 134
Appendix B - Descriptive Sensory Analysis for Tomato Lexicon 137
Appendix C - Tomato Planting and Planning for Evaluation 146
Appendix D - Tomato Juice Processing Instruction 150
Appendix E - Tomato Paste Processing Instruction 152
Appendix F - SAS Code for ANOVA for pH, TSS (ºBrix) and TA Data 154
Appendix G - SAS Code for ANOVA for Dry Matter Data 156
Appendix H - SAS Code for ANOVA for Fresh Tomatoes 158

Appendix I - SAS Code for ANOVA for Tomato Juice and Paste................................ 163
Appendix J - Additional Tomato Juice and Paste Data 170
Appendix K - Code of Federal Regulations for Tomato Juice 173
Appendix L - Code of Federal Regulations for Tomato Paste....................................... 176

List of Figures

Figure 5.1 Sensory map of the first two principal components for describing the aroma/flavor characteristics of tomato products 89
Figure 5.2 Sensory map of the first two principal components for describing the texture characteristics of tomato products 91
Figure 7.1 pH of fresh tomatoes by harvesting times 113
Figure 7.2 Titratable acidity of fresh tomatoes by harvesting times 113
Figure 7.3 Total soluble solids of fresh tomatoes by harvesting times 114
Figure 7.4 Principal Component Analysis (PCA) results for flavor and aroma attributes 128
Figure 7.5 Principal Component Analysis (PCA) for texture attributes 129
Figure A.1 Serial Dilution Technique Used for Chemical Solution Preparation 135
Figure B.1 Cluster Tree Diagram for Aroma and Flavor Attributes 144
Figure B.2 Cluster Tree Diagram for Texture Attributes 145
Figure C.1 Plotting Design for Tomato Planting in High Tunnel Greenhouse 147
Figure C.2 Tomato Yield 148
Figure J.1 Total Soluble Solid Plot for Tomato Juice 171
Figure J.2 Total Soluble Solid Plot for Tomato Paste 172

List of Tables

Table 1.1 Composition of dry matter content of fresh tomatoes (Davies and Hobson, 1981) 12

Table 1.2 USDA ripening categories for tomatoes (USDA, 1976) 15

Table 2.1 List of food products evaluated in phase 1: the lexicon development 41

Table 2.2 Chemical and physical properties of chemicals used 42

Table 3.1 Sensory attributes imparting green characteristics: definitions, references, and intensities on 15-point scale 53

Table 3.2 Odor attributes of chemicals exhibiting green characteristics at different concentrations 56

Table 3.3 Odor profiles of chemicals illustrating green character with descriptions and intensities 59

Table 3.4 Odor profiles of hexyl esters illustrating green character with descriptions and intensities 60

Table 4.1 List of tomato products evaluated 70

Table 5.1 Tomato sensory attributes, definitions, references and intensities on a 15-point scale 83

Table 5.2 Comparison of descriptive attributes used in previous literature 87

Table 6.1 Description of Tomato Varieties Selected for the Study 99

Table 7.1 Tomato characteristics and compositional properties 112

Table 7.2 Total soluble solids measured in tomato juice and paste 115

Table 7.3 Significant differences in the sensory characteristics of fresh tomatoes 116

Table 7.4 Significant differences in the sensory characteristics of fresh tomatoes by cultivars 117

Table 7.5 cv. Brandywine - Sensory characteristics by ripening stages 119

Table 7.6 cv. Florida 91 - Sensory characteristics by ripening stages 120

Table 7.7 cv. Jet Star - Sensory characteristics by ripening stages 121

Table 7.8 cv. Juliet - Sensory characteristics by ripening stages 122

Table 7.9 cv. Red Agate – Sensory characteristics by ripening stages 123

Table 7.10 Significant differences in the sensory characteristics of tomato juice by cultivars .. 125

Table 7.11 Significant differences in the sensory characteristics of tomato paste by cultivars .. 126

Table A.1 Orientation Schedule for Chemical Evaluation 135
Table A.2 Testing Schedule for Chemical Evaluation... 136
Table B.1 Aroma and Texture Intensity Scores for Tomato Products Based on 15-Point Scale 138
Table B.2 Flavor Intensity Scores for Tomato Products Based on 15-Point Scale 140
Table B.3 Pearson Correlation for All Sensory Attributes 142
Table C.1 Compositional Worksheet for pH, Total Soluble Solids and Titratable Acidity 149

Acknowledgements

A number of people deserve my deepest appreciation for their role in this achievement. This has been a challenging journey, but with the support of family, friends and colleagues, it has been exciting and rewarding.

First, a tremendous thank you to my adviser, Dr. Edgar Chambers. You have taught me what it takes to be a successful sensory scientist. Your guidance and patience was greatly appreciated.

I want to thank my committee members, Dr. Delores Chambers, Dr. Fadi Aramouni and Dr. George Milliken, for helping me work through my projects. I also would like to give special thanks to Dr. Ted Carey, whose advice and assistance was invaluable.

My thanks to everyone at the Sensory Analysis Center at Kansas State University. At times it was messy working with those tomatoes this past summer, but it passed by smoothly because of your help.

I would not be here without the support of my family and friends. Thank you very much for your love and understanding, which keeps me going every day. Thank you dad, Jeaw, Joy and Chai for giving me strength, even though you are half way around the world. Andy, thanks for your love and companionship, and for introducing me to Lazarus (the cutest and most demanding cat in the world). Thank you to all my Thai friends, who are always there for me when I needed. And last but not least, to my friends from JU 133: thank you so much for the conversations, the laughter, and the memories.

Dedication

I would like to dedicate this dissertation to the love and memory of my mother, Sunun Hongsoongnern. Her love and strength helped me become the person I am today. She was a true example of one who loved learning and was never afraid to try. She always encouraged me to learn and explore life, and to take full advantage of opportunities she never had. She said to me, "I don't have lots of money to offer, but I can give you education, which will stay with you forever." Though she faced death too early, she lived a full live and fought bravely until the last minutes. She was the strongest woman I have ever known.

"This is for you, mom."

I love you and miss you very much.

CHAPTER 1 - Review of Literature

This review of literature consists of 2 parts. Part 1 gathered information on studies related to identifying the sensory characteristic term "green". Part 2 included literature related to the flavor characteristics of tomatoes and various factors that have significant impact on their flavor characteristics.

Part 1 – The Sensory Characteristic "Green"

The sensory characteristic "green" is a commonly used term for describing the characteristic of a variety of fresh vegetables, unripe fruits, and some processed food products. A "green" note has been found to be among the important attributes necessary for consumer perception of many green plant-based products and food derivatives of those products, for example, olive oil (Aparcio and Morales, 1998). The term green and similar terms such as grassy have been referenced recently in many descriptive sensory analyses of various foods including tomatoes (Baldwin *et al*., 2004), bean products (Vara-Ubol *et al*, 2004), honey (Galán-Soldevilla *et al*., 2005) and wine (Vilanova and Soto, 2006). Various chemicals have been used to represent the green note in those descriptive sensory studies, including aldehydes, alcohols, ketones or their corresponding ester derivatives that contain six carbon atoms (C_6) in the molecule.

Volatiles Contributing to Green Notes

Salas *et al.* (2005) reported that the degradation of polyunsaturated fatty acids through the lypoxygenase pathway produced the volatile compounds contributing to the green notes in many fruits, vegetables and other derivative food products (e.g. olive oil and juices). Various volatile aldehydes and alcohols containing six carbon atoms, e.g. hexanal, *E*-2-hexanal, and hexanol, were reported to illustrate green odor (Salas *et al*., 2005). Hatanaka (1996) suggested that eight volatile compounds of C_6-aldehydes and C_6-alcohols including (2*E*)-hexenal (leaf aldehyde) and (3*Z*)-hexenol (leaf alcohol) contributed chiefly to the green odor characteristics of green leaves. Dravnieks (1985) also described a number of C_6 aldehydes (e.g. 1-hexanal) as having green-related characteristics such as cut-grass. Research by Guth and Grosch (1991, 1993) and Morales *et al*. (1996) showed that C_6 aliphatic compounds and the corresponding hexyl acetates contributed primarily to an "unripe" green characteristic of fruit flavor in olive oils. King *et al.* (2006) reported that damage to the cell structure of fruits and vegetables increased the release of six-carbon aldehydes, alcohols, and esters and resulted in intensified green notes.

Hexanal and closely related compounds, in particular, have been most commonly associated with green characteristics such as cut-grass (Krumbein and Auerswald, 1998; Reiners and Grosch, 1998; Baldwin *et al.*, 2004; Azodanlou *et al.*, 2003; and Buettner and Mestres, 2005). Wilkens and Lin (1970) and Takahashi *et al.* (1979) showed that hexanal was the key component for the green and bean-like characteristics of soy beans and their products. Jakobsen *et al*. (1998) described hexanal as a green-strong note in blanched green peas. Hexanal and hexanol were described as the key compounds producing the green and beany flavor in a variety of soy products (e.g. Wang *et al*., 1998). Komthong *et al*. (2006) found trans-2-hexenal to be responsible for a green, apple–like odor in apples. Jiang (2005) found that high level of (*E*)-2-hexenal and (*Z*)-3-hexen-1-ol in the laksa plant to be positively correlated with green notes. Aparicio and Morales (1998) described 2-, 3-hexenal, and 2-, and 3-hexen-1-ol as green, with sensory attributes such as fruity, flower, cut grass, and banana depending on the structure of the compounds. Citronellal was described as an important compound contributing to, and intensifying the green note in green fruits (Jiang and Kubota, 2005). Arais *et al*. (1967) reported that alcohols including isopentanol, hexanol and heptanol were responsible for the characteristic green aroma of soy beans. (*Z*)-3-Hexen-1-yl esters have been found to be green and fruity. For example, (*Z*)-3-hexen-1-yl acetate was described as green and banana by Pino *et al*. (2001), and powerful green and floral by Furia and Bellanca (1975).

Sensory Descriptions of Green Chemicals Used in Literature

Descriptions of volatile compounds used to reference green notes vary in the literature. Baldwin *et al.* (2004); Azodanlou *et al.* (2003); Krumbein and Auerswald (1998); Reiners and Grosch (1998) and Buettner and Mestres (2005) described hexanal as green, (cut) grass. Other descriptors used to describe the characteristics of hexanal included minty (Baldwin *et al.*, 2004), apple (Salas *et al*., 2005; Paçi Kora *et al*., 2003; and Morales and Aparicio, 1999), unripe green (Wright, 2004), herbal (Jordán *et al*., 2003), fatty (Pino *et al*., 2001), and hedge (Bult *et al*., 2002). Salas *et al*. (2005), Furia and Bellanca (1975) and Krumbein and Auerswald (1998) described (*E*)-2-hexenal as green-leafy; Azodanlou *et al.* (2003) described it as green and fatty; Baldwin *et al.* (2004) characterized (*E*)-2-hexenal as green, grassy, vine, and stale; Wright (2004) and Reiners and Grosch (1998) described it as green apple like; and Morales and Aparicio (1999) described it as almond. It is possible that some of these chemicals may illustrate a certain green characteristic at specific range of concentrations. For example, Vara-Ubol *et al.* (2004) showed that some chemicals associated with beany aroma were found to be beany only at concentrations between 1-10 ppm, and the characteristics changed completely at higher concentrations. Caporale *et al.* (2004) reported that different concentrations of cis-3-hexen-1-ol differed significantly in the green-cut grass intensity.

Many studies described odors of volatile chemicals by having human subjects sniff the headspace from gas chromatographs. Some studies used a human sensory panel with minimal training. No studies were found that used highly trained descriptive sensory panelists to describe the chemicals potentially associated with green notes. The sensory characteristic "green" has been very commonly used; however, a well defined lexicon that includes definitions and references to determine the green character has not been developed.

Part 2 – The Sensory Characteristic of Tomatoes

Tomatoes, both fresh and processed forms, are one of the most consumed and produced vegetables worldwide. Tomatoes, which originated in South America, belong to the family of *Solanaceae* and genus of *Lycopersicon*. Tomato is considered a berry fruit, but usually cultivated and consumed as a vegetable (Petro-Turza, 1978). Tomatoes have been a popular item since the early sixteenth century and the number of tomato varieties available in the marketplace has increased dramatically during the past century.

In the past two decades, the consumption of both fresh and processed tomatoes has increased steadily. Various factors influencing the increase in tomato consumption include the popularity of ethnic foods such as Italian and Mexican and the increased awareness of the potential health benefits from tomatoes in reducing the incidence of chronic diseases such as cancer. Despite the increase in consumption, many studies in the past several years have reported that fresh tomatoes commercially available in retail marketplace exhibit poor flavor (Watada and Aulenbach, 1979; Hobson, 1988; Bruhn *et al*., 1991; Maul *et al*., 2000; Yilmaz, 2001; Batu, 2004; Krumbein *et al*., 2004; and Serrano-Megías and López-Nicolás, 2006), which can have an impact on consumption. Recent development has focused primarily on creating tomato varieties that provide high yields, increased shelf-life, and resistance to diseases, which may have contributed to compromised flavor characteristics in fresh market tomatoes. The lack of flavor of these retail tomatoes is also due partly to harvesting at a mature-green stage, which is done to ensure that the fruits would maintain their integrity during transportation and additional postharvest treatments (Kader *et al*., 1977).

Consumption Trends for Tomato

The consumption of tomatoes has increased continuously over the last 15 - 20 years. In 1993, world production of tomatoes exceeded 70 million tons (Thakur *et al*., 1996). During the past two decades, the annual use of fresh market tomatoes in the United States has increased 18% per person per year based on a report (Lucier, 2006) from the US. Department of Agriculture's Economic Research Service (ERS). Lucier *et al.* (2000) stated that the annual use of tomatoes and tomato products in the US "has increased nearly 30 percent over the past 20 years…" The increase in consumption of tomatoes is the result of a number of reasons including an increase in health awareness of consumers, an increase in the consumption trend toward restaurant-food or away-from-home food, an increase in the number of tomato varieties available in the marketplace, and an increase in ethnic populations in the U.S. such as Mexican (Lucier *et al*., 2000).

During the 1960's to 1970's, the consumption of fresh tomatoes flattened at approximately 12 lb per capita (Lucier *et al*., 2000). The consumption began to rise during the 1980's and 90's to at least 17 lb per capita. Lucier *et al*. (2000) reported that the increasing trend of fresh tomato consumption is partly due to the increasing popularity of salads, sandwiches, the introduction of improved varieties of tomatoes and the more national health awareness.

Because of their perishable nature, tomatoes are consumed as much processed as they are fresh. In the 1990s, the U.S. has been the largest consumer and producer of tomatoes for processing, accounting for almost 50% of tomatoes used in world tomato processing (Gould, 1993). A variety of types of canned tomatoes are available in the marketplace including whole peeled, diced, and crushed. Other processed tomatoes are consumed primarily as tomato juice, sauce, puree and paste. The consumption of diced tomatoes increased considerably during the 1980-1990s because of the considerable demand for high value salsa, pizza, and spaghetti sauces (Garcia and Barrett, 2006). Tomato puree and paste have been marketed both directly to consumers and as ingredient to manufacture other products such as ketchup, soup and pasta sauces (Hayes *et al*., 1998). The consumption of pizza has increased more than 300% since the 1970's, which potentially drove the consumption of tomato sauce, especially in fast food restaurant chains. Lucier *et al*. (2000) reported that approximately one-third of tomato sauces and canned whole tomatoes were purchased more often from grocery stores and the rest was consumed in a restaurant setting. The expanding of number of Mexican and Italian restaurants largely drove the use of canned whole tomato products.

Factors Influencing the Increase of Tomato Consumption

1. *Increasing awareness of health and nutritional needs*

More societal emphasis on nutrition and health matters could account for a large increase in demand for tomatoes. Perceived health benefits derived from tomatoes have been among the main forces driving the increase in tomato consumption (Cuellar, 2002). The possibility in preventing certain chronic diseases, such as cancer, encourages consumers to purchase and consume more tomatoes. Several studies indicated that consumption of tomatoes may reduce the risk of oesophagus, gastric, prostate and other epithelial cancers (Cook-Mozaffari *et al*., 1979; Tsugane *et al*., 1992; Liu *et al*., 2001; Lugasi *et al*., 2003). Others have suggested that a lycopene rich diet such as provided by eating more tomato-based products may help prevent cardiovascular diseases (Kohlmeier *et al*. 1997; Clinton, 1998). Lycopene, the most prevalent carotenoid pigment, about 83%, in tomatoes, has been studied and its role in reducing the risk of cancer in men has been proven, which further encourages tomato consumption. Lycopene shows significant antioxidant activity both in vivo and in vitro (Clinton, 1998 and Agarwal and Venketeshwer, 1998). Lee and coworkers (Lee *et al*., 2000) reported that eating tomatoes cooked in olive oil improved the antioxidant activity of lycopene and reduced the risk of cancer in men. The risk of prostate cancer can be reduced up to 40% when at least three to five servings of tomatoes are eaten each week for at least a decade (Lee *et al*., 2000). These research results showed the beneficial effects of tomato consumption. Studies also reported a relatively high stability of lycopene after undergoing multiple processing steps such as those for making tomato juice and paste (Agarwal *et al*., 2001; Xianquan *et al*., 2005). Those studies suggested that lycopene content in the processed tomato products were stable for up to 12 months at room temperature storage with minimal exposure to light.

2. Increase in number of tomato varieties

Cuellar (2002) reported that consumption of tomatoes has increased because of the introduction of new tomato varieties that are claimed to taste better, and to be more consistent in quality. Availability of fresh, field-grown, and greenhouse tomatoes all year round also promotes increasing demand.

3. Income, age, and gender

Consumption of fresh tomatoes is, to some extent, a function of income level. An individual or family tends to consume more fresh tomatoes as their income rises. Pollack (2001) stated that "fruit and vegetable consumption is positively correlated with income level…". Approximately 39% of the segment of the US population whose income exceeds the poverty level by at least 350% accounts for approximately 44% of fresh tomato consumption (Lucier *et al*., 2000). Adults, both men and women, aged 39 years and older consumed more fresh tomatoes than younger individuals (Lucier *et al*., 2000). This demographic group has, in general, more health awareness than other segments of the population. This group accounts for about 50% of the fresh tomato consumption in the US (Lucier *et al*., 2000). Children tend to consume more fresh tomatoes as they enter their teenaged years.

Flavor of Tomatoes

Consumers prefer fresh tomatoes that have full flavor and characteristic taste. The flavor characteristics of tomatoes have become an important purchasing criterion in recent years (Krumbein *et al*., 2004) in addition to physical factors such as color and firmness and price (Brumfield *et al*., 1993). Commercial tomatoes, however, have been criticized as lacking desirable flavor in the past two decades (Watada and Aulenbach, 1979; Hobson, 1988; Bruhn *et al*., 1991; Maul *et al*., 2000; Yilmaz, 2001; Batu, 2004; Krumbein *et al*., 2004; and Serrano-Megías and López-Nicolás, 2006). One reason for a declining flavor is that tomatoes are harvested at the mature-green stage (Kader *et al*., 1977) in order to prolong the shelf-life of the fruits through multiple handling and transporting periods. Other researchers have reported that lack of flavor of tomato is associated with various storage treatments, e.g. modified atmosphere (Kader *et al*., 1978; Hobson, 1988; Ho, 1996; and Maul *et al*., 2000). Several studies (e.g. Kader *et al.*, 1978) recommended that tomatoes should be harvested at the red-ripe stage to ensure the flavor desirability. However, because of the duration of transportation and handling processes, the shelf-life of those vine-ripened tomatoes is significantly shortened. Therefore, many researchers focused on developing tomato cultivars that provide increased yields, firmness, size, disease resistance, and prolonged shelf-life, instead of flavor aspects of tomatoes.

Compounds Contributing to Tomato Flavor

The characteristic flavor of tomatoes is formed from both volatile and non-volatile compounds (Stevens *et al*., 1977; Stevens *et al*., 1979; Petro-Turza, 1987; Bucheli *et al*., 1999; and Krumbein *et al*., 2004). Flavor of tomato not only results from the sum of volatile or non-volatile compounds, but also depends largely on their interactions as well (Petro-Turza, 1987). Volatile compound aspects have received much attention from many researchers (e.g. Buttery *et al.*, 1987; McGlasson *et al*., 1987; Langlois *et al*., 1996; Baldwin *et al*., 1998; Brauss *et al*., 1998; and Krumbein and Auerswald, 1998). Other researchers have studied the impact non-volatile compounds have on the characteristic taste of tomatoes (e.g. Stevens *et al*., 1979; and Malundo *et al*., 1995).

Volatile Compounds and Flavor of Tomatoes

Volatile compounds that contribute to the characteristic flavor and aroma of tomatoes are generated from lipids, carotenoids, amino acids, terpenoids, and lignins (Buttery and Ling, 1993). Presently, over 400 volatile compounds have been identified in fresh tomatoes (Petro-Turza, 1987). However, it is likely that only a portion of those actually contribute to the characteristic flavor of fresh tomatoes. Commonly, gas chromatographic analysis has been used to determine volatile compounds in fresh tomatoes. Buttery (1993) indicated that a combination of some volatiles at appropriate concentrations may contribute to the characteristic tomato flavor. Those included cis-3-hexenal, cis-3-hexenol, hexanal, 1-penten-3-one, 3-methylbutanal, trans-2-hexenal, 6-methyl-5-hepten-2-one, methyl salicylate, 2-isobutylthiazole, and β-ionone. Buttery and Ling (1993) suggested a similar set of volatiles contributing to the flavor of tomatoes, which included *cis*-3-hexanal, hexanal, *trans*-2-hexanal, hexanol, *cis*-3-hexanol, 2-isobutylthiazole, 6-methyl-hepten-2-one, geranylacetone, 2-phenylethanol, β-ionone, 1-penten-3-one, 3-methylbutanol, and 3-methylbutanal. Krumbein and Auerswald (1998) used gas chromatography-olfactometry and aroma extract analyses to determine that (*Z*)-3 hexanal,

hexanal, 1-octen-3-one, methional, 1-penten-3-one and 3-methylbutanal were the most odor-active aroma volatiles in fresh tomatoes. Similar results were obtained by Tandon *et al*. (2000). Some other aroma compounds that may contribute the characteristic tomato flavor included furaneol and norfuraneol. Yilmaz (2001) stated that furaneol is an important compound contributing to tomato aroma. Other compounds identified in fresh tomato, and not other foods, which may potentially contribute to tomato aroma, include 1-nitro-2-phenylethane, 1-nitro-2-methylpropane, and 1-nitro-3-methylbutane (Buttery, 1993). Dalal *et al.* (1967) reported that in tomatoes harvested at the mature green stage and ripened artificially, the amount of 2-butanol, 2-phenylethanol, 6-methyl-5-hepten-2-one, geranylacetone, farnesylacetone and 2-isobutylthiazole were increased substantially. *trans*-3-Hexenal, and 2E, 4E-decadienal were found to contribute to the desirable blending or mouthfeel properties of tomatoes (Petro-Turza, 1987). Petro-Turza (1987) reported that hexanal may contribute to the fresh green aroma of tomato, but at concentrations above 0.5 ppm it can also produce a flavor similar to rancid vegetable fat. At low concentrations, 2-isobutylthiazole was found to minimize the harsh and unpleasant character in tomato flavor, but, at higher concentrations it could generate "objectionable rancid and medicinal, metallic off-odors" (Petro-Turza, 1987). Despite the availability of some previous information, Azodanlou *et al*. (2003) stated that the contribution of volatiles to the perception of quality in tomatoes has not received much attention.

The amount of volatile compounds in fresh tomatoes develops and changes over the ripening stages of the fruits. Buttery (1993) reported that many volatile compounds increased significantly as the fruits ripen. For example, (*Z*)-3-hexenal was found at levels 20 times higher in vine-ripened fruits than in mature green tomatoes. Factors that account for differences in volatile compound content include tomato variety, growing conditions, and stage of ripeness. Thus, as a result of this large variability, it is a great challenge for a researcher to investigate the contribution of aroma compounds or determine which compounds primarily contribute to the flavor characteristics of fresh tomatoes. Johnson *et al*. (1968) suggested that the amount of volatile compounds were different when tomatoes were harvested at different times. Johnson *et al*. (1968) also reported that many differences in flavor characteristics could occur within the same variety due to factors such as harvesting time and ripening techniques. For instance, tomatoes grown in greenhouses and in open-fields have different flavors and aromas as a result of differences in the amount of volatile compounds produced in the fruits. Fruits that have not fully ripened when harvested not only will under-develop overall tomato flavor, but may also produce some off-flavors or aromas. Dirinck *et al*. (1976), Dalal *et al.* (1967) and Dalal *et al.* (1968) reported that field-grown tomatoes had significantly higher volatile compounds than those grown in hot-house or greenhouse conditions. In tomatoes harvested at the mature green stage, short chain ($C_4 – C_6$) volatile compounds were found instead of the long chain ($C_9 – C_{12}$) volatiles that would be found when the fruits were harvested at the red-ripe stage (Chung *et al*., 1979). Tomatoes harvested at the mature green or breaker stages have been reported to be less sweet, salty, and have less fruity-floral flavor compared to those harvested at the table-ripe stage (Hayase *et al.*, 1984; and Krumbein *et al*., 2004), largely due to the fact that much fewer volatile and non-volatile compounds fully developed at these stages. The chemical compositions such as soluble solids and titratable acids in fresh tomatoes also were fewer in tomato fruits harvested at the mature green stages (Lin and Block, 1998). Hayase *et al.* (1984) also reported that tomatoes harvested at green stage can have a presence of some off flavors.

In processed tomatoes, a number of volatile compounds have been demonstrated to have an impact of the product's flavor character. Petro-Turza (1987) suggested that two volatile compounds, dimethyl sulphide and acetaldehyde, may primarily contribute to flavor characteristics of some processed tomatoes. Kazeniac and Hall (1970) suggested that the increased cooked notes in processed tomatoes resulted from the decrease in green aroma components. Dimethyl sulphide, not present in raw tomato, was formed during the initial heating process and found to be associated with "cooked" aroma of tomato products (Miers, 1966). The concentration of dimethyl sulphide was reported to increase significantly in canned tomato juice (Petro-Turza, 1987). The concentration of acetaldehyde, one of the first volatile compounds identified in tomatoes, had been found much higher in processed tomatoes. Acetaldehyde also was found to be associated with the cooked aroma of tomato products (Kazeniac and Hall, 1970). Other compounds also have been determined to have a strong association with the flavor of processed tomatoes. Geranylactone was found to be associated with the hay-like aroma in tomato juice (Kazeniac and Hall, 1970). Furfural, 2, 4-heptadienal and phenylacetaldehyde have been reported to contribute to the cooked characteristics of processed tomatoes (Petro-Turza, 1987).

Non-Volatile Compounds and Flavor of Tomatoes

A number of non-volatile compounds present in the fruits have an impact on the flavor characteristics of fresh tomatoes. Those include sugars, minerals, organic acids, and free amino acids. Sugar and organic acid content have been reported to be most responsible for the pleasant sweet and sour taste of tomatoes. Salts and probably some free amino acids have a large impact on the character and intensity of the taste of tomatoes. Sugars, primarily glucose and fructose, contribute to about 50% of the dry matter content in tomatoes (Table 1.1). Of the sugars identified in tomato, fructose probably is the most important compound that produces the characteristic sweetness. Other sugars including saccharose, raffinose, arabinose, galactose, and sugar alcohol myoninositol have also been identified in tomatoes (Yilmaz, 2001), however, the quantities of these sugars probably are too small to have a significant impact on the flavor characteristics of tomatoes. Sugar content substantially increases during the ripening period of the fruits. For example, in the initial development of tomato fruit, glucose was dominant with the ratio of glucose/fructose approximately 1.8; as the fruit developed, the ratio of sugars increased to about 1.0. Petro-Turza (1987) reported that, in ripened tomato fruit, the sum of sugar content ranges approximately between 1.7 to 4.7%. Light was found to have a great impact on the sugar content in tomatoes, i.e. tomatoes receiving more sunlight generally would have more sugar content (Petro-Turza, 1987).

Organic acids, especially citric and malic acids, which are the major organic acids found in tomato, contribute to more than 10% of the dry content of tomatoes. Citric acid was reported to contribute to approximately 40 – 90% of the total acidity in ripe tomatoes depending on the varieties. Petro-Turza (1987) suggested that the sensation of sourness might be dependent upon the content of organic acids in the fruits. However, no definite relationship between the two has been established. A study by Kader *et al*. (1977) suggested that pH and the interaction between titratable acidity and pH contribute to the perceived sourness of tomatoes. A number of studies have shown a close relationship between the taste and overall flavor intensity of tomatoes and the amount of sugar and soluble solids including fructose and citric acid in the fruits. Although unable to demonstrate a significant influence of acid concentration on descriptive ratings of tomatoes, Malundo *et al.* (1995) suggested that there was a strong possibility that an optimal acid concentration exists in tomato fruit. At this optimal concentration, the quality of the tomato would be more favored by consumers. Those authors also made an assumption that improvements in breeding could help identify this concentration.

Table 1.1 Composition of dry matter content of fresh tomatoes (Davies and Hobson, 1981)

Constituent	Percentage (%)
Fructose	25.0
Glucose	22.0
Saccharose	1.0
Citric Acid	9.0
Malic Acid	4.0
Protein	8.0
Dicarboxylic Amino Acids	2.0
Pectic Substances	7.0
Cellulose	6.0
Hemicellulose	4.0
Minerals	8.0
Lipids	2.0
Ascorbic Acid	0.5
Pigments	0.4
Other Amino Acids, Vitamins, and Polyphenols	1.0
Volatiles	0.1

Instrumental vs. Descriptive Sensory Studies on Flavor of Tomatoes

One focus of tomato research is to determine instrumental quality of tomatoes, which includes compositional and physical properties. Attempts to correlate those quality properties to sensory data and consumer acceptance often have been performed in previous literature. The main goal of these research projects was to facilitate the development or improvement of tomato cultivars that would provide high yields, disease and handling resistant that would be favored by consumers.

Instrumental Measurements and Tomato Flavor

The initial step to instrumental analysis of tomato flavor generally is to separate the volatile from non-volatile components (Yilmaz, 2001). This can be accomplished by vacuum-steam distillation (Buttery *et al*., 1971) or distillation with low temperature (Etievant *et al*., 1996), vacuum condensation (Buttery *et al*., 1998), and dynamic or regular headspace techniques (e.g. Baldwin *et al*., 1991 and 1996). Various techniques then have been used commonly in the literature to identify and quantify tomato components, especially volatile compounds. These techniques include gas chromatography with mass spectrometry (GC-MS) (Baldwin *et al*., 1991 and 1998; Hakim *et al*., 2000; Maneerat *et al*., 2002; and Krumbein *et al.*, 2004), atmospheric pressure chemical ionization-mass spectrometry (API-MS) (Taylor, 1996; Taylor *et al*., 2000; Boukobza *et al*., 2001, 2002), HPLC (Tandon *et al*., 2003), and GC-Olfactometry (Langlois *et al*., 1996). The electronic nose has been introduced to facilitate the determination of flavor changes due to various postharvest factors (e.g. Mual *et al*., 2000).

A review by Petro-Turza (1987) indicated that the average tomato dry matter content ranges between 5.0 – 7.5%. Of the total dry matter content, almost 50% is sugars, 15% organic acids, 2-2.5% free amino acids, and 8% minerals (Yilmaz, 2001). The pH value of fresh tomatoes ranges from 4.2 to 4.6, due primarily to the content of organic acids (Hayes *et al.*, 1998). Sugar and organic acids contribute to the total soluble solids as well as the flavor of tomato (Stevens *et al*., 1977; Jones and Scott, 1983; Malundo *et al*., 1995; Petersen *et al*., 1998). Differences in compositional components were found to be closely associated to other factors including tomato cultivars, growing environment, and other agricultural practices (Bucheli *et al*., 1999). Maul *et al.* (2000) reported that various fresh tomatoes stored at different temperatures did not differ in pH and titratable acidity. Wu and Abbott (2002) and Lana *et al*. (2005) indicated that the firmness of tomatoes decreased minimally during storage period, especially at lower temperature (e.g. 2°C). In a study by Lin and Block (1998) in determining differences between tomatoes harvested at mature green stage and red-ripe stage, results indicated no significant differences in chemical compositions. Auerswald *et al*. (1999a) showed that reduced sugar content of various tomatoes was not different at 7 days after harvested, and that titratable acid content increased with the duration of storage. In addition, Auerswald *et al*. (1999b) indicated that treating tomatoes with increased concentration of nutrient solution increased reducing sugars and titratable acids in the fruit, which resulted in higher perceived sweetness and tomato-like attributes. Increased sugar contents may result in improved flavor quality of fresh tomatoes (Malundo *et al*., 1995).

Extensive reviews have been reported on the impact of various factors including genetic variability, harvest stages, growing conditions and environment on the flavor quality of fresh tomatoes (Davies and Hobson, 1981; Dorais *et al.*, 2001; and Causse *et al*., 2003). Different cultivars generally produce the fruits that vary in sugar contents (Stevens, 1972). Secondary metabolites have also been shown to vary genetically (Davies and Hobson, 1981; and Grolier and Rock, 1998). Garcia and Barrett (2006) stated that cultivar is likely the most important factor that influences the quality of processed tomatoes. Tomatoes harvested at different stages have been shown to differ in the flavor characteristics (Paull, 1999). USDA defined ripening categories for tomatoes (Grierson and Kader, 1986; USDA, 1976), as illustrated in Table 1.2. Fresh tomatoes harvested at the red-ripe stage are considered the best-taste tomatoes. However, fruits at this stage are very fragile and can become damaged easily during postharvest handling and treatments. It is more common that fresh market tomatoes are harvested at mature green stage to extend shelf-life and prevent damage during handling and transportation. Cook *et al*. (1958) indicated that tomatoes harvested at red-ripe stage are more tolerant to chilling injury than those at mature green. Other studies also reported the negative effect low temperature storage has on the flavor of tomatoes included Kader *et al*. (1978), Stern *et al*. (1994) and McDonal *et al*. (1996). Ketelaere *et al*. (2004) found that different tomato cultivars and harvesting time exhibited differences in firmness of the fruits. Kader *et al*. (1977) showed that fresh tomato harvested during mature green stage exhibited some off-flavor.

Table 1.2 USDA ripening categories for tomatoes (USDA, 1976)

Category (Ripening Stage)	Description
Mature Green	Entirely light-to dark-green, but mature
Breaker	First appearance of external pink, red or greenish-yellow color; not more than 10%
Turning	Over 10%, but not more than 30% red, pink or orange-yellow
Pink	Over 30%, but not more than 60% pinkish or red
Light Red	Over 60%, but not more than 90% red
Red	Over 90% red, desirable table ripeness

Aroma volatile compounds are key factors to the flavor characteristics of tomatoes. Over 400 volatile compounds have been identified in fresh tomatoes (Petro-Turza, 1987). Krumbein and Auerswald (1998) and Tandon *et al*. (2000) determined that approximately 34 volatile compounds are the most odor-active in fresh tomatoes and more likely to contribute their flavor characteristics. Many researchers agreed that only a few compounds seem to contribute significantly to the flavor characteristics of tomatoes. Those included hexanal, (*E*)-2-hexenal, (*Z*)-3-hexenal, (*Z*)-3-hexenol, (*E*)-2-(*E*)-4-decadienal, 2-isobutylthiazole, 6-methyl-5-hepten-2-one, 1-penten-3-one and β-ionone (Buttery *et al*., 1971; Petro-Turza 1987; Buttery *et al*., 1988; and Ulrich *et al*., 1997). Although the impact of genetic differences and growing environments on tomato flavor have not been fully understood due to difficulty in developing consistent measuring techniques (Bucheli *et al*., 1999), various factors have been reported to influence the amount of volatile compounds in tomatoes including postharvest treatments. Langlois *et al*. (1996) suggested that volatile compounds can be used to determine differences among tomato cultivars. Krumbein and Auerswald (2000) determined that the important aroma compounds were much higher in cherry tomatoes than others.

Volatile compounds have been shown to decrease significantly when tomatoes are stored at temperature lower than 12.5ºC (Maul *et al*., 2000; and Boukobza and Taylor, 2002). Maul *et al.* (2000) indicated that hexanal, *cis*-3-hexenal, 1-penten-3-one, *trans*-2-hexenal, *trans*-2-heptenal, and *cis*-3-hexenol were reduced significantly when storing tomato at 12.5ºC or lower for 2 days. Boukobza and Taylor (2002) used nine volatile compounds to study the effect storage temperature; those compounds included hexanal, methylbutanal, hexenal, hexenol, 6-methyl-5-hepten-2-one, 2-isobutylthiazole, ethanol, acetaldehyde, methylbutanol and methyl butanal. Boukobza and Taylor (2002) reported that tomato samples stored at 6°C showed a significant decrease in all the nine volatile compounds. They found a considerable increase in ethanol and acetaldehyde in these tomatoes. At lower temperature, the lipid metabolism was interrupted and thus blocked the production of those volatiles (Boukobza and Taylor, 2002). Boukobza and Taylor (2002) also indicated that the increase of ethanol and acetaldehyde primarily contributed to the off flavor in tomato fruits. Tomatoes stored with modified atmosphere conditions have been shown to have reduced amount of volatile compounds (Kader *et al*., 1978; Stern *et al*., 1994; Boukobza and Taylor, 2002; Krumbein *et al.*, 2004). Stern *et al.* (1994) determined that (Z)-3-hexenal was among the most odor-active volatiles and contributed the most to the flavor of red-ripe harvested tomatoes stored at 20ºC. Boukobza and Taylor (2002) reported a significant decrease in hexanal, hexenal, hexenol, methylbutanal, 6-methyl-5-hepten-2-one and 2-isobutylthiazole due to the enriched nitrogen and carbon dioxide gas. Decreased amount of volatile compounds, especially, hexanal, was also reported in tomatoes stored with enriched carbon dioxide gas. Krumbein *et al.* (2004) found differences in volatile compound contents varied among various tomato cultivars during short-term storage. Eight of the volatiles that were found increased during the storage included hexanal, (*E*)-2-heptenal, (*E, E*)-2,4 decadienal, 6-methyl-5-hepten-2-one, geranylacetone, 2-isobutylthiazole, 1-nitro-2-phenylethane, and geranial, and one compound decreased was methyl salicylate.

Tomatoes stored in refrigerators have been shown to have much less concentration of volatiles (Buttery, 1993). Significant loss of many volatile compounds resulted from the processing technique such as paste making. For example, the concentration for (*Z*)-3-hexenal decreased from 12,000 ppb in fresh tomato to 0.7 ppb in tomato paste (Buttery, 1993). On the other hand, some other compounds increased significantly in processed tomato products. Examples of these compounds include dimethyl sulfide, which none was detected in fresh tomato and 2,000 ppb detected in paste; β-damascenone, which 1 ppb found in fresh and 14 ppb in tomato paste; and 3-methylbutyric acid, which 200 ppb found in fresh and 2,000 ppb in tomato paste (Buttery, 1993).

Descriptive Sensory Analysis of Tomato Flavor

Numerous studies have used descriptive sensory analysis techniques and consumer tests to examine flavor quality of tomatoes. Many studies examined the impact of postharvest treatments on the flavor characteristics of tomatoes while others determined relationships between sensory analysis and compositional components of the fruits.

Stevens *et al*. (1977) compared four flavor characteristics of six varieties of fresh market tomatoes. Tomatoes were harvested at the red-ripe stage one day prior to the sensory evaluations. Tomatoes were diced and placed in ceramic cups. Panelist evaluated flavor attributes of each sample on an unstructured 10-cm line scale, anchored “weak” on the left and “strong” on the right. Those included sweetness, sourness, tomato-like, and overall intensity. Some reference standards were provided to assist panelists with their evaluation. The authors reported that tomatoes differed significantly in sweetness and sourness, but not tomato-like flavor. They indicated differences among the samples resulted from variation in sugar and acid contents that differed genetically. They suggested that sugar and acid content contribute not only to the sweetness and sourness, but the overall flavor intensity of tomatoes.

Watada and Aulenbach (1979) determined the impact of harvesting one variety of fresh market tomato at different stages on nine sensory characteristics. Fruits were harvested at mature green, breaker and red-ripe stages. Sensory attributes evaluated in this study included sweetness, acidity, saltiness, grassiness, stemminess, fruity-floral flavor, mustiness, bitterness and astringency. Results indicated that harvesting stages had a significant impact on some sensory characteristics of fresh tomatoes. Sweetness and fruity-floral notes increased significantly when fruits were harvested at red-ripe stage. Saltiness was also higher in red-ripe tomatoes. However, other sensory attributes (i.e. grassiness, stemminess, bitterness, and mustiness) were not found to be different. However, attributes such as green/stemmy, bitter and musty were not found different among tomatoes picked at various ripening stages.

Resurreccion and Shewfelt (1985) used factor and cluster analyses to determine a relationship between sensory information and instrumental measurements of tomato flavor. A variety of fresh tomatoes harvested in winter and spring season, both vine-ripened and ethylene-treated were used. Sensory evaluation was performed using six panelists, who had prior experience in sensory evaluation and discriminative abilities. Panelists rated flavor attributes on 150-mm line scales. The flavor attributes used included sweetness, acidity, tomato-like, off-flavor, overall flavor intensity, juiciness, firmness, color, and preference. The authors did not mention whether the panelists had been trained to be familiar with the sensory attributes used, but the measurement of preference suggests that the panelists were less like trained panelists and more like consumers. Color and firmness were the only attributes that were found to be correlated among the sensory terms and the instrumental measurements reported. Resurreccion and Shewfelt (1985) reported that temperature for storage of tomatoes and ripening techniques were important factors of the flavor quality of fresh tomatoes. They found that tomatoes stored at 21ºC had increased color, sweetness and juiciness. However, tomatoes treated with ethylene gas were not significantly different from those vine-ripened tomatoes.

Bedford (1989) studied the effect of nutrient media varying in electrical conductivities on the sensory characteristics of cherry tomatoes. Two tomato varieties harvested at different ripening stages were used in the study. Sensory evaluation was done with trained panelists. A nine-point numerical scale was used to determine the intensity of each sensory attribute. Texture and flavor characteristics evaluated were firmness of flesh, toughness of skin, dry/pulpy, juiciness, strength of flavor, acid, sweet, savory, salty, green/stemmy, and hay/musty. Definitions of each attribute were provided to facilitate the evaluation. Bedford (1989) showed that tomato fruits became softer and juicier as the electrical conductivity increased. With increased conductivity of the nutrient media, the overall flavor and sweetness of tomatoes were also found more intense. However, no significant differences in the sensory characteristics were identified due to variety.

Malundo *et al.* (1995) attempted to understand the effect of adding sugar and acid to fresh cut tomatoes on their sensory characteristics. Descriptive sensory analysis was conducted to determine the difference between control (i.e. no sugar or acid added) and fresh cut tomatoes soaked with sugar and acid solutions. Malundo *et al.* (1995) only used one variety of tomato and three sensory characteristics, which included sour, sweet and tomato impact. Results from the study showed that adding sugar and acid changed the sweetness and sourness of tomatoes significantly. Malundo *et al*. (1995) reported that although increasing levels of sugar and acid did not affect the so-called “overall tomato impact” of fresh tomatoes, but it did result in higher consumer acceptability.

Ratanachinakorn *et al*. (1997) used quantitative descriptive analysis to evaluate fresh tomatoes harvested at three ripening stages. The scale used for the evaluation was a 15-cm unstructured line scale. Attributes evaluated included tomato aroma, green aroma, off flavor, sweet to sour balance, and blandness. Results showed that only green aroma was significantly different among tomatoes harvested at different stages. The authors indicated treating fresh harvested tomatoes with modified gas such as oxygen, nitrogen and carbon dioxide did not improve or worsen the flavor or aroma characteristics of the tomatoes. Applying modified atmosphere gas to fresh tomatoes delayed the ripening process of tomato fruits differently depending on factors such as application methods, tomato cultivars, and maturity (Ratanachinakorn *et al*., 1997).

Johannson *et al*. (1999) conducted sensory descriptive study to understand the characteristics of various fresh market tomatoes grown cost-effectively and conventionally. Thirteen tomato varieties were used for this study. Seven panelists were trained for the evaluation using an unstructured line scale. The sensory attributes used were red-color, firmness, juiciness, taste intensity, sweetness, bitterness and acidulous. Reference standards were provided only for the basic tastes (i.e. sweet, acid, and bitter) for calibration purposes. The results showed that tomatoes grown ecologically were firmer and juicier than those conventionally grown. However, no flavor differences were found. Johannson *et al*. (1999) indicated that no differences in sensory characteristics were found due to the tomato varieties.

Mual *et al*. (2000) studied the effect of postharvest storage temperatures on the flavor characteristics of fresh tomatoes harvested at red-ripe. The samples were divided and stored at 4 temperatures: 5°C, 10°C, 12.5°C and 20°C for 2 to 12 days. The samples were removed from storage and kept at 20°C for 6 hr before the sensory evaluation began. Descriptive sensory analysis was conducted along with chemical composition and volatile content analysis. For sensory analysis, tomatoes were chopped into coarse puree for the evaluation. Five flavor attributes including typical tomato, sweetness, sourness, green/grassy, and off-flavor, and two aroma attributes, ripe-tomato and off-odor, were used to describe the sensory characteristics of the samples. In general, descriptive results showed that, regardless of the storage duration, tomatoes stored between 5 – 12.5°C were significantly lower in ripe aroma, typical tomato flavor and sweetness, and higher in off-flavor compared to those stored at 20°C. Additionally, the authors reported that mature green tomatoes are more likely to suffer chilling injury when stored at temperature lower than 13ºC.

A study by Rodríguez and coworkers (Rodríguez *et al*., 2001) on canned diced tomatoes used sensory characteristics including integrity of pieces, firmness, fibrosity, juiciness, flavor intensity, freshness, sweetness, acidity, bitterness, saltiness, maturity, tomato concentrate, astringency, and pungency to describe and discriminate canned tomatoes produced from different varieties and locations. Five varieties of tomato were selected for the study and planted in two different locations. In addition to a sensory evaluation technique, physical and chemical analyses of the tomato samples also were performed. These measurements included pH, °Brix, and firmness. The authors suggested that, with the sensory analysis technique used, canned diced tomato samples can be differentiated from one another based on their specific sensory characteristics.

Azodanlou *et al*. (2003) evaluated sensory attributes of fresh tomatoes harvested at the red-ripe stage to determine the appropriateness of the sensory attributes. The sensory panel evaluated intensity of various attributes on a 9-point scale, where 1 represented "very weak intensity" and 9 represented "very strong intensity." Attributes rated included odor, aroma, sweetness, acidity, skin hardness, flesh firmness, juiciness, and mealiness. Twenty eight tomato varieties were used for the evaluation. Significant differences were reported among the set of fresh tomatoes. The authors suggested that of the attributes measured, aroma, sweetness, skin hardness, flesh firmness and juiciness appeared to be important for describing the sensory characteristics of fresh tomatoes. However, the data had low reproducibility, possibly due to the amount of training. Azodanlou *et al*. (2003) did not specify if the panelist received any training prior to performing the evaluation.

Causse *et al.* (2003) examined eight sensory characteristics including sweetness, acidity, tomato aroma, strange aroma, firmness, juiciness, mealiness and skin of fresh tomatoes that varied in genetic variety and environment conditions. Thirteen varieties, ten of which were large round and three were cherry tomatoes, were used in the study. Significant differences in sensory characteristics were found among genotype and growing conditions. Tomato varieties recently developed were found less sweet, more sour and firmer with lower soluble solids and ascorbic acid content than the older tomato varieties. The authors also reported that cherry tomatoes were more flavorful than larger-fruit tomatoes. Hybrid cultivars with old parent lines have been found sweeter, juicier, less firm and mealier than hybrid tomatoes of modern line parents (Causse *et al*., 2003). The authors suggested that even though some instrumental measurements are related to the sensory attributes of tomatoes, they cannot replace the information one would obtain from a descriptive study to understand the characteristics of fresh tomatoes.

Tandon *et al.* (2003) developed prediction models for sensory descriptors to differentiate between different tomatoes based on sensory data and instrumental data. Twelve cultivars of fresh tomatoes grown in greenhouse conditions were selected for the evaluation. Tomato fruits were harvested at red-ripe stage. They were shipped the same day to the evaluation site. The sensory analysis occurred within 2 days after harvested. A modified Spectrum™ technique for descriptive analysis was used to evaluate the flavor attributes of the samples. Panelists were trained to become familiar with the characteristics of tomatoes for eight 1-hr sessions. A 150-mm line scale was used. Tomatoes were cut in halves for the evaluation. Individual panelist evaluated the samples in temperature-controlled separated booths. The attributes used for the evaluation included sweet, salty, sour, bitter, grassy, fruity, tomato-like, green tomato, bite, astringent and metallic. Tandon *et al*. (2003) was among a very few studies that provided definitions and reference standards of sensory attributes to assist the panelists with their evaluation. The authors reported that significant differences were determined in sweetness, sourness, fruity, tomato-like, and bite attributes among the twelve samples. The differences likely were due to intrinsic genetic characteristics of each tomato cultivar. Those tomato samples also showed significant differences in volatile compounds, which suggested that the amount of volatile compounds could contribute to the difference found in the flavor properties.

Abegaz *et al.* (2004) attempted to determine if partitioning taste from flavor components would help to better determine the sensory descriptors for fresh tomatoes. Tomato samples were grown conventionally and harvested at breaker and red-ripe stages. Panelists were trained to evaluate tomato samples using Spectrum™ technique. Definitions and reference standards for the sensory attributes were provided to the panelists. The attributes evaluated include sweet, sour, salty, bitter, tomato-like, over-ripe, green/grassy, fruity, astringency and bite. Results showed that partitioning taste and flavor by blocking the nasal cavity created significant correlation between sensory attributes and some instrumental measurements. Abegaz *et al.* (2004) suggested that the evaluation of tomatoes would be more sensitive when taste and flavor are partitioned.

Krumbein *et al*. (2004) studied the impact of tomato storage condition similar to those of retail/household environment. Three fresh market tomato cultivars were used. All tomatoes were grown hydroponically in a steel-glass greenhouse with climate controlled condition. Tomatoes were harvested at the red-ripe stage and were separated into 3 groups depending on color variation. Storage condition was set to mimic the conditions generally found at retail and household environments. Aroma compounds, sugar and acid analyses as well as a sensory analysis were conducted at harvest and after 4, 7, 10 and 21 days in storage. Qualitative Descriptive Analysis (QDA) was conducted using 10 panelists who completed 40 hours of training. Panelists received whole fruits in random order for the evaluation. An unstructured line scale with 0 – not perceptible and 100 – strongly perceptible was used. The study used a set of sensory attributes including odor (8 attributes), flavor (11 attributes) and aftertaste (8 attributes). Those attributes included intensive, tomato-like, sour, sweet, fruity, moldy, raw potato, fresh-cut grass, bitter, and burning. The tomato-like and moldy attributes were found significantly increased at 4 days after storage, suggesting a relatively short shelf-life of these tomatoes. Other attributes changed over the course of storage but no specific pattern was observed. The impact of variety was not significant. The results, however, showed the increase in amount of volatile compounds in various vine-ripened tomatoes with short-term storage conditions that mimicked those of retail outlets.

Thybo *et al.* (2005) evaluated the sensory characteristics of tomatoes varying in harvest time, maturity, electrical conductivities and nutrient growth media. Ten panelists were trained to participate in the study. The attributes evaluated were redness of surface skin, firmness, crispness, sourness, sweetness, tomato aroma and overall tomato impression after chewing. The authors mentioned that these attributes were used because they can be evaluated with high reproducibility. The evaluation was done using a 15-cm unstructured line scale. Results showed that some sensory attributes including firmness, crispness, sweetness and sourness of tomatoes were significantly different primarily due to the difference in harvesting time. Thybo *et al.* (2005) suggested that the impact of variety and harvesting time was much greater than that of electrical conductivities or growth media.

Relating Sensory Analysis and Instrumental Measurement of Tomato Flavor

Numerous studies attempted to determine the relationship between compositional information and descriptive sensory data of fresh tomatoes. Interest also has increased in studies on relating sensory evaluation information with consumer preference or physico-chemical data

(Sinesio *et al*., 2000; Thybo *et al*., 2005; Serrano-Megias and Lopez-Nicolas, 2006; Lê and Ledauphin, 2006; and Plaehn and Lundahl, 2006). Watada and Aulenbach (1979) suggested that sensory attributes may be quantified using objective measurements. Various research has been conducted to determine the relationship between instrumental and sensory data in order to predict consumer preference of tomatoes, but Causse *et al*. (2003) indicated that although instrumental data were correlated strongly with external quality aspects of tomatoes such as color and firmness, sensory evaluation is necessary for determining flavor quality.

The sugar and acid composition of tomatoes has been related to sensory measures of sweetness and sourness. Reducing sugars, total soluble solids and titratable acid contents have been found to be related, respectively, to the sweetness and sourness of tomatoes (Bisogni *et al*., 1976; Stevens *et al*., 1977; Stevens *et al*., 1979; Malundo *et al*., 1995; Bucheli *et al*., 1999; Tandon *et al*., 2003). Glucose and fructose are the primary sugar compounds contributing to the sweetness; and citric and malic acid are the primary contributor to the acidity of tomatoes (Stevens *et al.*, 1977; Petro-Turza, 1987; and Abegaz *et al*., 2004). In other studies by Kader *et al*. (1977) and Stevens *et al*. (1977), sourness was found to be correlated with pH, sweetness with reducing sugar contents, and off-flavor with the amount of volatile compounds. Bisogni *et al*. (1976) determined that the soluble solids content was correlated with sweetness, overall quality and overall flavor of tomatoes. The flavor characteristics of processed tomato products are influenced by the balance of sugar and acid contents (Garcia and Barrett, 2006). Stevens and colleagues (Stevens *et al*., 1977) reported the relationship between the “sensation of sweetness” and “the glucose-acid interaction” that the presence of glucose and fructose, the interaction between glucose and citric acid, and the interaction between glucose and fructose are responsible for about 80% of the sweetness character of tomatoes. Stevens *et al*. (1977) also indicated that citric acid resulted in lower sweetness of tomatoes when the concentration of sugar was low and in higher sweetness perception when sugar concentration was high. Bisogni *et al*. (1976) reported a strong correlation between titratable acid content and acidity of tomato fruit and determined that total soluble solids was positively correlated with sweetness, overall quantity and flavor of tomatoes. Tandon *et al*. (2003) reported that the sucrose equivalent was correlated with the characteristics of sour, fruitiness, tomato-like, green-tomato, and bite attribute of fresh tomatoes. Additionally, total acidity can be used to describe the sweet, grassy, tomato-like, and astringency characters, whereas sucrose equivalent can describe sour, fruitiness, tomato-like, green-tomato, and bite characters (Tandon *et al*., 2003). Most sugars are, however, destroyed during the processing through heat treatments.

A large body of literature exists attempting to determine the relationship between volatile compounds and sweetness and sourness of tomatoes. Mual *et al*. (2000) found that ripe aroma was primarily influenced by hexanal, β-ionone, methanol, 2+3-methylbutanol, cis-2-hexanal and total soluble solids. Off-odor was impacted by acetaldehyde, acetone, methanol, and pH. Sweetness was influenced by trans-2-heptanal, 1-penten-3-one, and β-ionone and sourness by titratable acidity, β-ionone, hexanal, and 1-nitro-2-phenylethane. Sourness score was negatively correlated with hexanal, trans-2-heptenal, geranylacetone, and β-ionone and positively correlated with methanol. Tandon *et al.* (2003) reported a positive influence of cis-3-hexanal on fruitiness characteristic and a negative influence on astringency. Sweet, sour, grassy, tomato-like, bite and astringency were found influenced by the presence of ethanol. Krumbein *et al*. (2004) associated the volatile compounds with sensory attributes of fresh market tomatoes and found that (*E*)-2-hexenal was associated with fresh-cut grass, intensive, fruity and sweet attributes. (*Z*)-hexanal and 1-penten-3-one were associated with sweet flavor. Hexanal, 2-isobutythiazole, 6-methyl-5-hepten-2-one and (*E*)-2-heptenal were associated with the moldy attribute. Sinesio *et al*. (2000) compared data from electronic noses and sensory attributes and reported that the electric nose provided better discrimination of fresh tomatoes.

Various studies have attempted to determine the relationship between descriptive sensory analysis information with consumer data. The primary goal for these attempts was to determine a means to improve the quality of tomatoes that meet consumer expectation while providing high yield, disease resistant, and long shelf-life. Azodanlou *et al*. (2003) reported that aroma and sweetness were the most important quality attributes for tomatoes and the sweetness may be used to determine consumer acceptability of tomatoes, but those authors did not measure many specific sensory qualities of flavor or aroma. Thybo *et al*. (2005) reported high correlation between sensory and physical data on firmness of tomatoes and Serrano-Megias and Lopez-Nicolas (2006) reported that tomato odor, flavor, sweetness, acidity and hardness were positively correlated with consumer preference. In studies with more detailed sensory descriptions, Lengard and Kermit (2006), Lê and Ledauphin (2006), and Plaehn and Lundahl (2006) attempted to determine positive and negative drivers of liking of tomatoes, and reported similar results in that some sensory attributes including tomato odor and flavor, sweetness, juiciness, skin color and firmness illustrated positive impact on consumer liking whereas mealiness and skin thickness illustrated negative impact.

Conclusions

Numerous published studies have been done to examine the sensory characteristics and compositional properties of fresh tomatoes as influenced by factors such as genotypes, growing conditions, and postharvest treatments. That research has received much attention because of continued criticism on the lack of flavor characteristics in fresh market tomatoes in the past two decades. Many studies focused on using instrumental measurements to understand these impacts, while others attempted to use sensory evaluation to determine the flavor and texture quality of tomatoes. Attempts to correlate instrumental and sensory data have been done. Although sensory evaluation has been considered, many studies only included a small number of flavor/texture attributes. In order to better understand the sensory components of fresh tomatoes, more extensive descriptive sensory analysis should be pursued. In addition, minimal work has been done to determine the sensory characteristics appropriate for describing both fresh and processed tomatoes. Moreover, no research has been conducted to compare and contrast similarities or differences between fresh and processed tomatoes of the same cultivars, to better understand the impact of heat processing on the sensory properties of the products.

References

ABEGAZ, E.G., TANDON, K.S., SCOTT, J.W., BALDWIN, E.A. and SHEWFELT, R.L. 2004. Partitioning taste from aromatic flavor notes of fresh tomato (*Lycopersicon esculentum*, Mill) to develop predictive models as a function of volatile and nonvolatile components. Postharvest Biol. Technol. *34*, 227-235.

AGARWAL, S. and VENKETESHWER, R. 1998. Tomato lycopene and low-density lipoprotein oxidation: a human dietary intervention study. Lipids. *33*, 981-984.

AGARWAL, S., SHEN, H. and AGARWAL, S. 2001. Lycopene content of tomato products: its stability, bioavailability and *in vivo* antioxidant properties. J. Med. Food. *4*, 9-15.

APARICIO, R. and MORALES, M.T. 1998. Characterization of olive ripeness by green aroma compounds of virgin olive oil. J. Agric. Food Chem. *46*, 1116-1122.

ARAIS, S., KOYANAGI, O. and FUJIMAKI, M. 1967. Studies on flavor components in soybean part IV: Volatile neutral compounds. Agric. Biol. Chem. *7*, 868-873.

AUERSWALD, H., PETERS, P., BRUCKNER, B. KRUMBEIN, A. and KUCHENBUCH, R. 1999a. Sensory analysis and instrumental measurements of short-term stored tomatoes (Lycopersicon esculentum Mill.) Postharvest Biol. Technol. *15*, 323-334.

AUERSWALD, H., SCHWARZ, D., KORNELSON, C., KRUMBEIN, A. and BRUCKNER, B. 1999b. Sensory analysis, sugar and acid content of tomato at different EC values of the nutrient solution. Sci. Hort. *82*, 227-242.

AZODANLOU, R., DARBELLAY, C., LUISIER, J.L., VILLETTAZ, J.C. and AMADÒ, R. 2003. Quality assessment of strawberries (*Fragaria* species). J. Agric. Food Chem. *51*, 715-721.

BALDWIN, E.A., NISPEROS-CARRIEDO, M.O. BAKER, R. and SCOTT, J.W. 1991. Quantitative analysis of flavor parameters in six Florida tomato cultivars (Lycopersican esculentum, Mill). J. Agric. Food Chem. *39*, 1135-1140.

BALDWIN, E.A., MCDONALD, R.E. and MCCOLLUM, T.G. 1996. Prestorage heat treatment influence free sterols and flavor volatiles of tomatoes stored at chilling temperature. J. Am. Soc. Hort. Sci. *121*, 531-536.

BALDWIN, E.A., SCOTT, J.W., EINSTEIN, M.A., MALUNDO, T.M.M., CARR, B.T., SHEWFELT, R.L. and TANDON, K.S. 1998. Relationship between sensory and instrumental analysis for tomato flavor. J Am Soc Hort Sci. *125*, 906–915.

BALDWIN, E.A., GOODNER, K., PLOTTO, A., PRITCHETT, K. and EINSTEIN, M. 2004. Effect of volatiles and their concentration on perception of tomato descriptors. J. Food Sci. *69*, S310-S318.

BATU, A. 2004. Determination of acceptable firmness and colour values of tomatoes. J. Food Eng. *61*, 471-475.

BEDFORD, L.V. 1989. Sensory quality of fresh tomatoes: comparison of tomatoes grown in nutrient media of different conductivities. Camden Food and Drink Research Association/Technical Memorandum No. 531.

BISOGNI, C.A. and AMBREESTER, G. 1976. Quality comparisons of room ripened and field ripened tomato fruits. J. Food Sci. *41*, 333-338.

BOTT, L. and CHAMBERS, E. IV. 2006. Sensory characteristics of combinations of chemicals potentially associated with beany aroma in foods. J. Sens. Stud. *21*, 308-321.

BOUKOBZA, F., DUNPHY, P.J. and TAYLOR, A.J. 2001. Measurement of lipid oxidation-derived volatiles in fresh tomatoes. Postharvest Biol. Technol. *23*, 117-131.

BOUKOBZA, F. and TAYLOR, A.J. 2002. Effect of postharvest treatment on flavour volatiles of tomatoes. Postharvest Biol. Technol. *25*, 321-331.

BRAUSS, M.S., LINFORTH, R.S. and TAYLOR, A.J. 1998. Effect of variety, time of eating and fruit-to-fruit variation on volatile release during eating of tomato fruits (*Lycopersicon esculentum*). J. Agric. Food Chem. *46*, 2287–2292.

BRUHN, C.M., FELDMANN, N., GARTITZ, C., HARWOOD, J., IVANS, E., MASHALL, M., RILEY, A., THURBER, D. and WILLAMSON, E. 1991. Consumer perceptions of quality: apricots, cantaloupes, peaches, pears, strawberries, and tomatoes. J. Food Qual. *14*, 187–195.

BRUMFIELD, R.G., ADELAJA, A.O. and LININGER, K. 1993. Consumer tastes, preferences, and behavior in purchasing fresh tomatoes. J. Am. Soc. Hort. Sci. *118*, 433-438.

BUCHELI, P., VOIROL, E., DELATORRE, R., LOPEZ, J., RYTZ, A., TANKSLEY, S.D. and PETIARD, V. 1999. Definition of nonvolatile markers for flavor of tomato (*Lycopersicon esculentum* Mill.) as tools in selection and breeding. J. Agric. Food Chem. *47*, 659–664.

BUESCHER, R.W. 1979. Influence of carbon dioxide on postharvest ripening and deterioration of tomatoes. J. Am. Soc. Hort. Sci. *104*, 545–547.

BUETTNER, A. and MESTRES, M. 2005. Investigation of the retronasal perception of strawberry aroma aftersmell depending on matrix composition. J. Agric. Food Chem. *53*, 1661-1669.

BULT, J. H. F., SCHIFFERSTEIN, H. N. J., ROOZEN, J. P., BORONAT, E. D., VORAGEN, A. G. J. and KROEZE, J. H. A. 2002. Sensory evaluation of character impact components in an apple model mixture. Chem. Senses. *27*, 485-494.

BUTTERY, R.G., SEIFERT, R.M., GUADAGNI, D.G. and LING, L.C. 1971. Characterization of additional volatile components of tomato. J. Agric. Food Chem. *19*, 524-529.

BUTTERY, R.G., TERANISHI, R. and LING, L.C. 1987. Fresh tomato aroma volatiles: A quantitative study. J. Agric. Food Chem. *35*, 540–544.

BUTTERY, R. G., TERANISHI, R., LING, L. C. and FLATH, R. A. 1988. Quantitative studies on origins of fresh tomato aroma volatiles. J. Agric. Food Chem. *36*, 1247–1250.

BUTTERY, R.G. 1993. Quantitative and sensory aspects of flavour of tomato and other vegetables and fruits. Flavor Science. Acree, T.E., Teranishi, R., American Chemical Society, Washington DC, 259–285.

BUTTERY, R.G. and LING, L.C. 1993. Volatile components of tomato fruit and plant parts: Relationship and biogenesis. In: Teranishi, R., Buttery, R.G., Sugisawa, H. (Eds.), Bioactive Volatile Compounds from Plants: ACS Symposium Series No. 525. American Chemical Society, Washington, DC, pp. 23–34.

BUTTERY, R.G., TERANISHI, R., FLATH, R.A. and LING, L.C. 1998. Fresh tomato volatiles: Composition and sensory studies. In: Teranishi, R., Buttery, R.G., Shahidi, F. (Eds.), Flavor Chemistry: Trends and Developments: ACS Symposium Series No. 388. American Chemical Society, Washington, DC, pp. 213–222.

CAPORALE, G., POLICASTRO, S. and MONTELEONE, E. 2004. Bitterness enhancement induced by cut grass odorant (cis-3-hexen-1-ol) in a model olive oil. Food Qual. Pref. *15*, 219–227.

CAUSSE, M., BURET, M., ROBINI, K. and VERSCHAVE, P. 2003. Inheritance of nutritional and sensory quality traits in fresh market tomato and relation to consumer preferences. J. Food Sci. *68*, 2342-2350.

CHAMBERS D.H, ALLISON, A.A. and CHAMBERS E. IV. 2004. Effects of Training on Performance of Descriptive Sensory Panelists. J. Sens. Stud. 19: 486-499.

CHAMBERS, E. IV, JENKINS, A. and MCGUIRE, B. 2006. Flavor properties of plain soymilk. J. Sens. Stud. 21: 165-179.

CHUNG, T.Y., KURATA, T., KATO, H. and FUJIMAKI, M. 1979. Change of flavor components of tomato fruits during artificial ripening. J. Agric. Chem. Soc. Japan (Nippon Nogei Kogaku Kaishi). *53*, 391-341.

CLINTON, S.K. 1998. Lycopene: Chemistry, biology and implications for human health and disease. Nutr. Rev. *56*, 35–51.

COOK, C.C., PARSONS, C.S. and MCCOLLOCH, L.P. 1958. Methods to extend storage of fresh vegetables aboard ships of the U.S. Navy. Food Tech. *12*, 548.

COOK-MOZAFFARI, P.J., AZORDEGAN, F., DAY, N.E., RESSICAUD, A., SABAI, C. and ARAMESH, B. 1979. Oesophageal cancer studies in the Caspian Littoral of Iran: results of a case-control study. Br. J. Cancer. *39*, 293–309.

CROUZET, J., SIGNORET, A., COULIBALY, J. and ROUDSARI, M.H. 1986. Influence of controlled atmosphere storage on tomato volatile components. Dev Food Sci. *12*, 355–367.

CUELLAR, S. R. 2002. Marketing fresh fruit and vegetable imports in the U.S.: Status, Challenge and Opportunity. Research Bulletin (R. B. 2002-2004). pp. 20. Food Industry Management, Cornell University, Ithaca, New York.

DALAL, K.B., OLSON, L.E., YU, M.H. and SALUNKHE, K.B. 1967. Gas chromatography of the field-, glass-greenhouse-grown, and artificially ripening tomatoes. Phytochemistry. *6*, 155-157.

DALAL, K.B., SALUNKHE, D.K., OLSON, L.E., DO, S.Y. and YU, M.H. 1968. Volatile components of developing tomato fruit grown under field and greenhouse conditions. Plant Cell Physiol. *9*, 389-400.

DAVIES, J.N. and HOBSON, G.E. 1981. The constituents of tomato fruit – the influence of environment, nutrition and genotype. Crit. Rev. Food Sci. Nutr. *15*, 205-280.

DIRINCK, P., SCHREYEN, L., van WASSENHOVE, F.V. and SCHAMP, N. 1976. Flavor quality of tomatoes. J. Sci. Food Agric. *27*, 499-508.

DORAIS, M., PAPADOPOULOS, A.P. and GOSSELIN, A. 2001. Greenhouse tomato fruit quality. Hortic. Rev. *26*, 239-319.

DRAVNIEKS, A. 1985. *Atlas of odor character profiles. ASTM Data series DS61*. American Society for Testing and Materials, Philadelphia, PA.

ETIEVANT, P.X., LANGLOIS, D., PIERRON, P. and JERROT, A. 1996. Sensory and instrumental characterization of commercial tomato varieties. Z Lebens Unters Forsch. *203*, 534-540.

FURIA, T.E., and BELLANCA, N. eds. 1975. *Fenaroli's handbook of flavor ingredients, 2nd ed. Vol. 2*, pp. 248, 253. CRC Press, Cleveland, Ohio.

GALÁN-SOLDEVILLA, H., RUIZ-PÉREZ-CACHO, M. P., SERRANO JIMÉNEZ, S., JODRAL VILLAREJO, M. and BENTABOL MANZANARES, A. 2005. Development of a preliminary sensory lexicon for floral honey. Food Qual. Pref. *16*, 71-77

GARCIA, E. and BARRETT, D.M. 2006. Evaluation of processing tomatoes from two consecutive growing seasons: quality attributes, peelability and yield. J. Food Process. Preserv. *30*, 20-36.

GEESON, J.D., BROWNE, K.M., MADDISON, K., SHEPHERD, J., and GUARALDI, F. 1985. Modified atmosphere packaging to extend the shelf-life of tomatoes. J. Food Technol. *20*, 339–349.

GOULD, W.A. 1983. Tomato production, processing and quality evaluation. Avi. Pub. Co., Westport, Colorado. pp. 445.

GREEN-PETERSEN, D.M.B., NIELSEN, J. and HYLDIG, G. 2006. Sensory Profiles of the most common salmon products on the Danish market. J. Sens. Stud. *21,* 415-427.

GRIERSON, A. and KADER, A.A. 1986. Fruit ripening and quality. In J. G. Atherton, & J. Rudich (Eds.), Tomato crop (pp. 241–280). USA: Chapman and Hall Ltd.

GROLIER, P. and ROCK, E. 1998. Composition of tomato in antioxidants: variations and methodology. In Proceedings of the tomato and health seminar, 1998, May 25-28, Pamplona, Spain, Avignon, France: Amitom. pp 23-25.

GUTH, H. and GROSCH, W. 1991. A comparative study of the potent odorants of different virgin olive oils. Fat. Sci. Technol. *93*, 335-339.

GUTH, H. and GROSCH, W. 1993. Quantitation of potent odorants of virgin olive oil by stable-isotope dilution assays. J. Am. Oil Chem. Soc. *70*, 513-518.

HAKIM, A., BATAL, K.M., AUSTIN, M.E., GULLO, S. and KHATOON, M. 2000. Quality of packaged fresh-cut tomatoes. Adv. Hort. Sci. *14*, 59-64.

HATANAKA, A. 1996. The fresh green odor emitted by plants. Food Rev. Int. *12*, 303-350.

HAYASE, F., CHUNG, T.Y. and KATO, H. 1984. Changes of volatile components of tomato fruits during ripening. Food Chem. *14*, 113-124.

HAYES, W.A., SMITH, P.G. and MORRIS, A.E.J. 1998. The production and quality of tomato concentrates. Crit. Rev. Food Sci. Nutr. *38*, 537-564.

HO, L. 1996. The mechanism of assimilates partitioning and carbohydrate compartmentation in fruit in relation to the quality and yield of tomato. J. Exp. Bot. *47*, 1239–1243.

HOBSON, G. 1988. How the tomato lost its taste. New Scientist. *1632*, 46–50.

HOBSON, G.E. 1981. The short-term storage of tomato fruit. J. Hortic. Sci. *56*, 363–368.

ITO, Y., SUGIMOTO, A., KAKUDA, T. and KUBOTA, K. 2002. Identification of potent odorants in Chinese Jasmine Tea scented with flower of *Jasminum sambac*. J. Agric. Food Chem. *50*, 4878-4884.

JAKOBSEN, H.B., HANSEN, M., CHRISTENSEN, M.R. BROCKHOFF, P.B. and OLSEN, C.E. 1998. Aroma volatiles of blanched green peas (*Pisum sativum* L.). J. Agric. Food Chem. *46*, 3727-3734.

JIANG, L. and KUBOTA, K. 2004. Differences in the volatile components and their odor characteristics of green and ripe fruits and dried pericarp of Japanese pepper (*Xanthoxylum piperitum* DC.). J. Agric. Food Chem. *52*, 4197-4203.

JIANG, L. 2005. Volatile composition of the laksa plant (*Polygonum hydropiper* L.), a potential source of green note aroma compounds. Flavour Fragr. J. *20*, 455-459.

JOHANSSON, L., HAGLUND, A., BERGLUND, L., LEA, P. and RISVIK, E. 1999. Preference for tomatoes, affected by sensory attributes and information about growth conditions. Food Qual. Pref. *10*, 289-298.

JOHNSON, J.H., GOULD, W.A., BADENSHOP, A.F. and JOHNSON, R.M. JR. 1968. Quantitative comparison of isoamylol, pentanol, and 3-hexen-1-ol in tomato juice. Varietal and harvest differences and processing effects. J. Agric. Food Chem. *16*, 255-258.

JONES, R.A. and SCOTT, S.J. 1983. Improvement of tomato flavor by genetically increasing sugar and acid content. Euphytica. *32*, 845-855.

JORDÁN, M.J., MARGARÍA, C.A., SHAW, P.E. and GOODNER, K.L. 2003. Volatile components and aroma active compounds in aqueous essence and fresh pink guava fruit puree (*Psidium guajaVa* L.) by GC-MS and multidimensional GC/GC-O. J. Agric. Food Chem. *51*, 1421-1426.

KADER, A.A., STEVENS, M.A., ALBRIGHT-HOLTON, M., MORRIS, L.L. and ALGIZI, M. 1977. Effect of fruit ripeness when picked on flavor and composition in fresh market tomatoes. J. Am. Soc. Hortic. Sci. *102*, 724–731.

KADER, A.A., MORRIS, L.L., STEVENS, M.A. and ALLBRIGHT-HOLTON, M. 1978. Composition and flavor quality of fresh market tomatoes as influenced by some postharvest handling procedures. J. Am. Soc. Hort. Sci. *103*, 6–13.

KADER, A.A., ZAGORY, D. and KERBEL, E.L. 1989. Modified atmosphere packaging of fruits and vegetables. Crit. Rev. Food Sci. Nutr. *28*, 1–30.

KAZENIAC, S.J. and HALL, R.M. 1970. Flavor chemistry of tomato volatiles. J. Food Sci. *35*, 519-530.

KETELAERE, B.D., LAMMERTYN, J., MOLENBERGHS, G., DESMET, M., NICOLAÏ, B. and BAERDEMAEKER., J.D. 2004. Tomato cultivar grouping based on firmness change, shelf life and variance during postharvest storage. Postharvest Biol. Technol. *34*, 187-201.

KING, B.M., ARENTS, P., DUINEVELD, C.A.A., MEYNERS, M., SCHROFF, S.I. and SOEKHAI, S.T. 2006. Orthonasal and retronasal perception of some green leaf volatiles used in beverage flavors. J. Agric. Food Chem. *54*, 2664 - 2670.

KLIEBER, A., RATANACHINAKORN, B. and SIMONS, D.H. 1996. Effects of low oxygen and high carbon dioxide on tomato cultivar ‘Bermuda’ fruit physiology and composition. Sci. Hortic. *65*, 251–261.

KOHLMEIER, L., KARK, J.D., GOMEZ-GRACIA, E., MARTIN, B.C., STECK, S.E., KARDINAAL, A.F., RINSTAD, J., THAMM, M., MASAEV, V., RIEMERSMA, R., MARTIN-MORENO, J.M., HUTTUNEN, J.K. and KOK, F.J. 1997. Lycopene and myocardial infarction risk in the EURAMIC Study. Am. J. Epidemiol. *146*, 618 –626.

KOMTHONG, P., KATOH, T., IGURA, N. and SHIMODA, M. 2006. Changes in the odours of apple juice during enzymatic browning. Food Qual. Pref. *17*, 497–504

KRUMBEIN, A. and AUERSWALD, H. 1998. Characterization of aroma volatiles in tomatoes by sensory analysis. Nahrung. *42*, 395–399.

KRUMBEIN, A., PETERS, P. and BRÜCKNER, B. 2004. Flavor compounds and a quantitative descriptive analysis of tomatoes (Lycopersicon esculentum Mill.) of different cultivars in short-term storage. Postharvest Biol. Technol. *32*, 15-28.

LANA, M.M., TIJSKENS, L.M.M., and KOONER, O. 2005. Effect of storage temperature and fruit ripening on firmness of fresh cut tomatoes. Postharvest Biol. Technol. *35*, 87-95.

LANGLOIS, D., ETIEVANT, P.X., PIERRON, P. and JORROT, A. 1996. Sensory and instrumental characterisation of commercial tomato varieties. Z. Lebensm. Unters. Forsch. *203*, 534–540.

LÊ, S. and LEDAUPHIN, S. 2006. You like tomato, I like tomato: segmentation of consumers with missing values. Food Qual. Pref. *17*, 228-233.

LEE, S.Y., LUNA-GUZMÁN, I., CHANG, S., BARRETT, D.M., and GUINARD, J.X. 1999. Relating descriptive analysis and instrumental texture data of processed diced tomatoes. Food Qual. Pref. *10*, 447-455.

LEE, A., THURNHAM, D.I. and CHOPRA, M. 2000. Consumption of tomato products with olive oil but not sunflower oil increases the antioxidant activity of plasma. Free Rad. Biol. Med. *29,* 1051-1055.

LENGARD, V. and KERMIT, M. 2006. 3-Way and 3-block PLS regressions in consumer preference analysis. Food Qual. Pref. *17*, 234-242.

LIN, S. and BREWER, M.S. 2005. Effects of blanching method on the quality characteristics of frozen peas. J. Food Quality. *28*, 350-360.

LIN, W.C. and BLOCK, G.S. 1998. The effect of culture practice and storage temperature on quality and flavor volatiles of greenhouse tomatoes. Acta Hortic. *464*, 213 – 218.

LIU, Q.Y., HUNG, J.C., HEBER, D., GO, V.L., REUTER, V.E., CORDON-CARDO, C., SCHER, H.I., MARSHALL, J.R. and ZHANG, Z.F. 2001. Inverse associations between plasma lycopene and other carotenoids and prostate cancer. Cancer Epidemiol. Biomarkers Prev. *10*, 749 –756.

LUCIER, G., LIN, B., ALLSHOUSE, J. and KANTOR, L. 2000. Factors affecting tomato consumption in the United States. Economic Research Service; Vegetables and Specialties. *282*, 26-32.

LUCIER, G. 2006. Tomatoes. Economic Research Services Briefing Room. www.ers.usda.gov.

LUGASI, A., BÍRÓ, L., HÓVÁRIE, J., SÁGI, K.V., BRANDT, S. and BARNA, É. 2003. Lycopene content of foods and lycopene intake in two groups of Hungarian population. Nutr. Res. *23*, 1035-1044.

MALUNDO, T.M.M., SHEWFELT, R.L. and SCOTT, J.W. 1995. Flavor quality of fresh tomato (*Lycopersicon esculentum* Mill.) as affected by sugar and acid levels. Postharvest Biol. Technol. 6, 103–110.

MANEERAT, C., HAYATA, Y., KOZUKA, H., SAKAMOTO, K. and OSAJIMA, Y. 2002. Application of the Porapak Q column extraction method for tomato flavor volatile analysis. J. Agric. Food Chem. *50*, 3401-3404.

MAUL, F., SARGENT, S.A., SIMS, C.A., BALDWIN, E.A., BALABAN, M.O. and HUBER, D.J. 2000. Tomato flavor and aroma quality as affected by storage temperature. J. Food Sci. *65*, 1228–1237.

MCDONALD, R.E., MCCOLLUM, T.G. and BALDWIN, E.A. 1996. Prestorage heat treatments influence free sterols and flavor volatiles of tomatoes stored at chilling temperature. J. Am. Soc. Hort. Sci. *121*, 531-536.

MCGLASSON, W.B., LAST, J.H., SHAW, K.J. and MELDRUM, S.K. 1987. Influence of non-ripening mutants rin and nor on the aroma of tomato fruit. Hort. Sci. *22*, 632–634.

MIERS, J.C. 1966. Formation of Volatile Sulfur Compounds in Processed Tomato Products. J. Agric. Food Chem. *14*, 419-423.

MORALES, M.T., CALVENTE, J.J. and APARICIO, R. 1996. Influence of olive ripeness on the concentration of green aroma compounds in virgin olive oil. Flavour Fragr. J. *11*, 171-178.

MORALES, M.T. and APARICIO, R. 1999. Effect of extraction conditions on sensory quality of virgin olive oil. J. Am. Oil Chem. Soc. *76*, 295-300.

PAÇI KORA, E., LATRILLE, E., SOUCHON, I. and MARTIN, N. 2003. Texture-flavor interactions in low fat stirred yogurt: how mechanical treatment, thickener concentration and aroma concentration affect perceived texture and flavor. J. Sens. Stud. *18*, 367-390.

PAULL, R.E., 1999. Effect of temperature and relative humidity on fresh commodity quality. Postharvest Biol Technol. *15*, 263–277.

PETERSEN, K.K., WILLUMSEN, J. and KAACK, K. 1998. Composition and taste of tomatoes as affected by increased salinity and different salinity sources. J. Hortic. Sci. Biotechnol. *73*, 205-215.

PETRO-TURZA, M. 1987. Flavor of tomato and tomato products. Food Rev. Int. *2*, 309-351.

PINO, J.A., MARBOT, R. and VAZQUEZ, C. 2001. Characterization of volatiles in strawberry guava (*Psidium cattleianum* Sabine) fruit. J. Agric. Food Chem. *49*, 5883-5887.

PLAEHN, D. and LUNDAHL, D.S. 2006. An L-PLS preference cluster analysis on French consumer hedonics to fresh tomatoes. Food Qual. Pref. *17*, 243-256.

POLLACK, S. L. 2001. Consumer demand for fruit and vegetables: the U.S. Example. Changing structure of global food consumption and trade. pp. 49-54. Economic Research Services/USDA.

RATANACHINAKORN, B., KLIEBER, A. and SIMONS, D.H. 1997. Effect of short-term controlled atmospheres and maturity on ripening and eating quality of tomatoes. Postharvest Biol. Technol. *11*, 149-154.

REINERS, J. and GROSCH, W. 1998. Odorants of virgin olive oils with different flavor profiles. J. Agric. Food Chem. *46*, 2754-2763.

RESURRECCION, A.V.A. and SHEWFELT, R.L. 1985. Relationship between sensory attributes and objective measurements of postharvest quality of tomatoes. J. Food Sci. *50*, 1242-1245.

RODRÍGUEZ, A., LOPEZ, J., GONZALEZ, C., DE LA TORRE, R. and MANGUT, V. 2001. Sensory Evaluation of canned diced tomato varieties. Proc. 7th Int. Symp. On Processing Tomato. Acta Hort 542, ISHS 2001. pp. 269-275.

SALAS, J.J., SANCHEZ, C., GARCIA-GONZALEZ, D.L. and APARICIO, R. 2005. Impact of the suppression of lipoxygenase and hydroperoxide lyase on the quality of the green odor in green leaves. J. Agric. Food Chem. *53*, 1648-1655.

SANO, K., TSUDA, Y., SUGANO, H., AOU, S. and HATANAKA, A. 2002. Concentration effects of green odor on event-related potential (P300) and pleasantness. Chem. Senses. *27*, 225-230.

SERRANO-MEGÍAS, M. and LÓPEZ-NICOLÁS J.M. 2006. Application of agglomerative hierarchical clustering to identify consumer tomato preferences: influence of physicochemical and sensory characteristics on consumer response. J. Sci. Food Agri. *86*, 493-499.

SINESIO, F., DI NATALE, C., QUAGLIA, G.B., BUCARELLI, F.M., MONETA, E., MACAGNANO, A., PAOLESSE, R. and D'AMICO, A. 2000. Use of electronic nose and trained sensory panel in the evaluation of tomato quality. J. Sci. Food Agric. *80*, 63-71.

STERN, D.J., BUTTERY, R.G., TERANISHI, R., LING, L., SCOTT, K. and CANTWELL, M. 1994. Effect of storage and ripening on fresh tomato quality, Part I. Food Chem. *49*, 225-231.

STEVENS, M.A. 1972. Citrate and malate concentrations in tomato fruits: genetic control and maturational effects. J. Am. Soc. Hort. Sci. *97*, 655-658.

STEVENS, M.A., KADER, A.A., ALBRIGHT-HOLTON, M. and ALGAZI, M. 1977. Genotypic variation for flavor and composition in fresh market tomatoes. J. Am. Soc. Hortic. Sci. *102*, 680-689.

STEVENS, M.A., KADER, A.A. and ALBRIGHT, M. 1979. Potential for increasing tomato flavor via increased sugar and acid content. J. Am. Soc. Hort. Sci. *104*, 40–42.

TAKAHASHI, N. SASAKI, R. and CHIBA, H. 1979. Enzymatic improvement of food flavor IV: Oxidation of aldehydes in soybean extracts by aldehyde oxidase. Agric. Biol. Chem. *43*, 2557-2562.

TANDON, K.S., BALDWIN, E.A. and SHEWFELT, R.L. 2000. Aroma perception of individual volatile compounds in fresh tomatoes (*Lycopersicon esculentum*, Mill.) as affected by the medium of evaluation. Postharvest Biol. Technol. *20*, 261-268.

TANDON, K.S., BALDWIN, E.A., SCOTT, J.W. and SHEWFELT, R.L. 2003. Linking sensory descriptors to volatile and nonvolatile components of fresh tomato flavor. J. Food Sci. *68*, 2366-2371.

TAYLOR, A.J. 1996. Volatile flavor release from foods during eating. Crit. Rev. Food Sci. Nutr. *36*, 765–784.

TAYLOR, A.J., LINFORTH, R.S.T., HARVEY, B.A. and BLAKE, A. 2000. Atmospheric pressure chemical ionisation mass spectrometry for in vivo analysis of volatile flavour release. Food Chem. *71*, 327–338.

THAKUR, B. R., SINGH, R. K., and NELSON, P. E. 1996. Quality attributes of processed tomato products: a review. Food Rev. Int. *12***,** 375–401.

THYBO, A.K., BECHMANN, I. and BRANDT, K. 2005. Integration of sensory and objective measurements of tomato quality: quantitative assessment of the effect of harvest date as compared with growth medium (soil *versus* rockwool), electrical conductivity, variety and maturity. J. Sci. Food Agric. *85*, 2289–2296.

TSUGANE, S., TSUDA, N., GEY, F. and WATANABE, S. 1992. Cross-sectional study with multiple measurements of biological markers for assessing stomach cancer risks at the population level. Environ. Health Perspect. *98*, 207–210.

ULRICH, D., KRUMBEIN, A. and RAPP, A. 1997. Analysis of aroma compounds in strawberry, sour cherry and tomato by gas chromatography after solid phase micro-extraction. Deutsche Lebensmittel Rundschau. *93*, 311–316.

USDA. 1976. United States standards for grade of fresh tomatoes. US Dept. Agric., Mktg., Serv., Washington DC. pp. 10.

VARA-UBOL, S., CHAMBERS, E. IV. and CHAMBERS, D.H. 2004. Sensory characteristics of chemical compounds potentially associated with beany aroma. J. Sens. Stud. *19*, 15-26.

VILANOVA, M. and SOTO, B. 2005. The impact of geographic origin on sensory properties of *Vitis vinifera cv.* Mencia. J. Sens. Stud. *20,* 503-511.

WANG, Z.H., DOU, J., MACURA, D. DURANCE, T.D. and NAKAI, S. 1998. Solid phase extraction for GC analysis of beany flavours in soymilk. Food Res. Intern. *30*, 503-511.

WATADA, A.E. and AULENBACH, B.B. 1979. Chemical and sensory qualities of fresh market tomatoes. J. Food Sci. *44*, 1013–1016.

WILKENS, W.F. and LIN, F.M. 1970. Gas chromatographic and mass spectral analyses of soybean milk volatiles. J. Agric. Food Chem. *18*, 333-336.

WRIGHT, J. 2004. *Flavor Creation*. Allured Publishing, Carol Stream, Illinois. pp. 200.

WU, T. and ABBOTT, J.A. 2002. Firmness and force relaxation characteristics of tomatoes stored intact or as slices. Postharvest Biol. Technol. *24*, 59–68.

XIANQUAN, S., SHI, J., KAKUDA, Y. and YUEMING, J. 2005. Review stability of lycopene during food processing and storage. J. Med. Food. *8*, 413-422.

YILMAZ, E. 2001. The chemistry of fresh tomato flavour. Turk. J. Agric. Forest. *25*, 149-155.

CHAPTER 2 - Detailed Materials and Methods to a Lexicon for Green Odor and Characteristics of Chemicals Associated with Green Odor in Foods

This study consisted of two phases: Phase 1 - Determining the Sensory Characteristics of "Green" and Phase 2 - Evaluation of Various Chemicals Associated with "Green". The objectives of this study were (1) to identify and define the sensory attributes contributing to green aroma/flavor, and (2) to describe the sensory characteristics, using clearly defined terms established by a highly trained descriptive sensory panel, of various chemicals that had been associated with green notes in previous literature.

Panelists

A six-member highly trained panelists from the Sensory Analysis Center, Kansas State University (Manhattan, KS) participated in the study. Each panelist had completed 120 hours of training on general sensory techniques and analysis. They have more than 1000 hours of experience in testing a wide variety of food products including products where a descriptor such as "green" has been used (e.g. beans). Each panelist had a broad background of experience in odor description and evaluation.

Samples and Sample Preparation

Food Products

A total of 32 products were evaluated in Phase 1. Food products used included fresh and processed vegetables, ripe and unripe fruits, herbs, soy products, green tea, potatoes, and raw nuts (Table 2.1). Products were purchased from local grocery stores approximately 3-5 days prior to testing. Most samples were evaluated at room temperature (~ 20°C). In general, all fruits and vegetables were rinsed and cut into small pieces, before placing in odor-free 3.25 oz. (~96 mL) plastic cups covered with lids. The green tea sample was steeped for 1 min at 70°C and served warm. Soy milks were kept refrigerated and evaluated cold (~ 5-7°C). The preparation for each food evaluated was also provided in Table 2.1.

Chemicals

Twenty-two compounds were used in the study. Thirteen chemicals selected have been referred to in previous literature to exhibit green characteristics in various foods, either in flavor or the odor headspace of packaged foods. Nine chemicals selected were the corresponding ester derivatives of hexyl (C_6 aliphatic) compounds. All chemicals were available commercially and were not considered toxic when used at low levels or in limited exposure as for sensory reference materials. The chemicals used and their properties are illustrated in Table 2.2. Most chemicals were purchased from Aldrich Chemical Co. (Milwaukee, WI). Hexanal and trans-2-hexenal were purchased from Sigma Chemical Co. (St. Louis, MO). Citronellal and 2-isobutylthiazole were obtained from Givaudan Flavor Corp. (Cincinnati, OH).

Propylene glycol (Fisher Scientific Co., Fair Lawn, NJ) was used as a solvent for all the chemicals studied. A serial dilution technique was used to prepare a series of 7 concentrations starting from a 100,000 ppm stock solution. The seven concentrations were 1 ppm, 10 ppm, 100 ppm, 1,000 ppm, 5,000 ppm, 10,000 ppm, and 100,000 ppm. Chemical samples were prepared by dipping a fragrance strip to a 1.25-cm depth into the specified chemical solution. The strip was then placed into a 20-mL capped, coded glass tube. Chemical solutions and the fragrance strip preparation were made approximately 24 hr prior to testing.

Table 2.1 List of food products evaluated in phase 1: the lexicon development

Products	Preparation	Code
Fresh Broccoli	Rinse, cut the floret parts into small pieces	502
Fresh Cucumber	Peel, rinse, and slice into ½ inch thick pieces	631
Fresh Spinach	Rinse, place 4-5 leaves in plastic cups	661
Cooked Spinach	Weigh 45 g of spinach, rinse, chop coarsely, add 300 mL water, microwave on high for 3 minutes	784
Fresh Strawberries	Rinse, cut in fours lengthwise	807
Vine-ripe Fresh Tomatoes (greenhouse produced)	Rinse, cut tomatoes into wedges (lengthwise).	106
Fresh Green Onion	Rinse, cut to ½ inch long to serve	950
Fresh Pear	Peel, rinse, cut into ½ inch cubes to serve	799
Fresh Green Beans	Rinse, cut into ½ inch long to serve	112
Raw Peanuts	Fill raw peanuts in cup	456
Fresh Cilantro	Rinse and chop in ½ inch long	291
Fresh Cabbage	Rinse, cut the cabbage into ½ in^2 pieces	675
Fresh Lettuce	Rinse, cut the cabbage into ½ in^2 pieces	396
Fresh Asparagus	Rinse, cut into ½ inch pieces	484
Green Tea (Korean)	Steep a tea bag in 6 oz. 70 °C water for 1 min, serve warm	741
Green Tea (Lipton)	Steep a tea bag in 2 cups of boiling water for 3 min, serve warm	677
Cauliflower	Rinse, cut the floret parts into small pieces	507
Green Pepper	Rinse, cut the cabbage into ½ in^2 pieces	278
Frozen Lima Beans	Let thawed overnight, and place in cups	897
Fresh Basil Leaves	Rinse, only use the leaves	147
White Onion	Peel, rinse and chop into ½ inch pieces	233
Fresh Red Pepper	Rinse, cut the cabbage into ½ in^2 pieces	249
Fresh Mint	Rinse, only use the leaves	923
6-Grain Cereal Mix	Combine ¼ c cereal and ¾ c water, cover and microwave for 3 min	862
Canned Diced Tomatoes	Empty the content of 2 tomato cans, mix and serve	117
Fresh Parsley	Rinse, cut into small pieces	314
Vine-Ripe Tomatoes	Rinse, cut tomatoes into wedges (lengthwise).	980
Artichoke	Remove outside skin and center hairs, and cut flesh into ½ inch cubes	270
Tomato Leaves	Rinse before serving	540
Soymilk	Keep refrigerated until serve	101
Wheat Germs	Keep refrigerated until serve	791
Apple Juice	Keep refrigerated until serve	282

Table 2.2 Chemical and physical properties of chemicals used

Chemical	Formula[a]	Molecular Weight[a]	Odor Description[a]
Hexanal	$C_6H_{12}O$	100.160	Fatty-green, grassy, unripe fruit, fruity
Cis-3-Hexen-1-ol	$C_6H_{12}O$	100.160	Intense grassy-green, cut-grass
1-Penten-3-ol	$C_5H_{10}O$	86.13	Fruity, green, vegetable
2-Isobutylthiazole	$C_7H_{11}NS$	141.23	Tomato leave
2-Pentanol	$C_5H_{12}O$	88.15	Mild green
3-Heptanone	$C_7H_{14}O$	114.18	Green, fruity, fatty, sweet
β-Cyclocitral	$C_{10}H_{16}O$	152.10	Minty, fruity, green
Citronellal	$C_{10}H_{18}O$	154.24	Powerful lemon, fresh, green
Geranyl Formate	$C_{11}H_{18}O_2$	182.26	Green, leafy, rose odor
Heptyl Butyrate	$C_{11}H_{22}O_2$	186.30	Sweet, green, tea
Trans-2-Hexen-1-ol	$C_6H_{12}O$	100.16	Leafy, green, wine-like
Trans-2-Hexenal	$C_6H_{10}O$	98.15	Sweet, green leafy
Trans-2-Pentenal	C_5H_8O	84.11	Pungent, green, apple, tomato
Hexyl Benzoate	$C_{13}H_{18}O_2$	206.28	Green, woody
Hexyl Formate	$C_7H_{14}O_2$	130.18	Green, fruity, ethereal
Hexyl Hexanoate	$C_{12}H_{24}O_2$	200.32	Fresh vegetable, fruity
Hexyl Octanoate	$C_{14}H_{28}O_2$	228.37	Fresh vegetable, green, fruity, apple
Hexyl Phenylacetate	$C_{14}H_{20}O_2$	220.31	Wine-like, rose, green
Hexyl Propionate	$C_9H_{18}O_2$	158.24	Pear, green, musty
Hexyl Tiglate	$C_{11}H_{20}O_2$	184.27	Fresh, green, fruity
Hexyl-2-Furoate	$C_{11}H_{16}O_3$	196.24	Fatty, waxy, green, wine-like
Hexyl-2-Methylbutanoate	$C_{11}H_{22}O_2$	186.29	Sweet, fruity, green

[a] – Furia and Bellanca (1975)

Evaluation Procedure

Phase 1: Determining the Sensory Characteristics of "Green"

Three 1.5-hr orientation sessions were held to familiarize the panelists with the range of products they would evaluate and to facilitate the vocabulary development process. During this period, seven to ten food products were provided per session. The panelists described the sensory characteristics of "green" and defined the terms using the food products provided. Two additional discussion sessions were held to clarify each sensory attribute established and to determine the appropriateness of the attributes. Two more sessions were held to identify reference standards to be used for each of the sensory attributes of "green". The panelists were asked to use vocabulary that exhibited to the extent possible a one-dimensional meaning and to select products to the extent possible that generally were easily reproducible as reference standards. For each attribute, panelists identified at least 2 reference standards that cover a portion of the range of the scale. After discussions, panelists determined and eliminated any redundant vocabulary or terms that may have been included initially, but were determined unrelated to green or redundant with other terms after further discussion. Similar evaluation procedures have been used by several researchers. For example, Vara-Ubol *et al.* (2004) and Bott and Chambers (2006) established vocabularies for beany aroma of chemicals; Chambers *et al.* (2006) evaluated soymilk; and Green-Peterson *et al.* (2006) studied salmon products.

Reference standards were prepared approximately 24 hours before an evaluation session. Many references were refrigerated overnight and removed 30 minutes prior to the session. Reference standards and their preparations are illustrated in Table 3.1 (see Chapter 3).

Phase 2: Evaluation of Various Chemicals Associated with "Green"

A 1.5-hr orientation session was held before to familiarize the panelists with the evaluation technique of this part of the study. In this session, panelists received two chemicals (i.e. hexanal and cis-3-hexen-1-ol) with three concentrations each. The list of chemicals presented in this session is shown in Table A.1.

The order in which a chemical was evaluated was randomized. All seven dilutions (1-100,000 ppm) of a chemical were presented simultaneously and the panel evaluated them in the order from lowest to highest concentrations. One or two chemicals were evaluated in each 1.5 hr session. All chemicals were coded with 3-digit numbers and evaluated in a sequential monadic fashion. A total of 12 1.5-hr sessions were used to evaluate the 22 chemicals. A modified flavor profile method as described by Vara-Ubol *et al.* (2004) was used for the evaluation of the chemicals. Panelists evaluated each chemical concentration by removing the impregnated fragrance strip from the bottle and taking quick sniffs of the fragrance testing strips. Each panelist first examined samples individually and then as a group they determined if the chemical had a green character. If the chemical was agreed not to have a green note for any concentration, the panelists described the characteristics, but not the intensities, of that chemical. Then a second chemical set was presented.

For the chemicals that were found to be green, the panel described the odor characteristics at each concentration level using the attributes established from Phase 1 of the study. They then determined the the odor characteristics (i.e. attributes and intensities) of the chemical at the concentration that the panelists considered to have the highest level of "green" character. For profiling, a 15-point intensity scale was used, where 1 represents "just recognizable" and 15 represents "extremely intense". Carryover effects were minimized by allowing 10 min intervals between evaluating chemical samples and approximately 5 to 10 min between different concentrations of chemicals. Panelists also were asked to take multiple short sniffs of fresh air to help cleanse their nasal passages between chemical samples.

References

APARICIO, R. and MORALES, M.T. 1998. Characterization of olive ripeness by green aroma compounds of virgin olive oil. J. Agric. Food Chem. *46*, 1116-1122.

BOTT, L. and CHAMBERS, E. IV. 2006. Sensory characteristics of combinations of chemicals potentially associated with beany aroma in foods. J. Sens. Stud. *21*, 308-321.

CHAMBERS, E. IV, JENKINS, A., and MCGUIRE, B. 2006. Flavor properties of plain soymilk. J. Sens. Stud. 21: 165-179.

FURIA, T.E. and BELLANCA, N. eds. 1975. *Fenaroli's handbook of flavor ingredients, 2nd ed. Vol. 2*. CRC Press, Cleveland, OH.

GREEN-PETERSEN, D.M.B., NIELSEN, J and HYLDIG, G. 2006. Sensory Profiles of the most common salmon products on the Danish market. J. Sens. Stud. *21,* 415-427.

VARA-UBOL, S., CHAMBERS, E. IV and CHAMBERS, D.H. 2004. Sensory characteristics of chemical compounds potentially associated with beany aroma. J. Sens. Stud. *19*, 15-26

CHAPTER 3 - A Lexicon for Green Odor and Characteristics of Chemicals Associated with Green Odor in Foods

Abstract

The sensory characteristic "green" has been used frequently in descriptive sensory analyses of various foods. This research examined the odor characteristics of 22 chemicals in concentrations from 1-100,000 ppm. Thirteen chemicals including aldehydes, alcohols, ketones, azoles and ester derivatives had been reported to have green aroma. Nine additional ester derivatives, containing a six carbon core similar to hexanal, were included. A six-member highly trained descriptive panel determined that "green" is not a single characteristic, but can have several different manifestations. Generally, green can be characterized as either unripe, peapod, grassy/leafy, viney, or fruity or combinations of those. Additional attributes that were important to the green character included musty/earthy, pungent, bitter, overall sweet and floral. Most chemicals tested were found to be green at concentrations of 1,000 ppm and higher. Green-grassy/leafy was the most common green note and musty/earthy and pungent were frequent green adjunct aromas.

Introduction

The sensory characteristic "green" commonly is used in describing the characteristics of a variety of fresh vegetables, unripe fruits, and some processed food products. A "green" note is among the important attributes necessary for consumer perception of many green plant-based products and food derivatives of those products, for example olive oil (Aparcio and Morales, 1998). The term green and similar terms such as grassy have been referenced recently in many descriptive sensory analyses of various foods including tomatoes (Baldwin *et al*., 2004), bean products (Vara-Ubol *et al*, 2004), honey (Galán-Soldevilla *et al*., 2005) and wine (Vilanova and Soto, 2005). Various chemicals have been used to represent the green note in descriptive studies of products. Those chemicals generally include aldehydes, alcohols, ketones or their corresponding ester derivatives that contain six carbon atoms (C_6) in the molecules.

Salas *et al.* (2005) stated that the degradation of polyunsaturated fatty acids through the lypoxygenase pathway produced the volatile compounds contributing to the green notes in many fruits, vegetables and other derivative food products (e.g. olive oil and juices). Various volatile aldehydes and alcohols with six carbon atoms and corresponding hexyl ester derivatives were reported to illustrate or primarily contribute to perceived green odor (Dravnieks, 1985; Guth and Grosch, 1991, 1993; Hatanaka, 1996; Morales *et al*., 1996; Salas *et al*., 2005; King *et al.*, 2006).

Hexanal and closely related compounds, in particular, have been most commonly associated with green characteristics such as cut-grass (Baldwin *et al.*, 2004; Azodanlou *et al.*, 2003; Krumbein and Auerswald, 1998; Reiners and Grosch, 1998; Buettner and Mestres, 2005). Wilkens and Lin (1970) and Takahashi *et al.* (1979) determined hexanal was the key component for the green and bean-like characteristics of soy beans and their products. Jakobsen *et al.* (1998) described hexanal as a green-strong note in blanched green peas. Komthong *et al*. (2006) found trans-2-hexenal to be responsible for a green, apple–like odor in apples. Jiang (2005) found the high level of (*E*)-2-hexenal and (*Z*)-3-hexen-1-ol in laksa plant to be positively correlated with green notes. Aparicio and Morales (1998) described 2-, 3-hexenal, and 2-, and 3-hexen-1-ol as green with attributes such as fruity, flower, cut grass, and banana depending on the structure of the compounds. Citronellal was described as an important compound contributing to and intensifying the green note in green fruits (Jiang and Kubota, 2004).

Descriptions of volatile compounds used to reference green notes vary in the literature. Baldwin *et al.* (2004); Azodanlou *et al.* (2003); Krumbein and Auerswald (1998); Reiners and Grosch (1998); Buettner and Mestres (2005) described hexanal as green, (cut) grass. Other descriptors used to describe the characteristics of hexanal included minty (Baldwin *et al.*, 2004), apple (Salas *et al*., 2005; Paçi Kora *et al*., 2003; and Morales and Aparicio, 1999), unripe green (Wright, 2004), herbal (Jordán *et al*., 2003), fatty (Pino *et al*., 2001), and hedge (Bult *et al*., 2002). Salas *et al*. (2005), Furia and Bellanca (1975) and Krumbein and Auerswald (1998) described (*E*)-2-hexenal as green-leafy, Azodanlou *et al.* (2003) described it as green, fatty, Baldwin *et al.* (2004) characterized that compound as green, grassy, vine, stale, Wright (2004) and Reiners and Grosch (1998) described it as green apple like, and Morales and Aparicio (1999) described it as almond. It is possible that some of these chemicals may illustrate a certain green characteristic at a specific range of concentrations. For example, Vara-Ubol *et al.* (2004) showed that some chemicals associated with beany aroma were found to be beany only at concentrations between 1-10 ppm, and the characteristics changed completely at higher concentrations. In addition, Caporale *et al.* (2004) reported that different concentrations of cis-3-hexen-1-ol differed significantly in the green-cut grass intensity.

Many studies described odors of volatile chemicals by having human subjects sniffing the headspace from gas chromatographs. Those studies either did not indicate whether or not subjects were trained, or spent only several hours training subjects. No studies were found that used highly experienced descriptive sensory panelists to describe the chemicals potentially associated with green notes. The sensory characteristic "green" has been very commonly used; however, a well defined lexicon that includes definitions and references to determine the green character has not been developed. Data in previous research showing that green notes can be described using several descriptive attributes suggested that the green note is a complex character comprising multiple sensory attributes.

The objectives of this research were (1) to identify and define the sensory attributes contributing to green aroma/flavor, and (2) to describe the sensory characteristics, using clearly defined terms established by a highly trained descriptive sensory panel, of various chemicals that had been associated with green notes in previous literature.

Materials and Methods

The study was conducted in two parts. In phase 1, the lexicon for "green" was developed by evaluating a variety of food products that had been associated with green flavor or aroma in previous literature or work in our laboratory. In phase 2, the sensory characteristics of 22 chemicals, many of which have been referred to as green or associated with green odor in previous literature, were examined.

Panelists

Six highly trained panelists from the Sensory Analysis Center, Kansas State University (Manhattan, KS) took part in this research. The panelists had completed 120 hours of sensory descriptive training and each had more than 1000 hours of testing experience, including products where a descriptor such as "green" has been used. Each panelist had a broad background of experience in odor description and evaluation.

Phase 1: Determining the Sensory Characteristics of "Green"

To define the "green" character, panelists examined a variety of food products that have been associated with green flavor and aroma. Approximately, 30 products were evaluated in this phase. Food products used in this phase included fresh and processed vegetables, ripe and unripe fruits, herbs, soy products, green tea, raw potatoes, and raw peanuts. Vegetables and herbs included green onion, spinach, green pepper, fresh parsley, green beans, lima beans, artichoke, cilantro, asparagus, fresh and canned tomatoes, cauliflower, cabbage, cucumber, basil leaves, lettuce, broccoli, and mints. Fruit samples included strawberry, green apple, banana, pear, and grapes. Other products included soy milk, multigrain cereal, and apple juice. In the initial three orientation sessions (4.5 hrs), seven to 10 products were provided in each 1.5-hr session to familiarize the panelists with the range of products they would evaluate and to facilitate the vocabulary development process. The panelists described the sensory characteristics of "green" and developed appropriate definitions for each term. Discussion was held at the end of each session to determine if there was any redundancy in the terms established. Two additional discussion sessions (3 hrs) were held to determine the clarity and appropriateness of the terms and more sessions (3 hrs) were held to identify reference standards to be used for each of the sensory properties of "green". After discussion, panelists eliminated redundant terminology or terms that may have initially been included, but were not deemed related to green after further study and discussion. Once the attributes, definitions and reference standards were determined, the panel spent approximately 1 hour evaluating several products to ensure consistency of the evaluation technique. Similar procedures have been used by Vara-Ubol *et al.* (2004) and Bott and Chambers (2006) for establishing vocabularies for beany aroma of chemicals, by Chambers *et al.* (2006) for studying soymilk, and by Green-Peterson *et al.* (2006) for salmon products.

Phase 2: Evaluation of Various Chemicals Associated with "Green"

Chemicals

Twenty-two compounds were used in this study. Of those, 13 chemicals were selected because they have been referred to in previous literature to be potentially associated with green characteristics in various foods, either in flavor or the odor headspace of packaged foods. Nine chemicals selected were the corresponding ester derivatives of hexyl (C_6 aliphatic) compounds. All chemicals were available commercially and were not considered toxic when used at low levels or in limited exposure as for sensory reference materials. The chemicals used were hexanal; cis-3-hexen-1-ol; 1-penten-3-ol; 2-isobutylthiazole; 2-pentanol; 3-heptanone; β-cyclocitral; citronellal; geranyl formate; heptyl butyrate; trans-2-hexen-1-ol; trans-2-hexenal; trans-2-pentenal; and a series of hexyl esters including hexyl benzoate, hexyl hexaonate, hexyl formate, hexyl octanoate, hexyl phenylacetate, hexyl proprionate, hexyl tiglate, hexyl-2-furoate, and hexyl-2-methylbutanoate. Most chemicals were purchased from Aldrich Chemical Co. (Milwaukee, WI). Hexanal and trans-2-hexenal were purchased from Sigma Chemical Co. (St. Louis, MO). Citronellal and 2-isobutylthiazole were obtained from Givaudan Flavor Corp. (Cincinnati, OH).

Sample Preparation

All chemicals were diluted in propylene glycol (Fisher Scientific Co., Fair Lawn, NJ). Seven concentrations were prepared by a serial dilution technique starting from a 100,000 ppm stock solution. The seven concentrations included 1 ppm, 10 ppm, 100 ppm, 1,000 ppm, 5,000 ppm, 10,000 ppm, and 100,000 ppm. To deliver the chemicals, a fragrance strip was dipped to a 1.25-cm depth into the specified chemical solution and placed into a 20-mL capped, coded glass tube. Chemical solutions and the fragrance strip preparation were completed approximately 24 hrs prior to testing.

Evaluation Procedure

The order in which chemicals were evaluated was randomized. All seven dilutions (1-100,000 ppm) of a chemical were presented simultaneously and the panel evaluated them in order from lowest to highest concentration.

A total of 12 sessions (18 hrs) were used to evaluate the 22 chemicals. One or two chemicals were evaluated in each 1.5-hr session. All chemicals were coded with 3-digit numbers and evaluated in a sequential monadic fashion.The panel first determined if any level of the chemical had a green character. If not, the characteristics, but not the intensities, were described. Then a second chemical set was presented.

An evaluation method described by Vara-Ubol *et al.* (2004) was used for the evaluation of the chemicals. Panelists evaluated each chemical concentration by taking quick sniffs from the fragrance testing strips. Each panelist examined samples individually and then as a group they determined if the chemical had a green character.

For the chemicals that were found to be green, the panel described the odor characteristics at each level using the attributes established from Phase 1 of the study. They then determined the odor characteristics of the chemical at the concentration the panelists considered to have the highest level of "green" character. For profiling, a 15-point intensity scale was used, where 1 represents "just recognizable" and 15 represents "extremely intense". Carryover effects were minimized by allowing 10 min intervals between evaluating chemical samples and approximately 5 to 10 min between different concentrations of chemicals. Panelists also were asked to take multiple short sniffs of fresh air to help cleanse their nasal passages between chemical samples.

Results and Discussion

Phase 1: Determining the Sensory Characteristics of "Green"

The green characteristic was described as comprised of multiple sensory attributes often associated with plant-base materials. The green character can include one or more of five specific green attributes — green-unripe, green-peapod, green-grassy/leafy, green-viney, and green-fruity. Hatanaka (1996) described a similar set of attributes associated with green character including leafy green, grassy green, insect-like green, vegetable-like green and fruity. However, definitions of each term used were not specified in that study. Our definitions of the terms we used are given in Table 3.1.

The green-viney attribute was the primary green characteristic identified in fresh and processed tomatoes as well as cucumbers and green beans. The green-unripe attribute was the main characteristic green flavor/aroma found in many unripe fruits. Green-peapod described the green character generally found in beans, nuts, some vegetables and soy products including lima beans, green beans, raw peanuts, broccoli, asparagus and soy milk. The green character found in many herbs, green-leafy vegetables (e.g. cilantro, basil leaves, spinach and fresh parsley) and green tea products was described by a green-grassy/leafy attribute. The green note found in fruits and fruit-derivative products (e.g. pear and apple juice) was described primarily by the green-fruity attribute.

In addition to the characterizing green attributes, other sensory characteristics were identified that accompanied the green attributes: musty/earthy, pungent, astringent, bitter, sweet, sour, floral, beany, minty, and piney. One or more of those attributes were identified whenever green attributes were found. Those accompanying attributes did not impart the green character, but were intrinsically associated with various products that had the green note. Those particular attributes appeared "tied" to the green characteristic, i.e. depending on the product the accompanying attribute appeared simultaneously with or immediately preceding or following green. Musty/earthy, pungent, astringent and bitter were most often identified as accompanying attributes. Beany was normally found with the green-peapod attribute. Table 3.1 provides the definitions and references for the accompanying attributes. Because definitions and references for basic tastes can be found in various references including Chambers *et al*. (2006), they are not listed in the table.

Table 3.1 Sensory attributes imparting green characteristics: definitions, references, and intensities on 15-point scale

Attribute	Definition	Reference and Intensity[a]
Overall Green	Aromatic characteristics of plant-based materials. A measurement of the total green characteristics and the degree to which they fit together. Green attributes include one or more of the following: green-unripe, green-peapod, green-grassy/leafy, green-viney and green-fruity. These may be accompanied by musty/earthy, pungent, astringent, bitter, sweet, sour, floral, beany, minty and piney.	1:1 Diluted Fresh Parsley Water = 5.0 (f), 7.0 (a) Fresh Parsley Water = 7.0 (f[b]), 9.0 (a[c]) (Preparation: 25 g chopped fresh parsley soaked in 300 ml water for 15 min, filtered)
Green-Unripe	An aromatic associated with unripe or not-fully-developed plant-based materials; characterized by increased sour, astringent and bitter.	Green Banana = 8.0 (f) Watermelon Rind = 10.0 (f)
Green-Peapod	An aromatic associated with green peapods and raw green beans; characterized by increased musty/earthy character.	Kroger Frozen Baby Lima Beans[d] = 6.0 (f, a) Kroger Frozen Lima Beans[d] = 8.0 (f, a) Kroger Raw Peanuts = 12.0 (f)
Green-Grassy/Leafy	An aromatic associated with newly cut-grass and leafy plants; characterized by sweet and pungent character.	Kroger Fresh Spinach = 4.5 (f) (Preparation: place 3 Fresh Parsley Water = 7.0 (f), 9.0 (a)
Green-Viney	An aromatic associated with green vegetables and newly cut vines and stems; characterized by increased bitter and musty/earthy character.	Kroger Raw ½-in Diced Potatoes = 2.0 (f) ½-in Sliced Fresh Cucumber = 5.0 (f, a) Fresh Sliced Tomatoes = 10.0 (f), 9.0 (a)
Green-Fruity	A green aromatic associated with some fruits and vegetables; characterized by increased sweet, sour and floral character.	Welch's White Grape Juice, diluted 1:1 = 2.0 (f, a) Granny Smith Apple = 4.0 (f), 6.0 (a) Fresh Lime Peel = 12.0 (a)
Musty/Earthy	Humus-like aromatics that may or may not include damp soil, decaying vegetation, or cellar-like characteristics.	Kroger Frozen Baby Lima Beans = 3.0 (f), 5.0 (a) ½-in Sliced Fresh Cucumber = 6.0 (f)
Floral	Sweet, light, slightly perfumey impression associated with flowers.	Welch's White Grape Juice, diluted 1:1 = 5.0 (f), 6.0 (a)

Attribute	Definition	Reference and Intensity[a]
Beany	Aromatics characteristic of beans and bean products; includes musty/earthy, musty/dusty, sour aromatics, starchy, powdery feel and one or more of the following characteristics: green/pea pod, nutty, or browned.	Kroger Frozen Baby Lima Beans = 4.5 (f), 6.0 (a)
Piney	Aromatics reminiscent of resinous pine tree; can be medicinal or disinfectant in character.	Diamond Raw Pine Nuts = 4.0 (f, a)
Minty	Sweet, green, earthy, pungent, sharp, mentholic aromatics associated with mint oils; commonly associated with wintergreen, spearmint, or peppermint.	Mint Mixture (equal parts of - Wintergreen, Spearmint, and - Peppermint oils) = 10.0 (a)
Overall Sweet	The overall aromatics associated with sweet substances.	Granny Smith Apple = 2.0 (a) Wheaties = 3.0 (a)
Pungent	The sharp physically penetrating aromatic sensation in the nasal cavity.	Lime Peel = 13.0 (a) Fresh Green Pepper = 5.0 (a)
Astringent	The dry, puckering mouthfeel associated with placing an alum solution in the mouth.	0.03% Alum Solution = 1.5 0.05% Alum Solution = 2.5

[a] Intensity based on a 15-point numerical scale with 0.5 increments, where 0 represents “just recognizable” and 15 represents “extremely intense”;
[b] Flavor;
[c] Aroma;
[d] Frozen beans were thawed overnight in a refrigerator before serving

Phase 2. Evaluation of Various Chemicals Associated with "Green"

No green characteristics were found in 2-pentanol and β-cyclocitral. 2-Pentanol, although described as green in some literature (e.g. Ito *et al*., 2002), was associated with rubbing alcohol and nail polish in our study. β-Cyclocitral, described as green, cut-grass by Dravnieks (1985) was described as fertilizer-like at concentrations of 1,000 ppm and lower, and as musty/earthy and cellar-like at the higher concentrations. Because many studies examined effluent from gas chromatographs, differences in chemical purity or the ability to sniff for longer periods in this study may explain some differences from other literature. In addition, some compounds may contribute to green odor/flavor only when combined with other compounds. Similarly, Bott and Chambers (2006) found that hexanal, which was not beany by itself, became beany when combined with some other compounds.

Most of the chemicals cited in previous literature as "green" were found to be green, depending on their concentration. The odor characteristics of all chemicals illustrating the green character are shown in Table 3.2. Most chemicals illustrated the green character at the concentration of 1,000 ppm and higher. None of the chemicals was found to be green at 1 ppm. 2-Isbutylthiazole was the only chemical the panel described as green at a concentration as low as 100 ppm.

In general, as the chemical concentration increased, the chemical odor characteristics became more intense. For example, the green-grassy/leafy attribute of hexanal increased from a score of 2 at 1,000 ppm to 5.5 at 10,000 ppm. Additional odor attributes were found in many chemicals as the concentration increased. For instance, green-viney, musty/earthy and pungent were perceived in addition to green-grassy/leafy when the hexanal concentration reached 5,000 ppm and higher.

Table 3.2 Odor attributes of chemicals exhibiting green characteristics at different concentrations

<table>
<tr><th rowspan="2">Chemicals</th><th colspan="6">Odor characteristics of green chemicals at different concentrations (ppm)[a]</th></tr>
<tr><th>10</th><th>100</th><th>1,000</th><th>5,000</th><th>10,000</th><th>100,000</th></tr>
<tr><td>Hexanal</td><td colspan="2">Musty/Earthy</td><td>Green-Grassy/Leafy</td><td colspan="3">Green-Grassy/Leafy, Green-Viney, Musty/Earthy, Pungent</td></tr>
<tr><td>cis-3-Hexen-1-ol</td><td colspan="2">-[b]</td><td>Green-Grassy/Leafy, Green-Viney, Musty/Earthy</td><td>Green-Grassy/Leafy, Fruity, Pungent, Floral</td><td>Green-Grassy/Leafy, Green-Viney, Pungent Musty/Earthy</td><td>Green-Grassy/Leafy, Pungent, Musty/Earthy</td></tr>
<tr><td>trans-2-Hexen-1-ol</td><td colspan="2">-</td><td>Green-Peapod, Green-Viney</td><td colspan="3">Green-Peapod, Green-Viney, Sweet, Pungent, Musty/Earthy</td></tr>
<tr><td>trans-2-Hexenal</td><td colspan="2">-</td><td>Green-Grassy/Leafy, Sweet, Almond</td><td colspan="3">Green-Grassy/Leafy, Green-Fruity, Floral, Sweet, Pungent</td></tr>
<tr><td>trans-2-Pentenal</td><td colspan="2">-</td><td>Chocolate</td><td>Green-Grassy/Leafy, Sweet</td><td colspan="2">Green-Grassy/Leafy, Sweet, Floral, Pungent</td></tr>
<tr><td>1-Penten-3-ol</td><td colspan="3">-</td><td>Green-Grassy/Leafy, Musty/Earthy</td><td colspan="2">Green-Grassy/Leafy, Pungent, Musty/Earthy</td></tr>
<tr><td>2-isobutylthiazole</td><td>-</td><td>Green-Viney</td><td colspan="3">Green-Viney, Pungent, Musty/Earthy</td><td>Green-Grassy/Leafy, Green-Viney, Piney, Pungent, Musty/Earthy</td></tr>
<tr><td>3-Heptanone</td><td colspan="2">-</td><td>Minty</td><td colspan="2">Artificial banana</td><td>Green-Unripe, Pungent, Musty/Earthy, Sweet, Floral</td></tr>
<tr><td>Citronellal</td><td colspan="2">-</td><td>Lemon Pledge</td><td colspan="3">Fruity, Pungent, Floral</td></tr>
<tr><td>Geranyl formate</td><td colspan="2">-</td><td>Musty/Earthy</td><td>Green-Grassy/Leafy, Musty/Earthy, Pungent</td><td colspan="2">Green-Grassy/Leafy, Green-Fruity, Piney, Pungent, Musty/Earthy, Floral</td></tr>
<tr><td>Heptyl butyrate</td><td colspan="4">-</td><td colspan="2">Green-Viney, Green-Peapod, Musty/Earthy, Pungent</td></tr>
</table>

Odor characteristics of C-6 aliphatic ester derivatives

	10	100	1,000	5,000	10,000	100,000
Hexyl benzoate	Musty/Earthy			Green-Grassy/Leafy, Musty/Earthy	Green-Grassy/Leafy, Pungent, Musty/Earthy	
Hexyl formate	-		Caramelized	Green-Peapod, Green-Fruity, Musty/Earthy		Green-Fruity, Green-Peapod, Pungent, Musty/Earthy, Floral
Hexyl hexanoate	-		Musty/Earthy	Green-Viney, Musty/Earthy		Green-Viney, Green-Fruity, Floral, Musty/Earthy
Hexyl octanoate	-				Green-Grassy/Leafy, Floral	
Hexyl phenylacetate	-			Green-Grassy/Leafy, Musty/Earthy, Floral, Sweet		Green-Viney, Green-Grassy/Leafy, Musty/Earthy, Floral, Sweet
Hexyl propionate	-		Green-Grassy/Leafy, Minty, Sweet	Green-Grassy/Leafy, Minty, Green-Viney, Pungent, Sweet, floral		
Hexyl tiglate	Musty/Earthy		Green-Grassy/Leafy, Musty/Earthy	Green-Grassy/Leafy, Minty, Pungent, Musty/Earthy		Green-Grassy/Leafy, Minty, Floral, Sweet, Pungent, Musty/Earthy
Hexyl-2-furoate	-			Green-Grassy/Leafy, Minty, Musty/Earthy	Green-Grassy/Leafy, Minty, Sweet, Musty/Earthy	Green-Grassy/Leafy, Minty, Sweet, Pungent, Musty/Earthy
Hexyl-2-methylbutanoate	-		Green-Grassy/Leafy	Green-Grassy/Leafy, Viney, Minty, Pungent	Green-Grassy/Leafy, Minty, Sweet, Pungent	Green-Grassy/Leafy, Sweet, Pungent

[a] The odor characteristics of each chemical are shown under specific concentrations
[b] "-" indicates that the odor characteristics are unidentified

The odor character of some compounds changed at different concentrations. For example, 3 heptanone was minty at 1,000 ppm, artificial banana between 5,000 – 10,000 ppm, and green-unripe at 100,000 ppm. The finding that a change in concentration can result not only in differences in attribute intensities, but also dramatic changes in character have been found by other researchers. This points to the importance of specifying the concentration of a chemical used as a sensory reference. It shows the pitfalls of identifying a chemical as having a certain odor, without also specifying the concentration that resulted in that odor character.

All the hexyl (C_6) ester derivatives tested were found to be green at some level. Hexyl tiglate was the only chemical exhibiting an identifiable odor (i.e. musty/earthy) between 10 – 100 ppm. Increasing concentration of the hexyl esters increased attribute intensities in many cases, or changed the odor characteristics in some others. For example, hexyl formate had green-peapod as a primary character at 5,000 -10,000 ppm, but green-fruity became its primary odor character at 100,000 ppm. Many of the hexyl esters exhibited green-grassy/leafy as a primary characteristic (e.g. hexyl benzoate, hexyl phenylacetate, hexyl proprionate and hexyl tiglate). Hexyl hexanoate was characterized as green-viney at 5,000 ppm and higher. Hexyl proprionate and hexyl tiglate exhibited a minty note as a characterizing attribute. These findings that C_6 aliphatic ester derivatives exhibit green characteristics show that the C_6 aliphatic group of chemicals may act as a key contributor to the green odor characteristics of chemicals that contain a similar core structure. Hatanaka (1996) specifically reported that eight C_6-aliphatic alcohols and aldehydes were responsible for the green odor of green leaves.

Odor profiles of chemicals cited as green in previous literature at the concentration best illustrating the green character are shown in Table 3.3. Of these, 2-isobutylthiazole (at 5,000 ppm) was the most green with green-viney, musty/earthy and pungent as the characterizing attributes. The odor character of 2-isobutylthiazole has been often associated with tomatoes or tomato leaves (e.g. Dravnieks, 1985). Hexanal exhibited a moderate green character with green-grassy/leafy as the characterizing attribute. Citronellal, trans-2-pentenal, and 1-penten-3-ol were the least green with an overall green intensity of 2.0 on a 15-point scale. Many chemicals exhibited multiple characterizing green attributes (e.g., cis-3-hexen-1-ol had a combination of green-grassy/leafy, green-viney and green-fruity). Additional odor attributes found in these green chemicals included overall sweet and floral, which were found in trans-2-hexenal, trans-2-hexen-1-ol and trans-2-pentenal.

Table 3.3 Odor profiles of chemicals illustrating green character with descriptions and intensities

Hexanal at 5,000 ppm		***trans-2-hexenal at 5,000 ppm***	
Overall Green	5.0	Overall Green	3.0
Green-Viney	3.5	Green-Fruity	3.0
Green-Grassy/Leafy	3.5	Green-Grassy/Leafy	1.5
Musty/Earthy	2.0	Floral	2.0
		Overall Sweet	5.5
cis-3-hexen-1-ol at 1,000 ppm		***trans-2-hexen-1-ol at 5,000 ppm***	
Overall Green	4.0	Overall Green	6.0
Green-Grassy/Leafy	3.5	Green-Peapod	4.0
Green-Viney	2.5	Green-Viney	4.0
Musty/Earthy	2.0	Overall Sweet	3.5
		Pungent	2.0
1-penten-3-ol at 5,000 ppm		***trans-2-pentenal at 10,000 ppm***	
Overall Green	2.0	Overall Green	2.0
Green-Grassy/Leafy	2.0	Green-Grassy/Leafy	2.0
Musty/Earthy	1.5	Overall Sweet	3.0
		Floral	2.0
2-isobutylthiazole at 5,000 ppm		***Geranyl formate at 5,000 ppm***	
Overall Green	7.0	Overall Green	6.0
Green-Viney	7.0	Green-Grassy/Leafy	6.0
Pungent	4.0	Musty/Earthy	3.0
Musty/Earthy	2.5	Pungent	3.0
Citronellal at 5,000 ppm		***Heptyl butyrate at 10,000 ppm***	
Overall Green	2.0	Overall Green	3.0
Green-Fruity	2.0	Green-Viney	3.0
Pungent	2.5	Green-Peapod	1.5
Floral	2.5	Musty/Earthy	4.0
		Pungent	3.0

[1]Intensity is based on a 1-15 point scale where 1 is just recognizable and 15 is extremely intense.

Table 3.4 Odor profiles of hexyl esters illustrating green character with descriptions and intensities

Hexyl Benzoate at 10,000 ppm	
Overall Green	3.5
Green-Grassy/Leafy	3.5
Pungent	2.5
Musty/Earthy	3.0
Hexyl formate at 5,000 ppm	
Overall Green	2.0
Green-Peapod	1.5
Green-Fruity	1.5
Musty/Earthy	2.0
Hexyl hexanoate at 10,000 ppm	
Overall Green	3.5
Green-Viney	3.5
Musty/Earthy	4.0
Hexyl octanoate at 100,000 ppm	
Overall Green	6.0
Green-Grassy/Leafy	6.0
Floral	2.0
Hexyl phenylacetate at 5,000 ppm	
Overall Green	2.0
Green-Grassy/Leafy	2.0
Musty/Earthy	3.0
Floral	1.5
Overall Sweet	1.0
Hexyl proprionate at 5,000 ppm	
Overall Green	6.5
Green-Grassy/Leafy	6.5
Minty	4.5
Pungent	4.5
Overall Sweet	2.5
Hexyl tiglate at 5,000 ppm	
Overall Green	6.0
Green-Grassy/Leafy	6.0
Minty	1.5
Pungent	3.0
Musty/Earthy	7.0
Hexyl-2-furoate at 5,000 ppm	
Overall Green	3.0
Green-Grassy/Leafy	3.0
Minty	2.0
Musty/Earthy	2.0
Hexyl-2-methylbutanoate at 5,000 ppm	
Overall Green	3.0
Green-Grassy/Leafy	2.5
Green-Viney	1.5
Minty	1.5
Pungent	2.0

[1]Intensity is based on a 1-15 point scale where 1 is just recognizable and 15 is extremely intense.

Table 3.4 illustrates odor profiles for the nine hexyl esters at the concentration best exhibiting the green character. Most of these chemicals only exhibited weak to moderate green characteristics. Hexyl proprionate and hexyl tiglate were the most green at a relatively low concentration (5,000 ppm). Most chemicals had green-grassy/leafy as the characterizing attribute. Other odor characteristics found in these hexyl esters were minty (in hexyl proprionate and hexyl tiglate), and overall sweet and floral (in hexyl phenylacetate).

Some attributes used to describe hexanal in previous literature [e.g. minty (Baldwin *et al.*, 2004), and apple (Salas *et al.*, 2005; Paçi Kora *et al.*, 2003; and Morales and Aparicio, 1999)], were not specifically found in this study. Differences could be related to differences in techniques or to differences in training and the concomitant ability to dissociate attributes from specific products (i.e. a person may associate green with apples and use the term green apple or apple when the odor actually is not apple). The panelists in this study had a high level of training and Chambers *et al*. (2004) found that with higher levels of training, panelists were better able to differentiate difficult or closely related attributes.

The sensory attributes that are intrinsically associated with green in products were not found in the evaluation of all of the chemicals, probably because the chemicals are single compounds and, thus, far less complex systems than food products. In addition, because the astringent, bitter, sweet and sour attributes are found associated with the green character only when tasted, these attributes generally were not expected in the chemical evaluation portion of this research because the chemicals were evaluated only by smell.

Conclusions

A lexicon for the sensory term "green" was established. The green note was described as being comprised of multiple sensory attributes. Green characteristics can be primarily described using green-unripe, green-peapod, green-grassy/leafy, green-viney and green-fruity attributes and this study provides definitions and references for those characteristics. Chemicals that have been cited in previous literature were described as green at various concentrations. Most of the hexyl (C_6-aliphatic) ester compounds also were described as green, but at relatively weaker intensities. Green-grassy/leafy was found as a characterizing attribute for many of the chemicals studied, while no chemical was found to be a good representation of green/unripe. Musty/earthy and pungent attributes were found in the odor characteristics of most chemicals exhibiting green characteristics.

References

APARICIO, R. and MORALES, M.T. 1998. Characterization of olive ripeness by green aroma compounds of virgin olive oil. J. Agric. Food Chem. *46*, 1116-1122.

ARAI, S., KOYANAGI, O. and FUJIMAKI, M. 1967. Studies on flavor components in soybean part IV: Volatile neutral compounds. Agric. Biol. Chem. *7*, 868-873.

AZODANLOU, R., DARBELLAY, C., LUISIER, J.L., VILLETTAZ, J.C. and AMADÒ, R. 2003. Quality assessment of strawberries (*Fragaria* species). J. Agric. Food Chem. *51*, 715-721.

BALDWIN, E.A., GOODNER, K., PLOTTO, A., PRITCHETT, K. and EINSTEIN, M. 2004. Effect of volatiles and their concentration on perception of tomato descriptors. J. Food Sci. *69*, S310-S318.

BOTT, L. and CHAMBERS, E. IV. 2006. Sensory characteristics of combinations of chemicals potentially associated with beany aroma in foods. J. Sens. Stud. *21*, 308-321.

BUETTNER, A. and MESTRES, M. 2005. Investigation of the retronasal perception of strawberry aroma aftersmell depending on matrix composition. J. Agric. Food Chem. *53*, 1661-1669.

BULT, J.H.F., SCHIFFERSTEIN, H.N.J., ROOZEN, J.P., BORONAT, E.D., VORAGEN, A.G.J. and KROEZE, J.H.A. 2002. Sensory evaluation of character impact components in an apple model mixture. Chem. Senses. *27*, 485-494.

CAPORALE, G., POLICASTRO, S. and MONTELEONE, E. 2004. Bitterness enhancement induced by cut grass odorant (cis-3-hexen-1-ol) in a model olive oil. Food Qual. Pref. *15*, 219–227

CHAMBERS D.H., ALLISON, A.A. and CHAMBERS, E.IV. 2004. Effects of training on performance of descriptive sensory panelists. J. Sens. Stud. *19*, 486-499.

CHAMBERS, E. IV, JENKINS, A. and MCGUIRE, B. 2006. Flavor properties of plain soymilk. J. Sens. Stud. *21*, 165-179.

DRAVNIEKS, A. 1985. *Atlas of odor character profiles. ASTM Data series DS61*. American Society for Testing and Materials, Philadelphia, PA

FURIA, T.E. and BELLANCA, N. eds. 1975. *Fenaroli's handbook of flavor ingredients, 2nd ed. Vol. 2*, pp. 248, 253. CRC Press, Cleveland, OH.

GALÁN-SOLDEVILLA, H., RUIZ-PÉREZ-CACHO, M. P., SERRANO JIMÉNEZ, S., JODRAL VILLAREJO, M. and BENTABOL MANZANARES, A. 2005. Development of a preliminary sensory lexicon for floral honey. Food Qual. Pref. *16*, 71-77

GREEN-PETERSEN, D.M.B., NIELSEN, J. and HYLDIG, G. 2006. Sensory profiles of the most common salmon products on the Danish market. J. Sens. Stud. *21,* 415-427.

GUTH, H. and GROSCH, W. 1991. A comparative study of the potent odorants of different virgin olive oils. Fat. Sci. Technol. *93*, 335-339.

GUTH, H. and GROSCH, W. 1993. Quantitation of potent odorants of virgin olive oil by stable-isotope dilution assays. J. Am. Oil Chem. Soc. *70*, 513-518.

HATANAKA, A. 1996. The fresh green odor emitted by plants. Food Rev. Int. *12*, 303-350.

ITO, Y., SUGIMOTO, A., KAKUDA, T. and KUBOTA, K. 2002. Identification of potent odorants in Chinese Jasmine Tea scented with flower of *Jasminum sambac*. J. Agric. Food Chem. *50*, 4878-4884.

JAKOBSEN, H.B., HANSEN, M., CHRISTENSEN, M.R., BROCKHOFF, P.B. and OLSEN, C.E. 1998. Aroma volatiles of blanched green peas (*Pisum sativum* L.). J. Agric. Food Chem. *46*, 3727-3734.

JIANG, L. and KUBOTA, K. 2004. Differences in the volatile components and their odor characteristics of green and ripe fruits and dried pericarp of Japanese pepper (*Xanthoxylum piperitum* DC.). J. Agric. Food Chem. *52*, 4197-4203.

JIANG, L. 2005. Volatile composition of the laksa plant (*Polygonum hydropiper* L.), a potential source of green note aroma compounds. Flavour Fragr. J. *20*, 455-459.

JORDÁN, M.J., MARGARÍA, C.A., SHAW, P.E. and GOODNER, K.L. 2003. Volatile components and aroma active compounds in aqueous essence and fresh pink guava fruit puree (*Psidium guajaVa* L.) by GC-MS and multidimensional GC/GC-O. J. Agric. Food Chem. *51*, 1421-1426.

KING, B.M., ARENTS, P., DUINEVELD, C.A.A., MEYNERS, M., SCHROFF, S.I. and SOEKHAI, S.T. 2006. Orthonasal and retronasal perception of some green leaf volatiles used in beverage flavors. J. Agric. Food Chem. *54*, 2664 - 2670.

KOMTHONG, P., KATOH, T., IGURA, N. and SHIMODA, M. 2006. Changes in the odours of apple juice during enzymatic browning. Food Qual. Prefer. *17*, 497–504

KRUMBEIN, A. and AUERSWALD, H. 1998. Characterization of aroma volatiles in tomatoes by sensory analyses. Nahrung. *42*, 395-399.

MORALES, M.T., CALVENTE, J.J.and APARICIO, R. 1996. Influence of olive ripeness on the concentration of green aroma compounds in virgin olive oil. Flavour Fragr. J. *11*, 171-178.

MORALES, M.T. and APARICIO, R. 1999. Effect of extraction conditions on sensory quality of virgin olive oil. J. Am. Oil Chem. Soc. *76*, 295-300.

PAÇI KORA, E., LATRILLE, E., SOUCHON, I. and MARTIN, N. 2003. Texture-flavor interactions in low fat stirred yogurt: how mechanical treatment, thickener concentration and aroma concentration affect perceived texture and flavor. J. Sens. Stud. *18*, 367-390.

PINO, J.A., MARBOT, R. and VAZQUEZ, C. 2001. Characterization of volatiles in strawberry guava (*Psidium cattleianum* Sabine) fruit. J. Agric. Food Chem. *49*, 5883-5887.

REINERS, J. and GROSCH, W. 1998. Odorants of virgin olive oils with different flavor profiles. J. Agric. Food Chem. *46*, 2754-2763.

SALAS, J.J., SANCHEZ, C., GARCIA-GONZALEZ, D.L. and APARICIO, R. 2005. Impact of the suppression of lipoxygenase and hydroperoxide lyase on the quality of the green odor in green leaves. J. Agric. Food Chem. *53*, 1648-1655.

TAKAHASHI, N. SASAKI, R. and CHIBA, H. 1979. Enzymatic improvement of food flavor IV: Oxidation of aldehydes in soybean extracts by aldehyde oxidase. Agric. Biol. Chem. *43*, 2557-2562.

VARA-UBOL, S., CHAMBERS, E. IV and CHAMBERS, D.H. 2004. Sensory characteristics of chemical compounds potentially associated with beany aroma. J. Sens. Stud. *19*, 15-26.

VILANOVA, M. and SOTO, B. 2005. The impact of geographic origin on sensory properties of V*itis vinifera cv.* Mencia. J. Sens. Stud. *20,* 503-511.

WILKENS, W.F. and LIN, F.M. 1970. Gas chromatographic and mass spectral analyses of soybean milk volatiles. J. Agric. Food Chem. *18*, 333-336.

WRIGHT, J. 2004. *Flavor Creation*. Allured Publishing, Carol Stream, IL. pp. 200.

CHAPTER 4 - Detailed Materials and Methods to Determining a Lexicon Describing the Sensory Flavor and Texture Characteristics of Tomatoes

The objectives of this study were to (1) develop a sensory lexicon that includes attributes, definitions and references to fully describe the sensory characteristics of a wide variety of fresh and processed tomatoes, and (2) determine the characteristics of a broad range of fresh and processed tomatoes as well as tomato-based products using the lexicon initially established.

Panelists

The six-member highly trained panelists from the Sensory Analysis Center, Kansas State University (Manhattan, KS) participated in this study. Each panelist had completed 120 hrs of training on general sensory analysis techniques. They all have a minimum of 1000 hours of experience in testing a wide variety of food products including fresh tomatoes and tomato-based products. The panel received six 1.5-hr sessions of orientation during which they were familiarized with the range of products that would be evaluated, and established the sensory attributes that describe these products. During the orientation sessions, various types of fresh and processed tomatoes were provided to help facilitate the panelists with terminology development.

Samples and Sample Preparation

Various fresh and processed tomatoes were used in the study. During the lexicon development, 30 fresh and processed tomatoes were used to facilitate the vocabulary development. During the product evaluation, all the 30 products with 10 additional products were used. These fresh and processed tomatoes were selected to represent a broad range of tomato sensory characteristics. The products consisted of nine fresh tomatoes; 25 processed tomato products, representing varying degrees of processing, including canned whole, diced and crushed tomatoes, tomato paste, tomato juice, and dried tomato; and six tomato-based products including ketchup and simple traditional pasta sauce. For the tomato-based products, those with minimal additional ingredients were used.

Various types of fresh tomatoes were selected because, presently, fresh vegetable markets not only display standard field-grown round tomatoes, many have included plum tomatoes, grape and cherry tomatoes as well as a number of greenhouse and hydroponic tomatoes. The greenhouse/hothouse hydroponic tomatoes, which tended to have higher prices, have dominated the fresh market tomatoes in the recent years (Economic Research Service, USDA). Thus, fresh tomatoes were selected to include round, plum, cherry and greenhouse/hothouse tomatoes that were commercially available in the markets. All samples were purchased from local large chain grocery stores and local fresh vegetable market. Fresh tomatoes were purchased approximately 3-5 days prior to testing. Processed tomato products were selected to represent a broad range of processed tomatoes at various processing levels. Tomato-based products used in the study included traditional pasta sauces and ketchup. Processed products were purchased 3-10 days before testing began. Multiple brands of each product, both national and generic brands, were selected to represent the variations in those products.

All tomato samples were stored at room temperature (~25ºC) and were prepared approximately 30 min to 1 hour prior to testing sessions. Fresh tomatoes were thoroughly rinsed using reverse osmosis, deionized, carbon-filtered water before cutting and serving. Fresh tomatoes were cut based on their size: large tomatoes were cut into approximately ½-in thick wedges, and small-size and cherry tomatoes were cut in half lengthwise. All processed products were well stirred before serving. Samples were served in odor-free, disposable 3.25 oz. (~ 96 mL) plastics cups with lids. Each panelist received approximately 4 pieces or 3 oz. (88 mL) of products for evaluation. To prevent potential bias, panelists were not provided with any information about the samples evaluated. Panelists cleansed the palate between samples using unsalted-top crackers (unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA), and reverse osmosis, deionized, carbon-filtered water. All samples were labeled with 3-digit random numbers.

Evaluation Procedure

Lexicon Development

The attribute determination and description procedure was modified from other similar studies (e.g. Heisserer and Chambers, 1993; Lotong *et al*., 2000; and Rétiveau *et al*., 2005). To generate the terminology for describing the sensory characteristics of tomatoes, the panel evaluated a variety of fresh tomatoes and tomato-based products. Six 1.5-hr sessions were held for establishing the sensory terminology of tomatoes. Approximately 30 fresh and processed tomato products commercially available in the local markets were used during this process. The panelists received a set of 5-6 products per session to assist them with terminology development. The panelists were additionally given, in the first session, a list of vocabulary, previously established for evaluating tomato products at the Sensory Analysis Center, Kansas State University as well as those found in previous literature (Stevens *et al.*, 1977; Watada and Aulenbach, 1979; Resurreccion and Shewfelt, 1985; Rodríguez *et al*., 2001; Azodanlou *et al*., 2003) to help them determine appropriate terminology. The panel discussed the appropriateness of terms found in previous literature to determine if those terms should be included. The panelists were asked to be as specific as possible in establishing attributes that illustrated to the extent possible a one-dimensional perspective, rather than a multidimensional concept. Additionally, panelists were told not to be concerned if the attributes established might potentially indicate positive or negative connotations to consumers. A discussion was held after each terminology development session to determine if any attributes were redundant as well as to clarify the vocabulary used for the attribute definitions and appropriate reference standards for each attribute used in that session. Attributes determined to be redundant were eliminated. Additionally, the panelists discussed the evaluation technique appropriate for each sensory attribute. All panelists then came to an agreement on the sensory attributes, their definitions, reference standards, and appropriate evaluation techniques for each attribute.

Product Evaluation

To provide validation to the established lexicon, 40 tomato samples including fresh tomatoes and tomato-based products were evaluated during 10 1.5-hr sessions, in which 5-6 samples were presented per session. All samples were coded with 3-digit random numbers. The order in which products were evaluated was randomized, as illustrated in Table 4.1. The samples were evaluated in a sequential monadic fashion. All panelists were present at all testing sessions. Panelists initially evaluated the intensity of each appropriate sensory attributes individually using a 15-point numerical scale, with increments of 0.5, where 0 represents none and 15 represents extremely strong. Then the panel leader led a discussion, after all panelists provided intensity scores for all the attributes, to determine consensus scores for each product. Reverse osmosis, deionized, carbon-filtered water and unsalted cracker (unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA) were provided to cleanse palate between samples during testing.

A consensus approach (e.g. Rétiveau *et al*., 2005) was used over individual balloting to allow further discussion following each sample, and a refinement to the lexicon, if necessary.

During the evaluation sessions, panelists could add an attribute to the lexicon established initially. The panel leader led a discussion on any attributes added to determine the appropriateness of the terms, definitions, reference standards as well as an evaluation technique. Once it was agreed the term should be included, the panel evaluated later samples for the intensity of the added attribute. One attribute, umami, was added to the tomato lexicon. Five minutes were allowed between each sample evaluation to minimize the carry-over effect. Panelists cleansed the palate between samples as previously described.

Table 4.1 List of tomato products evaluated

Products	Preparation	Code
Hunt's canned whole tomato	Separate tomato pieces from liquid, cut tomatoes in four	761
Kroger tomato juice	Shake bottle well before placing in cups	189
Contadina tomato sauce	Stir well, before placing in cups	341
Fresh round tomato ripened on vines	Slice off the top and bottom before cut into ½ in wedges	671
Campbell's tomato juice – Low sodium	Shake bottle well before placing in cups	441
Hunt's tomato sauce – No salt added	Stir well, before placing in cups	547
Emeril's Romainita cherry tomato	Cut tomatoes in half, lengthwise	116
Nature Sweet vine ripened cherry tomato	Cut tomatoes in half, lengthwise	233
San Marzano canned whole tomato	Separate tomato pieces from liquid, cut tomatoes in four	807
Del Monte fresh round tomato	Slice off the top and bottom before cut into ½ in wedges	129
Heinz ketchup	Shake bottle well before placing in cups	675
KS grown hydro fresh round tomato	Slice off the top and bottom before cut into ½ in wedges	175
AK grown fresh round tomato	Slice off the top and bottom before cut into ½ in wedges	909
Greenhouse grape tomato – Mexico	Cut tomatoes in half, lengthwise	415
Amore tomato paste	Stir before placing in cups	376
Kroger canned diced tomato	Separate tomato pieces from liquid before serve	730
GV canned whole tomato	Separate tomato pieces from liquid, cut tomatoes in four	438
Kroger canned whole tomato	Separate tomato pieces from liquid, cut tomatoes in four	995
Del Monte organic tomato sauce	Stir well, before placing in cups	182
Campbell's tomato juice – regular	Shake bottle well before placing in cups	568
Hunt's ketchup	Shake bottle well before placing in cups	345
Linguria canned crushed tomato	Separate tomato pieces from liquid before serve	875
GV tomato sauce	Stir well, before placing in cups	313
Contadina tomato paste	Stir before placing in cups	744
Hunt's canned crushed tomato	Separate tomato pieces from liquid before serve	317
Hunt's tomato paste	Stir before placing in cups	153
GV canned diced tomato	Separate tomato pieces from liquid before serve	941
FMV canned whole tomato	Separate tomato pieces from liquid, cut tomatoes in four	765
Hunt's canned diced tomato	Separate tomato pieces from liquid before serve	227
Del Monte canned diced tomato	Separate tomato pieces from liquid before serve	897
Del Monte ketchup	Shake bottle well before placing in cups	101
Dillon's fresh plum tomato	Slice off the top and bottom before cut into ½ in wedges	434
Dillon's AK fresh round tomato	Slice off the top and bottom before cut into ½ in wedges	811
Great Lakes sun dried tomato	Place 1 piece in cups	248
Kroger tomato paste	Stir before placing in cups	862
California sun dried tomato	Place 1 piece in cups	300
Melissa's dried tomato	Place 1 piece in cups	383
Prego traditional pasta sauce	Stir well, before placing in cups	631
Ragu traditional pasta sauce	Stir well, before placing in cups	712
Hunt's traditional pasta sauce	Stir well, before placing in cups	709

Data Analysis

Multivariate statistical analyses were used to explore the relationships among the sensory terms established. Principal components analysis (PCA) was constructed using the covariance matrix (SYSTAT® Version 10.2, 2006, Systat Software, Inc., San Jose, CA). PCA categorized attributes into a number of new uncorrelated variables (principal components) that were made up of the original sensory attributes. This analysis may help to determine attribute synonyms, covariate attributes, or any attribute redundancy that may exist in the established lexicon. Additionally, differences and similarities among the products evaluated can be shown using PCA maps.

References

AZODANLOU, R., DARBELLAY, C., LUISIER, J.L., VILLETTAZ, J.C. and AMADÒ, R. 2003. Quality assessment of strawberries (*Fragaria* species). J. Agric. Food Chem. *51*, 715-721.

ECONOMIC RESEARCH SERVICE. USDA. *www.ers.usda.gov/ers*.

HEISSERER, D.M. and CHAMBERS, E. IV. 1993. Determination of the sensory flavor attributes of aged natural cheese. J Sens. Stud. *8*, 121-132.

LOTONG, V., CHAMBERS IV, E. and CHAMBERS, D.H. 2000. Determination of the sensory attributes of wheat sourdough bread. J. Sens. Stud. *15*, 309-326.

RESURRECCION, A.V.A. and SHEWFELT, R.L. 1985. Relationship between sensory attributes and objective measurements of postharvest quality of tomatoes. J. Food Sci. *50*, 1242-1245.

RÉTIVEAU, A., CHAMBERS, D.H. and ESTEVE, E. 2005. Developing a lexicon for the flavor description of French cheeses. Food Qual. Pref. *16*, 517-527.

RODRÍGUEZ, A., LOPEZ, J., GONZALEZ, C., DE LA TORRE, R. and MANGUT, V. 2001. Sensory Evaluation of canned diced tomato varieties. Proc. 7th Int. Symp. On Processing Tomato. Acta Hort 542, ISHS 2001. pp. 269-275.

STEVENS, M.A., KADER, A.A., ALBRIGHT-HOLTON, M. and ALGAZI, M. 1977. Genotypic variation for flavor and composition in fresh market tomatoes. J. Am. Soc. Hortic. Sci. *102*, 680-689.

WATADA, A.E. and AULENBACH, B.B., 1979. Chemical and sensory qualities of fresh market tomatoes. J. Food Sci. *44*, 1013–1016.

CHAPTER 5 - A Lexicon for Texture and Flavor Characteristics of Fresh and Processed Tomatoes

Abstract

A lexicon for describing the sensory flavor and texture characteristics of fresh and processed tomatoes was developed. A six-member highly trained, descriptive sensory panel identified, defined, and referenced 33 sensory attributes for fresh and processed tomatoes. Forty products including a variety of raw, canned, concentrated, and dried tomatoes as well as tomato-based products including ketchup and simple pasta sauce were evaluated in the study. These products represented a wide range of sensory characteristics in raw and processed tomatoes. The lexicon established included five aroma attributes, 10 texture attributes, and 18 flavor attributes, including six taste and mouthfeel attributes. The lexicon provides attribute descriptors, definitions, and references that often are lacking in previous literature. Reducing the number of attributes may be appropriate when testing specific tomato products.

Practical Applications

Increased consumption of tomato products has expanded interest in improving the sensory characteristics of tomatoes and subsequent products. This research provides a list of sensory flavor and texture terms that can be used to describe the sensory characteristics of both fresh and processed tomatoes. This information will help researchers, breeders, and processors better understand the flavor and texture properties of fresh and processed tomatoes and the tomato characteristics of tomato products. Taste attributes, often used in previous literature, are important, but are not enough to describe the characteristics of tomatoes. In addition to flavor attributes, aroma and texture properties are important for describing tomato characteristics, but have not been thoroughly established in previous research.

Introduction

Tomatoes are one of the most valuable and most commonly used crops worldwide. In the United States, according to the U.S. Economic Research Service, fresh tomatoes are the second most popular item in the fresh-vegetable market. Factors influencing this considerable increase in tomato consumption include the rise of consumer awareness of potential benefits such as preventing cancer (Lee *et al.* 2000), an increasing trend toward restaurant-food or away-from-home food consumption (Lucier, 2003), the increase in the popularity of Mexican and Italian foods that frequently use tomatoes (Lucier, 2003), and an increase in the number of tomato varieties available in the marketplace (Cuellar, 2002).

Consumers prefer fresh tomatoes that have full flavor and characteristic taste. Flavor characteristics have become an important purchasing criterion in recent years (Krumbein *et al*., 2004). Commercial tomatoes, however, have been criticized as lacking desirable flavor (Watada and Aulenbach, 1979; Hobson, 1988; Bruhn *et al*., 1991; Maul *et al*., 2000; Yilmaz, 2001; Batu, 2004; Krumbein *et al*., 2004; and Serrano-Megías and López-Nicolás, 2006). One reason for this flavor problem is that tomatoes are harvested at the mature-green stage (Kader *et al*., 1977) in order to prolong the shelf-life of the tomatoes through multiple handling and transporting periods. Other researchers have reported that lack of flavor of tomato is associated with various storage treatments, e.g. modified atmosphere (Hobson, 1988; Ho, 1996; and Maul *et al*., 2000).

Several studies (e.g. Kader *et al.*, 1978) recommended that tomatoes should be harvested at the red-ripe stage to ensure the flavor desirability. However, because of the duration of transportation and handling processes, the shelf-life of those vine-ripened tomatoes is shortened. Most research appears to have focused on developing tomato cultivars that provide increased yields, are firmer, larger, and have greater disease resistance and a longer shelf-life, rather than improving the flavor aspect of tomatoes.

The overall flavor characteristics of tomatoes results from various components including the ratio of reducing sugars to organic acids and the level of volatile compounds present (Stevens *et al*., 1977; Stevens *et al*., 1979; Petro-Turza, 1987; Bucheli *et al*., 1999; Krumbein *et al*., 2004). Those substances develop and change throughout the ripening process of the fruits. Reducing sugar or total soluble solids and titratable acid contents have been found to be related, respectively, to the sweetness and sourness of tomatoes (Stevens *et al*., 1977; Malundo *et al*., 1995; Bucheli *et al*., 1999; and Tandon *et al*., 2003). A large body of research has been done to identify the volatile compounds that contribute to the characteristic flavor and aroma of fresh tomatoes using headspace analysis and gas chromatography (e.g. Petro-Turza, 1987; and Abegaz *et al*., 2004). Of the several hundred volatile compounds identified in fresh tomatoes, a small number of volatiles have been reported to be positively associated with the tomato-like flavor. The stage of harvest has tremendous impact on tomato flavor; tomatoes harvested at the table-ripe stage had been shown to have higher sweetness, saltiness and floral flavor as compared to those harvested at the mature-green stage (Watada and Aulenbach, 1979). The flavor characteristics of processed tomatoes are influenced by the quality of the fresh tomatoes used. Thus, those factors impacting the qualities of fresh tomatoes would consequently affect the qualities of processed products. Garcia and Barrett (2006) stated that the flavor of processed tomatoes is impacted by the balance of sugar and acid content. The soluble and insoluble solids are among the key components to obtaining most favorable processed tomato products.

Many studies have concentrated on examining the changes in quality of tomatoes (e.g. sugars, acid contents, and volatile compounds) as affected by various postharvest treatments (e.g. Watada and Aulenbach, 1979; Bedford, 1989; Malundo *et al*., 1995; Ratanachinakorn *et al*., 1997; Ketelaere *et al*., 2004; Krumbein *et al*., 2004; and Lana *et al*., 2005) or relating some sensory evaluation information with consumer preference or physico-chemical data (e.g. Thybo *et al*., 2005; Serrano-Megias and Lopez-Nicolas, 2006; Lê and Ledauphin, 2006; and Plaehn and

Lundahl, 2006). Ratanachinakorn *et al*. (1997) showed that treating tomatoes harvested at different ripening stages with varying level of O_2, N_2, and CO_2 did not affect their aroma or flavor characteristics. Ketelaere *et al*. (2004) found that different tomato cultivars and harvesting time exhibited differences in firmness of the fruits. During storage, the amount of volatile compounds in vine-ripened tomatoes increased (Krumbein *et al*., 2004) and tomato firmness decreases (Lana *et al*., 2005). Thybo *et al*. (2005) reported a high correlation between sensory and physical data on firmness of tomatoes. Serrano-Megias and Lopez-Nicolas (2006) reported that tomato odor, flavor, sweetness, acidity and hardness were positively correlated with consumer preference, but Malundo *et al*. (1995) found that increasing the level of sugar and acid affected consumer acceptance not "overall tomato impact". Lengard and Kermit (2006), Lê and Ledauphin (2006) and Plaehn and Lundahl (2006) attempted to determine positive and negative drivers of liking of tomatoes, and reported similar results in that some sensory attributes including tomato odor and flavor, sweetness, juiciness, skin color and firmness illustrated positive impact on consumer liking whereas mealiness and skin thickness illustrated negative impact.

Although previous studies have considered the sensory characteristics of tomatoes, none have reported complete information for describing the sensory characteristics of tomatoes. Most researchers have reported a modest number of sensory attributes for specific products. For example, Causse e*t al*. (2003) reported scores for sweetness, acidity, tomato aroma, strange aroma, firmness, juiciness, mealiness and skin of various tomato samples. Some studies provided information such as definitions of sensory attributes evaluated, but the information provided was usually minimal. One such study (Bedford, 1989) gave four texture (i.e. firmness, toughness, pulpy and juiciness) and seven flavor (i.e. strength of flavor, acid, savory, salty, green/stemmy, and hay/musty) attributes along with their definitions and evaluation techniques. Many sensory attributes used in previous studies not only were not defined, but some of the descriptors were non-discriminative and/or more appropriate for consumer language, for example "strange aroma" (Causse e*t al*., 2003) and "off-flavor" (Resurreccion and Shewfelt, 1985). Moreover, little has been done to fully understand the sensory characteristics of various processed tomatoes and tomato-based products. These issues indicate the potential need to establish a general lexicon that would be appropriate for describing the sensory characteristics of both fresh and processed tomatoes and could be used by a wide range of researchers. Such lexicons have been published previously for other food products. For example, in the past several years lexicons have been published or expanded for cheese (Rétiveau *et al*., 2005), floral honey (Galán-Soldevilla *et al*., 2005), specific fruits (Vara-Ubol *et al*., 2006), soymilk (Chambers *et al*., 2006 and Day N'Kouka *et al*., 2004), and beany chemical compounds (Bott and Chambers, 2006; Vara-ubol *et al*., 2004).

The objectives of this study were to (1) develop a sensory lexicon that includes attributes, definitions and references to describe the flavor and texture characteristics of a wide variety of fresh and processed tomatoes, and (2) validate the established lexicon by determining the characteristics of a broad range of fresh and processed tomatoes and tomato-based products as well as determine if any sensory attributes can be reduced.

Materials and Methods

Samples

Thirty fresh and processed tomatoes were used for the lexicon development process. The same set of samples plus 10 additional tomato products were evaluated for the validation of the lexicon. Fresh tomatoes (n=9) included round, plum, and cherry tomatoes. Processed tomato products (n=25), representing varying degrees of processing, included canned whole, diced and crushed tomatoes, tomato paste, tomato juice, and dried tomato. Tomato-based products (n=6) included ketchup and simple traditional pasta sauce. Ketchup and simple pasta sauce were selected because of their minimal additional ingredients. All products were available commercially at local grocery stores. Multiple brands of each product were used to represent the variation of these products. Products were purchased about 3-10 days prior to testing and were stored at room temperature (~70ºF).

Sample Preparation

All samples were served at room temperature. For fresh tomatoes, the fruits were washed and cut into ½-in thick wedges and placed in odor-free, disposable 3.25 oz. plastic cups (Sweetheart Cup Company INC., Owing Mills, MD. USA) for the evaluation. Small tomatoes, e.g. cherry tomatoes, were cut in half for the evaluation. All canned and jarred products were stirred before placing a sample into the plastic cups with lids for the evaluation. Samples were prepared approximately 30 min to 1 hr prior to testing. Each panelist received approximately four pieces of solid tomatoes or 3 oz. of liquid tomato product for evaluation.

Panelists

Six highly trained panelists from the Sensory Analysis Center, Kansas State University (Manhattan, KS) participated in this study. These panelists had completed 120 hours of general sensory descriptive analysis panel training with a wide variety of food products. That training included techniques and practice in attribute identification, terminology development, and intensity scoring. For this study the panelists also received a further orientation and training on tomato products. Each of the panelists had more than 1,000 hours of testing experience with a variety of food products including fresh tomatoes and tomato-based products.

Development and Description of the Terminology

The attribute determination and description procedure was modified from other similar studies (e.g. Heisserer and Chambers, 1993; Lotong *et al*., 2000; and Rétiveau *et al*., 2005). To generate the terminology for describing the sensory characteristics of tomatoes, the panel evaluated a variety of fresh tomatoes and tomato-based products. Initially, a list of potential lexicon terms, including those used previously for evaluating tomato products in our laboratories as well as those found in published literature (e.g. Stevens *et al*., 1977; Bedford, 1989; Azodanlou *et al*., 2003), were provided to the panelists. Six 1.5-hr sessions were held for establishing the sensory terminology of tomatoes. Thirty fresh and processed tomato products commercially available in the local markets were used during this process. The panelists received a set of 5-6 products per session to assist them with terminology development. The panel discussed the appropriateness of terms found in previously used terms to determine if those terms should be included. The panelists were asked to be as specific as possible in establishing attributes that illustrated a one-dimensional perspective, rather than a multidimensional concept. Additionally, panelists were told not to be considering whether a particular attribute might potentially indicate positive or negative connotations to consumers. A discussion was held at the end of each terminology development session to determine if any attributes appeared redundant, to clarify the attribute definitions if necessary, and to discuss potential attribute references that would be provided in the next session. Attributes determined to be redundant by the panel were not included. The panelists also discussed the evaluation technique appropriate for each sensory attribute. When all panelists had come to agreement on the sensory attributes, their definitions, reference standards, and appropriate evaluation techniques for each attribute lexicon development sessions were ended.

A necessary process during lexicon development was to determine reference standards for sensory attributes. For each attribute, panelists carefully determined simple, reproducible reference materials that would provide a broad range of intensities, which could be easily prepared without changing the character. Panelists tried to select references from a broad range of materials that would best represent the characteristics of a corresponding attribute evaluated. In addition, an attempt was made to select widely available branded products. In many cases, panelists determined more than one reference that potentially covered the intensity range of an attribute that could be found in both fresh and processed tomatoes. All the fundamental taste references were prepared by diluting appropriate chemicals at specific concentrations to represent various intensities of each basic taste attribute. For example, citric acid solution was used to represent sour attributes, where a 0.05% solution best represented the sour intensity of 3.5 and a 0.08% solution represented the sour intensity of 5.0.

Evaluation Procedure during Lexicon Validation

To assist in validating the established lexicon, 40 tomato samples including fresh and processed tomatoes and tomato-based products were evaluated during 10 1.5-hr sessions. Five to six samples, coded with 3-digit random numbers, were presented in each session. The order in which products were evaluated was randomized.

The panelists used a modified flavor profile (Caul, 1957, Keane, 1992) method similar to that used by Rétiveau *et al*. (2005), Galán-Soldevilla *et al*. (2005), Vara-Ubol *et al*. (2006), and Chambers *et al*. (2006). Panelists initially evaluated the intensity of each appropriate sensory attribute individually using a 15-point numerical scale, with increments of 0.5, where 0 represents none and 15 represents extremely strong. Then the panel leader led a discussion, to determine consensus scores for each product. Reverse osmosis, deionized, carbon-filtered water and unsalted cracker (unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA) were provided to cleanse palate between samples during testing.

A consensus approach was used over individual balloting to allow further discussion following each sample, and to refine the lexicon, if necessary. During the evaluation sessions, panelists could add an attribute to the lexicon established initially. The panel leader led a discussion on any attributes added to determine the appropriateness of the terms, definitions, reference standards as well as an evaluation technique. Once the term was agreed to be included, the panel evaluated the later samples for the intensity of those added attributes. One attribute, umami, was added to the tomato lexicon during this testing.

Data Analysis

Multivariate statistical analyses were used to explore the relationships among the sensory terms established. Principal components analysis (PCA) was constructed using the covariance matrix (SYSTAT®, Version 10.2, 2006, Systat Software, Inc., San Jose, CA). PCA categorized attributes into a number of new uncorrelated variables (principal components) that were made up of the original sensory attributes. This analysis may help to determine attribute synonyms, covariate attributes, or any attribute redundancy that may exist in the established lexicon. Additionally, differences and similarities among the products evaluated can be shown using plots of the PCA results.

Results and Discussion

Lexicon Development

The final lexicon developed in this research is given in Table 5.1. A total of 33 sensory attributes was established to describe the sensory characteristics of fresh and processed tomatoes. The lexicon is comprised of aroma, texture, flavor, basic taste and mouthfeel attributes.

During the lexicon development process, some terms, such as "fresh tomato" and "tomato ID", were discussed extensively. The panel believed it was important to have an overall identity note, thus "tomato ID" was retained in the lexicon. However, much of the definition for "fresh tomato" was included in the tomato ID characteristic and that, coupled with the fact that "fresh tomato" can include slightly different flavor combinations that can better be described by individual notes, resulted in "fresh tomato" not being included in the final lexicon.

Some attributes that were initially included or found in previous literature were eliminated. For example, the terms amount of juice and amount of tomatoes, initially listed, were discussed among panelists. The panelists agreed that the evaluation of these terms would not provide any additional information about the sensory characteristics of tomatoes, and thus they were eliminated. Those terms appeared to be related to specific information on canned tomatoes and are not so much a characteristic of the tomatoes as of the amount the manufacturer's pack. Thus, although the terms may be necessary and appropriate to describe the amount of specific product in a container (e.g. a can), they are not included in this lexicon because they were not an integral part of "tomato" flavor or texture.

Some terms used to describe the characteristics of tomatoes in previous studies either were too general or non-descriptive, thus some were eliminated from the lexicon. For example, the terms off flavor and off aroma (Mual *et al.*, 2000), strange aroma (Causse *et al*., 2003), and herbaceous (Azodanlou *et al*., 2003) were not included.

Some of the texture and flavor attributes determined in the current research for describing fresh tomatoes were similar to those in previous literature (e.g. Bedford, 1989; Mual *et al*., 2000; Causse *et al*., 2003; Krumbein *et al*., 2004; and Berna *et al*., 2005). For example, the term "tomato ID" established in our lexicon was similar to tomato-like or tomato aroma used in previous research. Previous literature, however, mainly evaluated a subset of texture and flavor attributes, whereas the present research attempted to fully described aroma, flavor and texture aspects of tomatoes.

Evaluation technique was included as part of the definitions for many attributes to ensure the consistency of the evaluation throughout the study period as well as the repeatability of such evaluation. For example, for viscosity evaluation, panelists rated the rate of flow of tomato products using 1 teaspoon of a sample. Consistent evaluation technique can ensure that an unnecessary source of variation is minimized and is given as part of the definition in classic articles on sensory texture evaluation (Szczesniak *et al*., 1963; Munoz, 1986).

Table 5.1 Tomato sensory attributes, definitions, references and intensities on a 15-point scale

Attribute	Definition	Reference[a] and Intensity[b]
Aroma		
Tomato ID	The aromatics commonly associated with tomato, which may be described as sweet, fruity, earthy, viney, ripe, and sour (citric).	Campbell's Tomato Juice = 8.0
Browned	Dark impression often associated with toasted and caramelized.	Great Lakes Sun Dried Tomato = 10.5 Contadina Tomato Paste = 7.5
Cardboard	Aromatics associated with cardboard and paper packaging. The aromatic may be associated with stale.	Kroger Raw Diced Potatoes = 2.0 (f) Fresh Cucumber = 5.0 (f, a) Fresh Sliced Tomatoes = 10.0 (f), 9.0 (a)
Decaying Vegetation	Aromatics associated with rotting plants (moldy/mildew).	Green Corn Shucks stored in a plastic bag for 1 week.
Green-Viney	A green aromatic associated with green vegetables and newly cut vines and stems; characterized by increased bitter and musty/earthy character.	½ in Wedged Fresh Tomatoes = 6.0 Crushed Tomato Leaves = 10.0
Texture		
Fiber- Awareness	The degree to which fiber are present. Evaluated during mastication after 5-8 chews. Evaluated only on those products with distinguishable pieces using ½ tsp sample.	Dole Canned Tidbits Pineapple = 10.0
Juiciness	The amount of liquid expressed from the sample during first and second chew. Evaluated only on those products with distinguishable pieces.	Hormel Cure 81 Extra Lean Ham, ½" cubed = 5.0 Dole Canned Tidbits Pineapple = 10.0
Mealy	A geometric attribute within the product. The perception of fine, soft, somewhat round and smooth particles evenly distributed within the product.	Fresh Pear, peeled, ½" cubed = 8.0
Pulp Amount	A measure of the amount of perceivable pulp in the liquid portion of and the pureed products, evaluated by manipulating the product to the roof of the mouth with the tongue.	Hunt's Tomato Sauce = 8.0 Contadina Tomato Paste = 14.0

Attribute	Definition	Reference[a] and Intensity[b]
Pulp Size	A measure of the size of the perceivable pulp in the product, evaluated by manipulating the product to the roof of the mouth with the tongue.	Hunt's Tomato Sauce = 6.0 Contadina Tomato Paste = 8.5 Musselman's Applesauce = 13.0
Skin- Awareness	The degree to which the outside skin of the product is perceived as intact pieces during mastication.	Fresh Seedless Red Grapes = 10.0
Seed- Awareness	The degree to which seeds are present. Evaluated during mastication after 3-5 chews from 1 tsp sample.	½ c Hunt's Tomato Sauce + ¼ tsp Sesame Seeds = 7.5
Thickness	A measure of resistance of the pureed product when stirred with a spoon.	Campbell's Tomato Juice = 4.0 Hunt's Tomato Sauce = 7.0 Musselman's Applesauce = 13.0
Viscosity	Degree of resistance to flow. Evaluated by the rate of flow of liquid when sample is poured from a spoon, using 1 tsp sample.	Campbell's Tomato Juice = 4.0 Hunt's Tomato Sauce = 7.5 Musselman's Applesauce = 13.0
Flavor		
Tomato ID	The aromatics commonly associated with tomato, which may be described as sweet, fruity, earthy, viney, ripe, and sour (citric acid).	Campbell's Tomato Juice = 10.0
Browned	Dark impression often associated with toasted and caramelized.	Hunt's Tomato Sauce = 8.0 Contadina Tomato Paste = 10.0
Cardboard	Aromatics associated with cardboard and paper packaging. The aromatic may be associated with stale.	Cardboard soaked in water = 11.0 (preparation: 2x2" cardboard in ½ c water)
Fermented	Aromatics associated with ripe/ overripe fruit; can be somewhat sweet, sour, browned and fruity.	Great Lakes Sun Dried Tomato = 9.0 Pompein Burgundy Cooking Wine = 10.0
Fruity	A sweet, slightly floral and sour aromatic associated with a variety of fruits.	Welch's White Grape Pear Juice, diluted 1:1 in water = 4.5
Green-Viney	A green aromatic associated with green vegetables and newly cut vines and stems; characterized by increased bitter and musty/earthy character.	1 g Crushed Tomato Leaves in medium snifter = 10.0 (a)
Musty/Earthy	Humus-like aromatics that may or may not include damp soil, decaying vegetation, or cellar-like characteristics.	Raw White Potato, ½" sliced in medium snifter = 8.5 (a)

Attribute	Definition	Reference[a] and Intensity[b]
Ripeness	A sweet full flavor of mature fruit. (Unripe → Overripe)	Campbell's Tomato Juice = 10.0
Cooked	The brown (not caramelized), woody aromatics associated with cooked and/or processed tomatoes. (Uncooked → Cooked)	Campbell's Tomato Juice = 9.5
Umami	Flat, salty flavor enhancer naturally occurring in some tomatoes.	0.35% Pillsbury Accent Flavor Enhancer Solution = 7.5
Basic Tastes		
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% Caffeine Solution = 2.0 0.02% Caffeine Solution = 3.5 0.035% Caffeine Solution = 5.0
Chemical	Aromatics associated with a broad range of compounds generally known as chemicals. It may or may not include chlorine, ammonia, aldehyde, etc.	
Overall Sweet	Aromatics associated with the impression of a general blend of sweet substances.	Wheaties = 3.0 Lorna Doone Cookies = 4.5
Salt	The fundamental taste factors associated with a sodium chloride solution.	0.20% NaCl Solution = 2.5 0.35% NaCl Solution = 5.0 0.50% NaCl Solution = 7.5 0.60% NaCl Solution = 8.5
Sour	The fundamental taste factors associated with a citric acid solution.	0.05% Citric Acid Solution = 3.5 0.08% Citric Acid Solution = 5.0
Sweet	The fundamental taste factors associated with a sucrose solution.	1% Sucrose Solution = 1.0 2% Sucrose Solution = 2.0 4% Sucrose Solution = 4.0
Mouthfeel		
Astringent	The dry, puckering mouthfeel associated with placing an alum solution in the mouth	0.03% Alum Solution = 1.5 0.05% Alum Solution = 2.5 0.10% Alum Solution = 5.0
Chemical	Aromatics associated with a broad range of compounds generally known as chemicals. It may or may not include chlorine, ammonia, aldehyde, etc.	
Metallic	An aromatic and mouthfeel associated with tin cans or aluminum foil.	Dole Canned Pineapple Juice, Unsweetened = 6.0

[a] References were prepared approximately 24 hr before a testing session, refrigerated overnight and removed from the refrigerator 30 minutes before a testing session.
[b] Intensity based on a 15-point numerical scale with 0.5 increments, where 0 represents none and 15 represents extremely strong.

Comparison of the Sensory Characteristics Established in Current Study and Previous Literature

Table 5.2 shows similarities and differences in attributes used to evaluate tomato sensory characteristics in previous literature as compared with the lexicon developed in this research. Although considerable research that included some sensory testing has been done on tomatoes, many studies have used only a few flavor (especially sweet and sour) and texture attributes to study the sensory characteristics of tomatoes. Ten previously published articles are included in Table 5.2 to help illustrate that more flavor and texture attributes would be necessary to fully describe the sensory properties of tomatoes. Additionally, most of the previous work focused primarily on studying the sensory characteristics of fresh tomatoes only. A study by Rodríguez *et al*. (2001) was among a small number of publications that examined the sensory characteristics of processed tomatoes. None of previous literature has determined sensory attributes that can describe the characteristics of both fresh and processed tomatoes.

Similarities and differences between our lexicon and those established in previous studies were noted. Stevens *et al*. (1977) described fresh tomatoes using three sensory attributes including overall tomato-like, sweet and sour, all of which we also included in this lexicon as tomato ID, sweet and sour. Aroma characteristics, which have recently been included as terminology describing the sensory properties of tomatoes (e.g. Lengard and Kermit, 2006; and Plaehn and Lundahl, 2006) were specifically described in our lexicon. In previous literature, aroma has only been described in general term as "aroma" (Azodanlou *et al*., 2003) or "tomato aroma" (Causse *et al*., 2003; Lengard and Kermit, 2006; and Plaehn and Lundahl, 2006). Our lexicon specified five specific aroma attributes including tomato ID, browned, green-viney, cardboard and decaying vegetation, which will help researchers further differentiate aroma character present in various tomato products.

Table 5.2 Comparison of descriptive attributes used in previous literature

	Stevens *et al.* (1977)[1]	Watada and Aulenbach (1979)	Resurreccion and Shewfelt (1985)[2]	Bedford (1989)	Rodríguez *et al.* (2001)[3]	Azodanlou *et al.* (2003)[4]	Tandon *et al.* (2003)[5]	Abegaz *et al.* (2004)	Lengard and Kermit (2006)[6]	Plaehn and Lundahl (2006)[6]
AROMA										
Tomato ID									X	X
Browned										
Cardboard										
Green-Viney										
Decaying Vegetation										
TEXTURE										
Fiber-Awareness					Fibrosity					
Firmness			X	X	X	X			X	X
Juiciness			X		X	X			X	X
Mealy						X			X	X
Pulp Size										
Pulp Amount				Dry /Pulp						
Skin-Awareness				Skin Toughness					Skin width	Skin width
Seed-Awareness										
Thickness										
Viscosity										
FLAVOR										
Tomato ID	Tomato like		Tomato like	Strength of flavor			Tomato like	X	X	X
Browned										
Cardboard										
Chemical										
Fermented										
Fruity		X					X			
Green-Viney		Grassy/ Stemmy		Green/ Stemmy			Green/ Grassy	Green/ Grassy		
Musty/Earthy		X		Hay/ Musty						
Overall Sweet										
Ripeness					Freshness			Overripe		
Tomato-Cooked										
Umami				Savoury						
BASIC TASTES AND MOUTHFEELS										
Astringent		X			X		X	X		
Bitter		X			X		X	X		
Metallic							X			
Salty		X		X	X	X	X	X		
Sour	X	X	Acidic	Acidic	Acidic	Acidic	X	X	X	X
Sweet	X	X	X	X	X	X	X	X	X	X

1 – Also listed overall intensity; 2 – Also listed off-flavor, overall flavor intensity; 3 – Also listed flavor intensity, maturity, tomato concentrate, freshness; 4 – Also listed odor, herbaceous, aroma; 5 – Also listed bite; 6 – Also listed melty

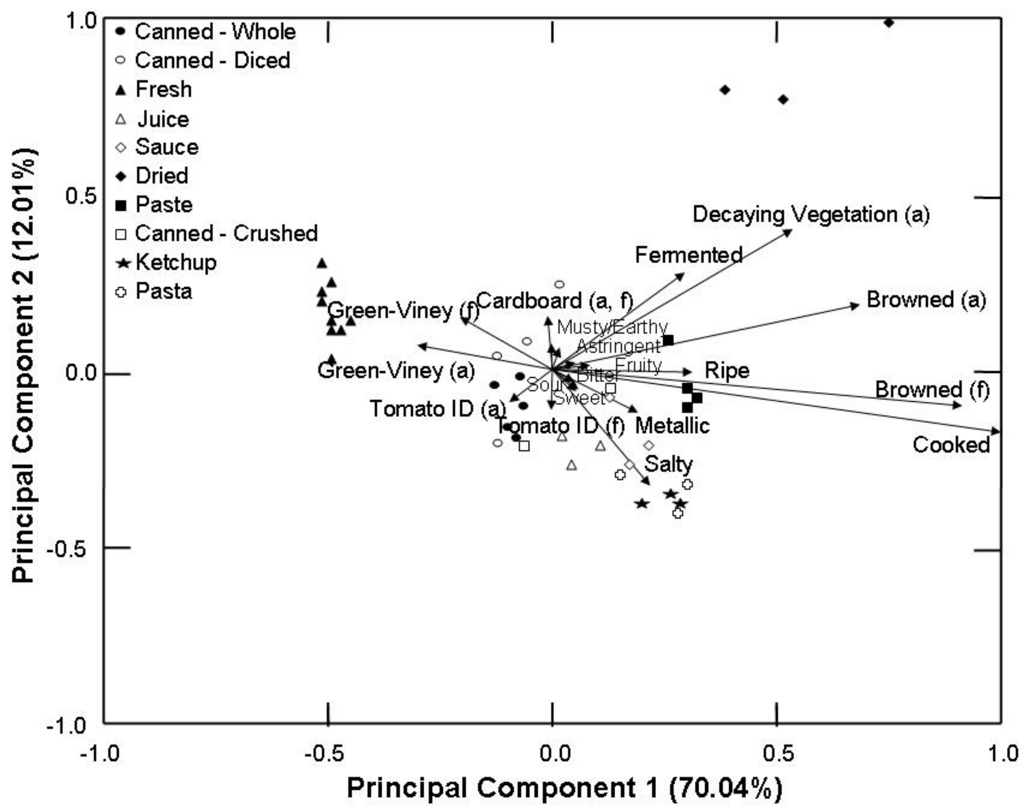
Some sensory attributes used in some previous studies were too broad; hence they were not included in the present lexicon. Several studies evaluated terms such as "overall intensity" (Stevens *et al.*, 1977), "overall flavor intensity" (Watada and Aulenbach, 1979; Resurreccion and Shewfelt, 1985), "herbaceous" and "aroma" (Azodanlou *et al.*, 2003), whereas in our study, specific terms possibly imparting these integral terms were described. For example, the terms ripeness, green-viney, fruity, and musty/earthy characteristics, which potentially impart the overall tomato ID character, were individually described in our lexicon. Other terms found in previous literature such as "off-flavor" (Watada and Aulenbach, 1979), "maturity", "melty" (Lengard and Kermit, 2006 and Plaehn and Lundahl, 2006) and "freshness" (Rodríguez *et al.*, 2001) were not included in our lexicon because these general terms can be interpreted differently, particularly when attribute definitions were not specified.

Evaluating the Characteristics of Fresh and Processed Tomatoes

As expected, products produced with different degrees of processing (e.g. fresh vs. dried vs. canned) exhibited greater differences as compared to those products at the same or similar level of processing. Fresh tomato samples illustrated similar sensory characteristics to other fresh tomatoes, and were different from some processed tomatoes (e.g. tomato paste samples), which had a much higher degree of processing. The sensory profiles generated for each product were unique from one another in both qualitative (i.e. the identified attributes) and quantitative (i.e. intensity) aspects. All sensory attributes were found in many of the products tested, although some attributes were appropriate only for a small number of products. For example, browned and cooked characters were found only in processed, and not in fresh tomatoes.

The first two principal components explained 82% of the total variability of the aroma and flavor attributes of the samples evaluated (Fig. 5.1). For texture attributes, the first two principal components accounted for approximately 80% of the total variance (Fig. 5.2). Ten texture attributes including viscosity, thickness, juiciness, firmness, mealy, skin awareness, seed awareness, fiber awareness, pulp size and pulp amount, and 19 aroma/flavor attributes including tomato ID, green-viney, decaying vagetation, ripeness, browned, cooked, fruity, cardboard, fermented, musty/earthy, salty, sweet, sour, bitter, metallic, astringent could be used to describe the variations in tomato products. It should be noted that because of the considerable fundamental differences in the texture properties of the tomato samples (e.g. fresh vs. tomato sauce), only some texture attributes would be appropriate for describing the characteristics of a specific type of tomato products.

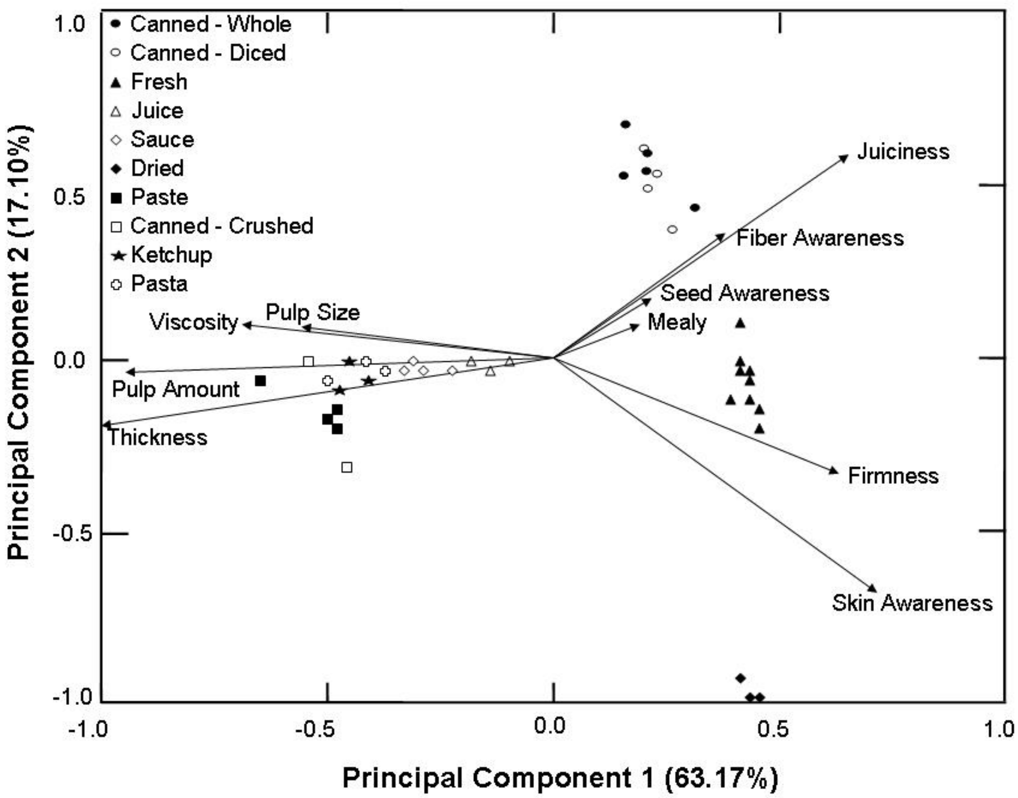
Figure 5.1 Sensory map of the first two principal components for describing the aroma/flavor characteristics of tomato products



The sensory map shown in Fig. 5.1 and 5.2 demonstrates differences in aroma/flavor and texture characteristics of tomato samples. For aroma/flavor, principal component 1 differentiated between raw and cooked notes in the products. It is clear that fresh tomatoes were located where tomato ID and green-viney characters are high, and those attributes associated with cooked notes are low. Principal component 2 categorized products based on their saltiness, fermented and decaying vegetation. It is interesting to also note that ripeness was found to be higher in some processed tomato products, including canned diced, whole, and crushed tomatoes than in fresh tomatoes. Heat treatment may result in increased concentration of the ripeness character in those tomato products. Based on aroma/flavor, tomatoes can be categorized into 3 groups. These groups included no processing (i.e. fresh tomatoes), with processing (i.e. canned-whole, -diced, -crushed, tomato juice, sauce, paste, ketchup and pasta sauce) and dried tomatoes. Dried tomatoes are located where attributes such as fermented and decaying vegetation are high. This distinct difference is likely due to the impact of drying/dehydrating processes, which were not used in other products selected. Fig. 5.2 shows clear differences in texture characteristics of tomato products impacted by the processing level. Texture map (Fig. 5.2) differentiated the products according to their level of processing. Fresh tomatoes are located where the firmness and skin awareness are high. Canned whole and diced tomatoes, which have minimal processing, retain the integrity of the flesh with high juiciness, mealiness, seed awareness and fiber awareness. Those products with higher processing level/heat treatment illustrate attributes such as pulp, viscosity and thickness.

The sensory characteristics of products in the same group tended to be more similar than those in different groups. However, products within the same group could show a few large differences in some attributes. For example, among the fresh tomatoes, those purchased from large chain grocery stores (e.g. Dillon's) were considerably lower in tomato ID flavor as compared to those purchased from a fresh vegetable market (e.g. KS and AK-local grown). Among the processed tomato products, the cooked and browned attributes varied considerably. For example, cooked flavor in canned tomatoes ranged from 7.0 to 9.0; juice, sauce, pasta and ketchup from 9.5 to 12.0; and paste and dried from 12.0 to 15.0. Although most processed tomatoes (i.e. canned, juice, sauce, paste, dried, and tomato-based products) exhibited similar sensory attributes, they differed considerably in their intensities probably because of processing level. For example, tomato ketchup and pasta sauce exhibited the characteristic green-viney aroma only at a detectable level, while those products processed to a lesser degree (i.e. canned) had higher levels of green-viney. These results indicate the impact that processing level has on the sensory characteristics of tomato products and the necessity to retain these attributes in the lexicon.

Figure 5.2 Sensory map of the first two principal components for describing the texture characteristics of tomato products



Correlation analysis of the data showed that some attributes were strongly correlated. For example, cooked and browned flavors had high correlation(r = 0.91). This suggested that these attributes were often present together in a particular sample. However, the attributes did not measure the same flavor properties because some samples with high cooked flavor were high in browned flavor, whereas some other samples had a high cooked note, but low browned flavor. A similar phenomenon was observed between decaying vegetation aroma and fermented flavor, which also were highly correlated (r = 0.91). These results suggest that all the attributes listed would need to be evaluated in order to determine the full sensory profile of a specific product.

Reducing the number of sensory attributes to be evaluated is possible, depending on the objective of a study, especially when products vary greatly due to the level of processing. For example, fewer flavor and texture attributes may be needed when products were raw, because attributes such as cooked, browned, fermented, metallic, chemical, and viscosity were only present in processed tomato products in this study. Therefore, it may be reasonable to remove those attributes when a researcher is examining only raw (fresh) tomatoes, but that finding would need to be confirmed with a study with a larger number of tomato varieties in various stages of ripeness under various storage conditions. It may be necessary to have all the established attributes to assure that a large pool of necessary attributes was available to researchers when studying a specific type of tomato product, and to maintain the overall integrity of the lexicon.

Conclusions

A lexicon containing 33 aroma, flavor and texture attributes for describing the sensory characteristics of fresh and processed tomato products was established. All attributes were defined and referenced. These objectively determined attributes can help researchers to adequately describe the sensory characteristics of fresh, processed tomatoes and tomato-based products. These sensory attributes also could be related to other information such as physical and chemical data to help researchers better understand the characteristics of various tomato products. Because of the wide range of the product characteristics caused, in part, by degree of processing, some attributes may only be appropriate for evaluating a specific set of tomato products. Thus the number of attributes may vary accordingly and may be reduced in specific studies.

References

ABEGAZ, E.G., TANDON, K.S., SCOTT, J.W., BALDWIN, E.A. and SHEWFELT, R.L. 2004. Partitioning taste from aromatic flavor notes of fresh tomato (*Lycopersicon esculentum*, Mill) to develop predictive models as a function of volatile and nonvolatile components. Postharvest Biol. Technol. *34*, 227-235.

AZODANLOU, R., DARBELLAY, C., LUISIER, J.L., VILLETTAZ, J.C. and AMADÒ, R. 2003. Quality assessment of strawberries (*Fragaria* species). J. Agric. Food Chem. *51*, 715-721.

BATU, A. 2004. Determination of acceptable firmness and colour values of tomatoes. J. Food Eng. *61*, 471-475.

BEDFORD, L.V. 1989. Sensory quality of fresh tomatoes: comparison of tomatoes grown in nutrient media of different conductivities. Camden Food and Drink Research Association/Technical Memorandum No. 531.

BERNA, A.Z., BUYSENS, S., DI NATALE, C., GRÜN, I.U., LAMMERTYN, J. and NICOLAÏ, B.M. 2005. Relating sensory analysis with electronic nose and headspace fingerprint MS for tomato aroma profiling. Postharvest Biol. Technol. *36*, 143-155.

BOTT, L. and CHAMBERS, E. IV. 2006. Sensory characteristics of combinations of chemicals potentially associated with beany aroma in foods. J. Sens. Stud. *21*, 308-321.

BRUHN, C.M., FELDMANN, N., GARTITZ, C., HARWOOD, J., IVANS, E., MASHALL, M., RILEY, A., THURBER, D. and WILLAMSON, E. 1991. Consumer perceptions of quality: apricots, cantaloupes, peaches, pears, strawberries, and tomatoes. J. Food Qual. *14*, 187–195.

BUCHELI, P., VOIROL, E., DELATORRE, R., LOPEZ, J., RYTZ, A., TANKSLEY, S.D. and PETIARD, V. 1999. Definition of nonvolatile markers for flavor of tomato (*Lycopersicon esculentum* Mill.) as tools in selection and breeding. J. Agric. Food Chem. *47*, 659–664.

CAUSSE, M., BURET, M., ROBINI, K. and VERSCHAVE, P. 2003. Inheritance of nutritional and sensory quality traits in fresh market tomato and relation to consumer preferences. J. Food Sci. *68*, 2342-2350.

CUELLAR, S. R. 2002. Marketing fresh fruit and vegetable imports in the U.S.: Status, Challenge and Opportunity. Research Bulletin (R. B. 2002-2004). pp. 20. Food Industry Management, Cornell University, Ithaca, New York.

DAY N'KOUKA, K., KLEIN, B.P. and LEE, S.Y. 2004. Developing a lexicon for descriptive analysis of soymilks. J. Food Sci. *69*, 259-263.

GALÁN-SOLDEVILLA, H., RUIZ-PÉREZ-CACHO, M.P., SERRANO JIMÉNEZ, S., JODRAL VILLAREJO, M. and BENTABOL MANZANARES, A. 2005. Development of a preliminary sensory lexicon for floral honey. Food Qual. Pref. *16*, 71-77.

GARCIA, E. and BARRETT, D.M. 2006. Evaluation of processing tomatoes from two consecutive growing seasons: quality attributes, peelability and yield. J. Food Process. Preserv. *30*, 20-36.

HO, L. 1996. The mechanism of assimilates partitioning and carbohydrate compartmentation in fruit in relation to the quality and yield of tomato. J. Exp. Bot. *47*, 1239–1243.

HOBSON, G. 1988. How the tomato lost its taste. New Scientist. *1632*, 46–50.

KADER, A.A., STEVENS, M.A., ALBRIGHT-HOLTON, M., MORRIS, L.L. and ALGIZI, M. 1977. Effect of fruit ripeness when picked on flavor and composition in fresh market tomatoes. J. Am. Soc. Hortic. Sci. *102*, 724–731.

KADER, A.A., MORRIS, L.L., STEVENS, M.A. and ALBRIGHT-HOLTON, M. 1978. Composition and flavor quality of fresh market tomatoes as influenced by some postharvest handling procedures. J. Am. Soc. Hortic. Sci. *103*, 6-13.

KETELAERE, B.D., LAMMERTYN, J., MOLENBERGHS, G., DESMET, M., NICOLAÏ, B. and BAERDEMAEKER., J.D. 2004. Tomato cultivar grouping based on firmness change, shelf life and variance during postharvest storage. Postharvest Biol. Technol. *34*, 187-201.

KRUMBEIN, A., PETERS, P. and BRÜCKNER, B. 2004. Flavor compounds and a quantitative descriptive analysis of tomatoes (Lycopersicon esculentum Mill.) of different cultivars in short-term storage. Postharvest Biol. Technol. *32*, 15-28.

LANA, M.M., TIJSKENS, L.M.M. and KOONER, O. 2005. Effect of storage temperature and fruit ripening on firmness of fresh cut tomatoes. Postharvest Biol. Technol. *35*, 87-95.

LÊ, S. and LEDAUPHIN, S. 2006. You like tomato, I like tomato: segmentation of consumers with missing values. Food Qual. Pref. *17*, 228-233.

LEE, A., THURNHAM, D.I. and CHOPRA, M. 2000. Consumption of tomato products with olive oil but not sunflower oil increases the antioxidant activity of plasma. Free Rad. Biol. Med. *29*: 1051-1055.

LENGARD, V. and KERMIT, M. 2006. 3-Way and 3-block PLS regressions in consumer preference analysis. Food Qual. Pref. *17*, 234-242.

LUCIER, G. 2003. Vegetable consumption away from home on the rise. Amber Waves Vol. 1.

MALUNDO, T.M.M., SHEWFELT, R.L. and SCOTT, J.R. 1995. Flavor quality of fresh tomato (Lycopersicon esculentum Mill.) as affected by sugar and acid levels. Postharvest Biol. Technol. *6*, 103-110.

MAUL, F., SARGENT, S.A., SIMS, C.A., BALDWIN, E.A., BALABAN, M.O. and HUBER, D.J. 2000. Tomato flavor and aroma quality as affected by storage temperature. J. Food Sci. *65*, 1228-1237.

PETRO-TURZA, M. 1987. Flavor of tomato and tomato products. Food Rev. Int. *2,* 311-353.

PLAEHN, D. and LUNDAHL, D.S. 2006. An L-PLS preference cluster analysis on French consumer hedonics to fresh tomatoes. Food Qual. Pref. *17*, 243-256.

RATANACHINAKORN, B., KLIEBER, A. and SIMONS, D.H. 1997. Effect of short-term controlled atmospheres and maturity on ripening and eating quality of tomatoes. Postharvest Biol. Technol. *11*, 149-154.

RESURRECCION, A.V.A. and SHEWFELT, R.L. 1985. Relationship between sensory attributes and objective measurements of postharvest quality of tomatoes. J. Food Sci. *50*, 1242-1245.

RÉTIVEAU, A., CHAMBERS, D.H. and ESTEVE, E. 2005. Developing a lexicon for the flavor description of French cheeses. Food Qual. Pref. *16*, 517-527.

RODRÍGUEZ, A., LOPEZ, J., GONZALEZ, C., DE LA TORRE, R. and MANGUT, V. 2001. Sensory Evaluation of canned diced tomato varieties. Proc. 7th Int. Symp. On Processing Tomato. Acta Hort 542, ISHS 2001. pp. 269-275.

SERRANO-MEGÍAS, M. and LÓPEZ-NICOLÁS, J.M. 2006. Application of agglomerative hierarchical clustering to identify consumer tomato preferences: influence of physicochemical and sensory characteristics on consumer response. J. Sci. Food Agri. *86*, 493-499.

SINESIO, F., DI NATALE, C., QUAGLIA, G.B., BUCARELLI, F.M., MONETA, E., MACAGNANO, A., PAOLESSE, R. and D'AMICO, A. 2000. Use of electronic nose and trained sensory panel in the evaluation of tomato quality. J. Sci. Food Agric. *80*, 63-71.

STEVENS, M.A., KADER, A.A., ALBRIGHT-HOLTON, M. and ALGAZI, M. 1977. Genotypic variation for flavor and composition in fresh market tomatoes. J. Am. Soc. Hortic. Sci. *102*, 680-689.

STEVENS, M.A., KADER, A.A. and ALBRIGHT-HOLTON, M. 1979. Potential for increasing tomato flavor via increased sugar and acid content. J. Am. Soc. Hortic. Sci. *104*, 40–42.

TANDON, K.S., BALDWIN, E.A., SCOTT, J.W. and SHEWFELT, R.L. 2003. Linking sensory descriptors to volatile and nonvolatile components of fresh tomato flavor. J. Food Sci. *68*, 2366-2371.

THYBO, A.K., BECHMANN, I. and BRANDT, K. 2005. Integration of sensory and objective measurements of tomato quality: quantitative assessment of the effect of harvest date as compared with growth medium (soil *versus* rockwool), electrical conductivity, variety and maturity. J. Sci. Food Agric. *85*, 2289–2296.

VARA-UBOL, S., CHAMBERS, E. IV. and CHAMBERS, D.H. 2004. Sensory characteristics of chemical compounds potentially associated with beany aroma in foods. J. Sens. Stud. *19*, 15-26

VARA-UBOL, S., CHAMBERS, E. IV., KONGPENSOOK, V., OUPADISSAKOON, C., YENKET, R. and RÉTIVEAU, A. 2006. Determination of the sensory characteristics of rose apples cultivated in Thailand. J. Food Sci. *71*, 547-552.

WATADA, A.E. and AULENBACH, B.B., 1979. Chemical and sensory qualities of fresh market tomatoes. J. Food Sci. *44*, 1013–1016.

YILMAZ, E. 2001. The chemistry of fresh tomato flavour. Turk. J. Agric. Forest. *25*, 149-155.

CHAPTER 6 - Detailed Materials and Methods to Sensory Characteristics of Fresh Tomatoes and the Impact of Processing on the Sensory Characteristics of Tomatoes

The objectives of this study were (1) to determine differences in the flavor characteristics of five varieties of fresh tomatoes representing home-style, commercial, and heirloom tomatoes and (2) to determine the effects of processing on flavor of those tomato varieties.

Plant Materials

Five tomato varieties were selected for the study. These included Florida 91, Jet Star, Brandywine, Red Agate, and Juliet. These varieties were used to represent round and plum type fresh market tomatoes as well as processing tomatoes. Florida 91 and Jet Star were selected because they are round large-fruited fresh tomatoes that can be found more commonly in grocery stores. Brandywine, an heirloom cultivar, was selected to represent fresh market tomato that has been known as one of the good-tasting tomatoes. Red Agate was selected to represent a plum-shape processing tomato, and Juliet was selected to represent a plum-type fresh market tomato. Juliet is commonly sold and used as a salad tomato.

Tomato seeds were purchased from commercial seed providers. The seed providers are listed in Table 6.1. The seeds were planted using standard potting media in the greenhouse facility at the department of Horticulture, Kansas State University (Manhattan, KS). The tomato transplants that were dark green with sturdy stems were selected for field planting. The transplanting occurred 25 days after planting the seeds. Tomatoes were grown on a Kennebec silt loam soil in a high-tunnel at the Kansas State University Horticulture Research and Extension Center, Olathe, KS. On April 21, 2006 transplants were planted in the high tunnel in 4-plant plots on 0.5 m-wide beds covered with black plastic mulch underlain with buried drip tape for irrigation. Plants were spaced 0.6 m apart within the row, and the entire trial was planted on two rows 1.2 m apart. The trial was laid out as randomized complete block trial with four replications, two of the blocks being assigned to each row. The plotting design is illustrated in Figure C.1.

Preplant soil analysis indicated a pH of 6.3, phosphorous (Mehlich 3-P) of 109 ppm, potassium 258 ppm, and nitrate-nitrogen of 21.9 ppm. There was no preplant application of fertilizer. Starting 4 weeks after transplanting, the trial was fertigated weekly with calcium nitrate at a rate of 3.4 kg N/ha. Fruit worms were controlled through applications of spinosad.

Table 6.1 Description of Tomato Varieties Selected for the Study

Variety	Fruit Shape	Use	Days to Maturity	Source
Brandywine	Round	"heirloom" line, Fresh market	80 days	Park Seed (Greenwood, SC., www.parkseed.com)
Florida 91	Round	Newer line, Fresh market	80 days	Morgan County Seeds (Barnett, MO., www.morgancountyseeds.com)
Jet Star	Round	Newer line, Fresh market	72 days	Park Seed (Greenwood, SC., www.parkseed.com)
Juliet	Plum - small	Fresh market (Salad)	60 days	Johnny's Selected Seeds (Winslow, ME., www.johnnyseeds.com)
Red Agate	Plum - large	Processing (Paste)	78 days	Johnny's Selected Seeds (Winslow, ME., www.johnnyseeds.com)

Plants were supported during growth with cages made from concrete reinforcing wire with large spaces into a cylinder of about 18-20 inches in diameter. Two cages, 2.5 feet in height, were stacked for caging each tomato plant. Weeding was done every 2 weeks. Harvesting began in the second week of July. Tomatoes were harvested 3 times: July 17, July 21 and July 28. At each time, light-red, red-ripe and red-soft tomatoes, based on visual classification and description provided by USDA (1976), were harvested. The same variety of tomatoes harvested from each plot was thoroughly mixed to create homogeneous samples. Harvested fruits were transported from the field to the Sensory Analysis Center at Kansas State University (Manhattan, KS) for storage. All fruits were stored on flat trays at room temperature (~25°C).

Analytical Method

Sample Preparation

Tomato samples were stored at room temperature for approximately five days before any analytical evaluations were conducted. Three to four red ripened fruits were randomly selected for each of the varieties. The fruits were rinsed, and then chopped into small pieces. The chopped tomatoes were then placed either on an aluminum foil tray for the dry matter testing or into an electronic blender (Hamilton Beach® 14-speed, model 54250, Washington, NC 27889) to extract tomato juice for other evaluations. Juice from each tomato sample was filtered through cheese cloth to remove large particles and seeds. Twenty ml of juice was placed into a 250-mL Erlenmeyer flask. Total soluble solids were measured directly from the juice. Fifty ml of reverse osmosis, deionized, carbon-filtered water was added to each flask of sample for the evaluation of pH, and titratable acidity (TA).

pH, Total Soluble Solids (ºBrix), Titratable Acidity (TA) and Dry Matter content

Total soluble solid (TSS) of each sample was measured using a portable refractometer (Fisher Scientific®, Catalog#13-946-24). The hand held refractometer is designed to measure the refractive index of a sample solution. Calibration of the refractometer must be done prior to measuring total soluble solid concentration in ºBrix value at room temperature (~ 25ºC). One ºBrix is equivalent to approximately 1 gram of soluble solids per 100 grams of a sample solution. ºBrix was measured immediately after extracting the juice from fresh tomato samples and prior to packaging the juice and paste samples.

pH value of the samples was measured using a digital pH meter (Fisher Scientific®, Accument Portable AP 63). Concentration of acids and some associated salts was determined from pH value (Gould 1983). Tomatoes are considered a high acid food (Gould 1983) and citric acid is the primary organic acid in tomato fruits (Yilmaz 2001). Before measuring the pH of each sample, the pH probe was calibrated using buffers with pH of 4.0 and 7.0. The probe was then rinsed thoroughly using double distilled water before submerging its tip into each tomato sample. The probe was similarly rinsed between testing tomato samples. After placing the probe in a sample, the meter is allowed to equilibrate before reading of pH of the sample.

Titratable acidity (TA) of tomato samples were done by titration of the tomato juice until pH reached 8.2±0.1 using 1.0 *N* NaOH. 1% Phenolphthalein solution was also prepared as an indicator. Three drops of phenolphathalein solution was placed into a sample flask. A pH meter was used to determine the end point at approximately pH 8.1 – 8.3. The volume of 1.0 *N* NaOH solution used for each titration was recorded. The percentage of citric acid was computed using the following formula.

$$Z = \frac{V \times N \times mEqwt}{Y} \times 100$$

(Gould, 1983)

where: Z = % of acid in sample

V = volume in ml of NaOH titrated

N = normality of NaOH (1.0 N)

nEqwt = milliequivalents of acid (0.064 for citric acid)

Y = volume in ml of sample

To determine dry matter content of tomato, four tomato fruits were randomly selected from red-ripe fruits. Samples were chopped coarsely, and 200 g was placed into aluminum foil dish. The weight of the dish and the samples were recorded. The samples were then placed into a 105 ºC temperature-controlled oven (Fisher Scientific®, Isotemp Oven) for 48 hours. Samples were removed from the oven and the final weights were recorded. The percentage of dry matter was calculated. Dry matter analysis was done only on fresh tomatoes.

Processing of Tomato – Tomato Juice and Tomato Paste

The impact of processing levels – lower processing for tomato juice and higher processing for tomato paste, on the tomato sensory characteristics was investigated. Tomato juice and paste identities and characteristics have been defined in the Code of Federal Regulations (CFR), title 21, volume 2 – 21CFR156.145 for tomato juice and 21CFR155.191 for tomato paste (FDA).

Approximately 2,000 grams of each variety of tomato were used to make tomato juice. Pickling salt and lemon juice were added as minimal ingredients for juice seasoning. The instructions for making tomato juice can be found in Appendix D. For tomato paste, approximately 4,000 to 4,500 grams of tomato were used for the processing. Pickling salt was added for minimal seasoning. The instructions for tomato paste making can be found in Appendix E. Tomato juice and paste processing and canning techniques were modified from Canning Tomatoes and Tomato Products (National Center for Home Food Preservation, University of Georgia, www.uga.edu/nchfp). Pint-sized (~ 473 ml) mason glass jars (Golden Harvest, Dyerburg, TN) were used for product containers. Tomato juice and paste were stored at room temperature prior to any evaluations.

Panelists

The six-member highly trained panelists from the Sensory Analysis Center, Kansas State University (Manhattan, KS) participated in this study. The panelists had completed 120 hours of training on general sensory analysis techniques. All panelists have a minimum of 1000 hours of experience in testing a wide variety of food products including fresh tomatoes and tomato-based products.

Descriptive Sensory Analysis

Sample Preparation

All tomato samples were served at room temperature. For fresh tomatoes, the fruits were rinsed and cut into ½-in thick wedges and placed in odor-free, disposable 3.25 oz (~ 96 mL). plastic cups (Sweetheart Cup Company INC., Owing Mills, MD) for the evaluation. Tomato juice and paste were thoroughly stirred before placing into 3.25 oz. plastic cups with lids for the evaluation. Samples were prepared approximately 30 min prior to the testing session. Each panelist received approximately five pieces or 3 oz. (~ 88 mL). of samples for the evaluation.

Evaluation Procedure

Descriptive analysis was conducted using the same group of panel participating in the previous study that developed the tomato lexicon (see Chapter 4). Prior to the evaluation, the panel was allowed additional five orientation sessions, equivalent to 7.5 hours to further familiarize themselves with the range of products they would be evaluated. An individual balloting approach was used for the evaluation. Each fresh tomato sample was evaluated with three times. Each time corresponded to the harvesting time (i.e. week 1, 2, 3). Factors included in the study were tomato varieties (i.e. five for fresh tomato and tomato juice, and four for tomato paste) and ripening stages (i.e. light-red, red-ripe, and red-soft). Fresh tomato samples were evaluated approximately five days after harvesting. Tomato juice and paste were produced three times according to the harvesting times for the processed tomato product evaluation. Samples were evaluated during 15 1.5-hr sessions, in which 5-6 samples were presented per session. All samples were coded with 3-digit random numbers. The order of product evaluation was randomized within each harvesting time and each product category (i.e. fresh, tomato juice and tomato paste). Sensory attributes used for the evaluation were obtained from the tomato lexicon established in Chapter 5. Panelists evaluated the intensity of each sensory attributes individually using a 15-point numerical scale, with increments of 0.5, where 0 represents none and 15 represents extremely strong. Reverse osmosis, deionized, carbon-filtered water and unsalted cracker (Nabisco Premium Saltine Unsalted Top Crackers, 8 oz, East Hanover, NJ) were provided to cleanse palate between samples during testing.

Data Analysis

All data were entered into Microsoft Excel spreadsheet. All data were analyzed using SAS® System for Windows V. 9, 2006, (SAS Institute, Cary, NC). Significant differences were determined at p-value ≤ 0.05. Analysis of variance (MIXED procedure, Appendix H for fresh tomatoes and Appendix I for juice and paste) was constructed for determining the differences in the samples. The analysis of variance for fresh tomato data were done separately from those for tomato juice and paste samples. Factors included in the study were tomato varieties (i.e. five for fresh tomato and tomato juice, and four for tomato paste), ripening stages (i.e. light-red, red-ripe, and red-soft), and harvesting times (i.e. week 1, 2, 3).

Principal components analysis (PCA) was also constructed using the covariance matrix (SYSTAT®, Version 10.2, 2006, Systat Software, Inc., San Jose, CA). PCA categorized attributes into a number of new uncorrelated variables (principal components) that were made up of the original sensory attributes. Cluster analysis (Ward's method) was performed to allow grouping the samples based on their similarities.

References

NATIONAL CENTER FOR HOME FOOD PRESERVATION. Canning Tomatoes and Tomato Products. University of Georgia. www.uga.edu/nchfp.

GOULD, W.A. 1983. Total Acidity and pH. In *Tomato Production, Processing and Quality Evaluation*. AVI Publishing Company, INC, Westport, CT. pp. 269.

UNITED STATES DEPARTMENT OF AGRICULTURE. 1976. United States standards for grade of fresh tomatoes. US Dept. Agric., Mktg., Serv., Washington DC. pp. 10.

FOOD AND DRUG ADMINISTRATION. www.fda.gov

YILMAZ, E. 2001. The chemistry of fresh tomato flavour. Turk. J. Agric. Forest. *25*, 149-155.

CHAPTER 7 - Sensory Characteristics of Fresh Tomatoes and the Impact of Processing on the Sensory Characteristics of Tomatoes

Abstract

Vine-ripened fresh tomatoes are believed to have better flavor than those harvested at the mature green stage and ripened artificially. However, tomato cultivars and various growing conditions impact the flavor characteristics of fresh market tomatoes considerably. When creating new tomato cultivars, breeders often have focused more on providing higher yields and more resistance to diseases and postharvest conditions than on the sensory quality of the fruit. The current research examined the sensory characteristics of various fresh tomatoes and the effect that processing of those tomatoes has on sensory properties. The research included newer and older cultivars to better understand their sensory properties. The effect of various ripening stages also was investigated. Fresh tomatoes and processed tomatoes (juice and paste) were produced and examined by descriptive sensory evaluation. The sensory properties of the tomato varieties and properties of fresh versus processed tomatoes were compared. Results showed significant differences in many sensory characteristics among the fresh tomatoes as a result of cultivar and ripening stages. The sensory characteristics of fresh and processed products were considerably different, but with lower heat processing such as that for making tomato juice, several key sensory attributes were intensified. In general, flavor differences among cultivars tended to disappear after processing, especially high levels of processing such as those found in tomato paste, but texture differences were prominent among cultivars when processed into tomato juice and paste.

Introduction

In the past 30 years, fresh tomatoes available commercially have been criticized as lacking flavorful characteristics (Watada and Aulenbach 1979, Hobson 1988, Bruhn and others 1991, Maul and others 2000, Yilmaz 2001, Batu 2004, Krumbein and others 2004, Serrano-Megías and López-Nicolás 2006). Kader and others (1977) reported that the lack of desirable flavor in tomatoes is partly caused by harvesting tomatoes at the mature green stage. In addition, various studies indicated that postharvest storage treatments can negatively affect the flavor properties of fresh market tomatoes (Kader and others 1978, Hobson 1988, Ho 1996, Maul and others 2000). It has been recommended (e.g. Kader and others 1978) that fresh market tomatoes should be harvested at the vine-ripened stage to maintain the flavor integrity. However, the shelf-life of those vine-ripened tomatoes is shortened significantly.

Tomato researchers often focus on development of tomato cultivars that provide higher yield, longer shelf-life, and more resistance to diseases, and may overlook flavor quality aspects. An economic issue of harvesting fresh tomatoes at a riper maturity is the susceptibility of the tomatoes to degradation during transportation and a shorter shelf-life. However, advantages of harvesting vine-ripened fresh tomatoes include the demand of higher flavor quality (Auerswald and others 1999).

Descriptive sensory analysis can be used to evaluate the quality of tomatoes and has been used successfully to describe the sensory properties of various food products. Many previous studies on tomatoes concentrated on examining changes in compositional quality (e.g. sugars, acid contents, and volatile compounds) as affected by various postharvest treatments (e.g. Ratanachinakorn and others 1997, Boukobza and Taylor 2002, Ketelaere and others 2004, Krumbein and others 2004, Lana and others 2005). Research also has been conducted to determine the relationship between instrumental and sensory data or consumer acceptance information (Lee and others 1999, Berna and others 2005).

Although published data reported some sensory characteristics of fresh tomatoes, minimal work has been done to understand differences in sensory characteristics of fresh tomato cultivars (e.g. Causse and others 2003) and we found no work that tracked sensory properties from the fresh tomato to processed tomato products. Thus, the objectives of this study were to

(1) determine the sensory characteristics of five varieties of fresh tomatoes, and (2) determine the impact processing level has on the sensory quality of tomatoes.

Materials and Methods

Tomatoes

Five tomato cultivars (*Lycopersicon esculentum* Mill.) – Florida 1 (large, globe-shape fruit), Red Agate (large, plum-shape fruit; processing tomato), Brandywine (large globe-shape fruit; heirloom with a reputation for good taste), Juliet (small, plum-shape fruit), and Jet Star (large, globe-shape fruit) were used in this study. Tomatoes were grown on a Kennebec silt loam soil in a high-tunnel at the Kansas State University Horticulture Research and Extension Center, Olathe, KS. Seedlings were grown from seeds in standard potting media in the greenhouse at Manhattan, Kansas, and were transplanted to the high tunnel 25 days after seeding. On April 21, 2007, transplants were planted in the high tunnel in 4-plant plots on 0.5 m-wide beds covered with black plastic mulch underlain with buried drip tape for irrigation. Plants were spaced 0.6 m apart within the row, and the entire trial was planted on two rows 1.2 m apart. The trial was laid out as randomized complete block trial with four replications, two of the blocks being assigned to each row. Plants were supported during growth with cages made from concrete reinforcing wire.

Preplant soil analysis indicated a pH of 6.3, phosphorous (Mehlich 3-P) of 109 ppm, potassium 258 ppm, and nitrate-nitrogen of 21.9 ppm. There was no preplant application of fertilizer. Starting 4 weeks after transplanting, the trial was fertigated weekly with calcium nitrate at a rate of 3.4 kg N/ha. Fruit worms were controlled through applications of spinosad.

Postharvest Treatments

Fruit were harvested 3 times, July 17, July 21, and July 28. At each harvesting time, light-red, red-ripe, and red-soft tomatoes were harvested based on visual classification and description (USDA 1976). The fruits of each cultivar harvested from each plot were thoroughly mixed to create a homogeneous sample for each of the ripening stages. All fruit were stored on flat trays at room temperature approximately five days prior to any evaluations.

Preparation of Tomato Juice and Paste

To determine the impact of processing level on the sensory characteristics of tomatoes, tomato juice was selected to represent a low processing level and tomato paste was selected to represent a high processing level. Tomato juice was produced from all five tomato cultivars; however, tomato paste samples were produced using only four cultivars. Brandywine was not made into paste because sample quantity was too low; this cultivar often gives low yields. Tomato juice and paste processing and canning techniques were modified from Canning Tomatoes and Tomato Products (National Center for Home Food Preservation, University of Georgia, www.uga.edu/nchfp). Products were canned in pint-sized mason glass jars (Golden Harvest, Dyerburg, TN) and stored at room temperature prior to any evaluations. The product identities were in compliance with the Code of Federal Regulations (CFR), title 21, volume 2, 21CFR156.145 for tomato juice, and 21CFR155.191 for tomato paste (www.fda.gov). Pickling salt and lemon juice were added to tomato juice samples; only salt was added to tomato paste.

Compositional Analyses

Tomato fruit from each cultivar were subject to compositional analyses including titratable acidity (TA), pH, total soluble solids (TSS), and dry matter. Only red-ripened fruit were randomly selected for each of the cultivars. The fruit were rinsed, and then chopped into small pieces. The chopped tomatoes were divided and placed either on an aluminum foil tray for dry matter evaluation or into an electronic blender (Hamilton Beach® 14-speed, model 54250, Washington, NC) to extract tomato juice for other evaluations. Juice from each tomato sample was filtered through cheese cloth to remove large particles and seeds. TA of the fruit was determined by potentiometric titration with 1.0 *N* NaOH; pH measured by a digital pH meter (Fisher Scientific®, Accument Portable AP 63); TSS measured by a portable refractometer (Fisher Scientific®, Catalog#13-946-24); and dry matter by placing 200 g of fresh chopped tomato into a 105 ºC temperature-controlled oven (Fisher Scientific®, Isotemp Oven) for 48 hours and obtaining weight after drying. Only the TSS content was measured in tomato juice and paste to ensure that they meet the CFR specifications. All tomato paste samples were measured to have at least 24% soluble solid content.

Descriptive Sensory Analysis

The descriptive sensory analysis for all fresh and processed tomatoes (i.e. juice and paste) was conducted at the Sensory Analysis Center at Kansas State University. The evaluation facility has controlled temperature, lighting, and humidity and is quiet.

Six highly trained panelists participated in the complete study. The panelists had completed 120 hours of general sensory descriptive analysis training with a wide variety of food products. They all have more than 1,000 hours of testing experience with a variety of food products including tomatoes and tomato-based products. Prior to the evaluation, five additional orientation sessions of 1.5 hr were conducted over five days. During the orientation sessions, sensory attributes and appropriate reference standards established previously by the same panel were provided to the panel to help further familiarize them with all attributes. The panel was given a variety of fresh tomatoes and tomato products during the orientation with which they practiced the evaluation procedure for each sensory attribute. Five aroma attributes, ten texture attributes, and 18 flavor attributes, including six taste and mouthfeeling attributes were evaluated.

All tomato samples were served and evaluated at room temperature. For fresh tomatoes, the fruits were rinsed and cut into ½-in (1.27 cm) thick wedges and placed in odor-free, disposable 3.25 oz. (~ 96 mL) plastic cups (Sweetheart Cup Company Inc., Owing Mills, MD). Tomato juice and paste were thoroughly stirred before placing into 3.25 oz. (~ 96 mL) plastic cups with lids. Samples were prepared approximately 30 min to 1 hr prior to the testing sessions. All samples were coded with 3-digit random numbers.

The evaluation was done using a 15-point numerical scale with 0.5 increments. An individual balloting approach was used for the evaluation. Samples were evaluated during 15 1.5-hr sessions, in which 5-6 samples were evaluated per session. Each panelist received approximately 5 pieces of fresh tomatoes or 3 oz. (88 mL) of processed tomatoes for the evaluation. Each tomato sample was evaluated at three harvesting times and the order of product evaluation was randomized within each harvesting time and product category (i.e. fresh, juice and paste). Reverse osmosis, deionized, carbon-filtered water and unsalted crackers (Nabisco Premium Saltine Unsalted Top Crackers, 8 oz, East Hanover, NJ) were provided to cleanse palate between samples during testing.

Statistical Analysis

Analysis of variance (PROC MIXED procedure) was conducted to determine differences in the samples using the SAS® System for Windows (Version 9, 2006, The SAS Institute, Cary, NC). Significant differences were determined at p-value ≤ 0.05. The analysis of variance for fresh tomato data were done separately from that of tomato juice and paste samples. Factors included the study were tomato varieties (i.e. five for fresh tomato and tomato juice, and four for tomato paste), three ripening stages, three harvesting times, and appropriate interactions.

Principal components analysis (PCA) was also conducted using the covariance matrix (SYSTAT®, Version 10.2, 2006, Systat Software, Inc., San Jose, CA). PCA categorized attributes into a number of new uncorrelated variables (principal components) that were made up of the original sensory attributes. The mean values for each sensory attribute for each fresh tomato (i.e. 5 cultivars x 3 ripening stages) were used to calculate and obtain PCA maps. A hierarchical cluster analysis with Ward's method (SYSTAT®, Version 10.2) was additionally conducted on all sensory attributes to allow grouping of those tomato samples based on their similarities.

Results and Discussions

Compositional Analyses

In fresh tomatoes harvested at the red ripe stage, pH, % TA, TSS (°Brix), and % dry matter components were significantly ($P<0.05$) different (Table 7.1). Red Agate had the lowest content of TA, TSS and dry matter, but the highest pH compared to other cultivars studied. pH appeared to have an inverse correlation with TA and TSS results. These results were similar to results found in Garcia and Barrett (2006), who indicated that in many cases pH and TA have a negative relationship. Malundo and others (1995), however, showed that pH and TA had a positive correlation. Because TA was calculated based only on the major acid in the fruit, it is possible to find a positive relationship between pH and TA. Malic acid, other major acid in tomato, was not accounted for in the calculation of TA. This may explain the results for Jet Star tomatoes in week three, where pH and TA seemed to have a positive relationship.

Table 7.1 Tomato characteristics and compositional properties

Tomato	Fruit Characteristics	pH	TA (%)	TSS (°Brix)	Dry Matter (%)	Acid to °Brix Ratio
Brandywine	Round, “heirloom” line, fresh market	4.21c	0.42a	5.30a	5.92b	12.62
Florida 91	Round, modern line, fresh market	4.30b	0.39ab	4.83b	5.03c	12.38
Jet Star	Round, fresh market	4.42a	0.32c	4.80b	5.20c	15.00
Juliet	Small plum, fresh market (salad tomatoes)	4.39ab	0.36bc	5.47a	6.88a	15.19
Red Agate	Large plum, processing tomato (paste tomatoes)	4.48a	0.25d	4.05c	4.90c	16.20

All cultivars, except Red Agate had a pH value at or below 4.4, which is a desirable maximum value recommended for preventing potential spoilage from thermophilic organisms (Monti 1980). The pH of 4.48 for cultivar Red Agate was higher than the optimum recommended pH for processing tomatoes, which is 4.25 (Monti 1980). However, various factors, which may include the cultivars used, maturity stage, cultivation practices, growing conditions and seasonal changes (Gould 1992) may account for this discrepancy. In all cases, as is typical in many industrial tomato products, acidic additives were added that lowered the pH of the finished juice and paste.

All five cultivars showed relatively similar results for pH during the first 2 weeks of harvesting, but a considerable increase in pH at week 3 harvesting (Fig. 7.1). These increases were especially prominent for Jet Star, Red Agate and Juliet, although significant differences were not determined due to limited sampling.

Titratable acidity of fresh tomatoes ranged from 0.25 – 0.42% in the five cultivars. Red Agate had the lowest mean acidity, whereas Brandywine had the highest. TA varied throughout the three harvesting periods, as illustrated in Fig. 7.2. Similar variations were illustrated in a study by Garcia and Barrette (2006). In addition, Stevens (1972) and Garcia and Barrett (2006) indicated that maturity stages of tomatoes have a greater contribution to variations in acidity content than does cultivar. For Brandywine, Juliet, and Red Agate, fruit harvested later at week 2 and week 3 showed decreased TA concentrations (Fig. 7.2). This decrease was not observed for the Jet Star and Florida 91 cultivars. TA content of many tomato cultivars decreases when harvested later in season (Garcia and Barrett 2006).

Figure 7.1 pH of fresh tomatoes by harvesting times

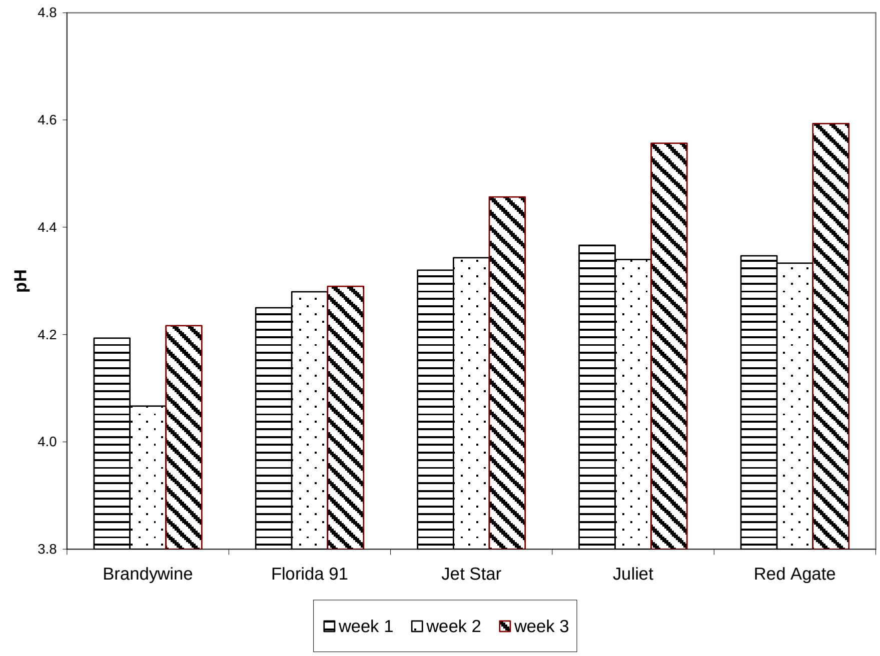


Figure 7.2 Titratable acidity of fresh tomatoes by harvesting times

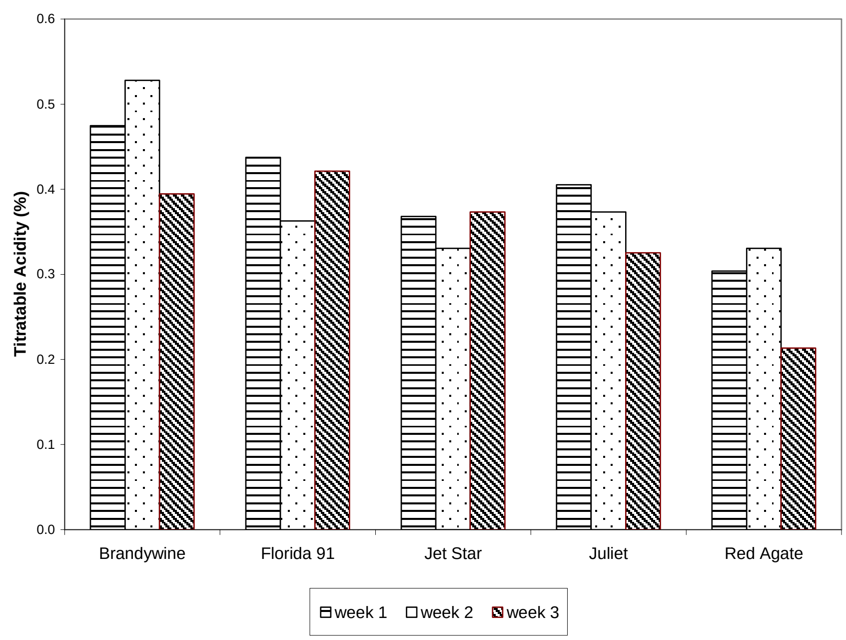
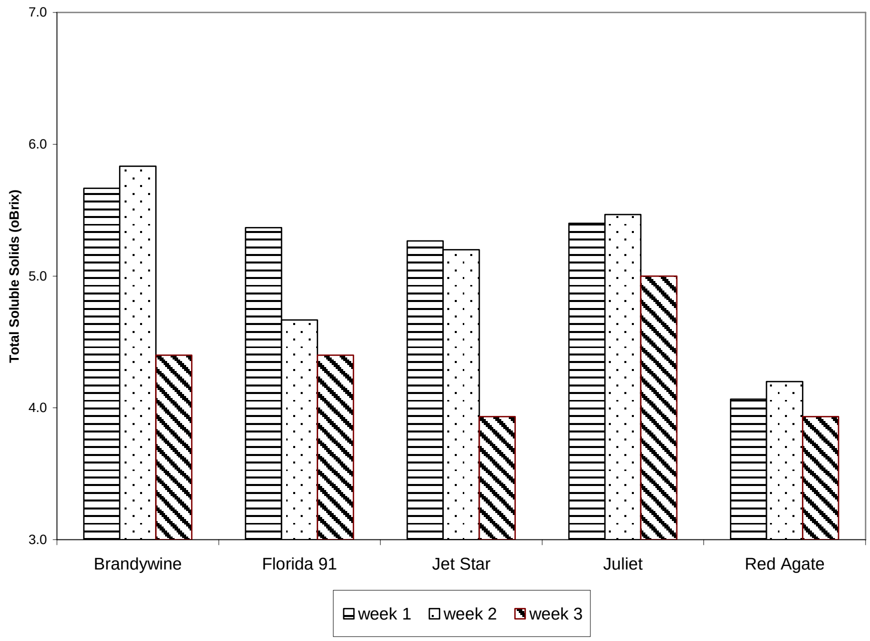


Figure 7.3 Total soluble solids of fresh tomatoes by harvesting times



TSS (ºBrix) content for fresh tomatoes was highest in Juliet and Brandywine. The Red Agate cultivar had the lowest ºBrix value of 4.05%. For common processing tomatoes, TSS content ranges approximately from 4.50 to 6.25% (Garcia and Barrett 2006). Picha (1986) indicated that vine-ripened cherry tomatoes have higher soluble solid content, which may explain why Juliet, a small fruited tomato cultivar exhibited the highest mean soluble solids. This also may suggest that small fruited cultivars have higher soluble solid content, but definite conclusion cannot be drawn because only one small fruited cultivar was included in the current study. TSS content of all cultivars decreased with harvesting period (Fig. 7.3). For all cultivars, except Red Agate, soluble solid concentrations decreased up to 22% at week three harvesting.

Significant differences in genetic variation also were found for dry matter analysis. Juliet had the highest dry matter content, followed by Brandywine; the cultivars Florida 91, Jet Star and Red Agate showed the lowest dry matter content.

Acid to ºBrix ratio was calculated for each tomato cultivar, but significant differences were not determined. The acid to ºBrix ratio is used commonly to help determine the maturity and quality of fruits. The range of acid to ºBrix ratio from approximately 12-15, suggesting minimal differences in the maturity of the cultivars. Fruit that have high acid and soluble solid content would have better flavor, whereas those with low acid and high soluble solids would be bland, and high acid and low soluble solids would be tart (Saltveit 2005).

TSS content of the final processed tomato products is illustrated in Table 7.2. The results showed that there were no significant differences in the soluble solids among the juice and paste samples produced. Other compositional data were not collected for the processed tomato products.

Table 7.2 Total soluble solids measured in tomato juice and paste

Cultivar	Juice	Paste
Brandywine	6.63	-
Florida 91	7.00	25.90
Jet Star	6.90	28.67
Juliet	7.50	28.27
Red Agate	5.90	26.17

Sensory Characteristics of Fresh Tomatoes

The main factors investigated including tomato cultivar, ripening stages and harvesting times produced significant effects ($P<0.05$) for many sensory attributes (Table 7.3), although harvesting time appeared less significant. Auerswald and others (1999) and Johansson and others (1999) reported that variety was more influential on the sensory characteristics than other growing condition factors. The differences among fresh tomato characteristics are illustrated in Table 7.4. On average, tomato ID, green-viney, ripeness, fruity, sweet and umami attributes were higher in fresh market tomatoes Brandywine and Florida 91. Brandywine is an older ‘heirloom’ cultivar known for its good flavor and Florida 91 is a newer cultivar developed specifically for the fresh market. Red Agate, a processing tomato, showed the lowest intensity of those characterizing tomato attributes. For texture, as expected, all four fresh market tomatoes were less firm, less mealy and more juicy than the processing tomato cultivar.

Table 7.3 Significant differences in the sensory characteristics of fresh tomatoes

Attributes	Tomato Cultivars (C)	Stages (S)	Harvesting Times/ Replication (T)	C × S
Aroma				
Tomato ID	< 0.001	< 0.001	ns	ns
Green-Viney	0.011	< 0.001	< 0.001	< 0.001
Decaying Vegetation	0.001	0.018	ns	0.001
Cardboard	0.034	0.002	ns	< 0.001
Texture				
Firmness	< 0.001	< 0.001	< 0.001	< 0.001
Juiciness	< 0.001	< 0.001	0.001	< 0.001
Mealy	< 0.001	< 0.001	ns	ns
Skin Awareness	< 0.001	< 0.001	< 0.001	< 0.001
Seed Awareness	ns	0.010	0.030	ns
Fiber Awareness	0.016	< 0.001	ns	0.015
Flavor				
Tomato ID	< 0.001	< 0.001	0.008	< 0.001
Ripeness	< 0.001	< 0.001	0.006	< 0.001
Green-Viney	< 0.001	< 0.001	ns	< 0.001
Umami	< 0.001	< 0.001	ns	ns
Fruity	< 0.001	< 0.001	< 0.001	ns
Cardboard	< 0.001	< 0.001	ns	< 0.001
Fermented	< 0.001	0.006	ns	0.006
Musty/Earthy	ns	ns	0.003	0.006
Sweet	< 0.001	< 0.001	0.018	ns
Sour	0.021	0.006	ns	ns
Salty	ns	ns	0.040	< 0.001
Bitter	< 0.001	< 0.001	< 0.001	< 0.001
Metallic	ns	ns	ns	ns
Astringent	ns	ns	ns	0.040

Table 7.4 Significant differences in the sensory characteristics of fresh tomatoes by cultivars

	Brandywine	Florida 91	Jet Star	Juliet	Red Agate
Aroma					
Tomato ID	7.95 a	7.86 a	7.60 b	7.56 b	7.40 b
Green-Viney	4.54 ab	4.67 a	4.20 b	4.42 b	4.27 b
Decaying Vegetation	0.21 ab	0.02 b	0.25 a	0.10 b	0.00 b
Cardboard	0.83 b	0.97 ab	1.13 a	1.09 a	1.03 a
Texture					
Firmness	3.63 c	4.69 b	3.62 c	5.32 a	5.14 a
Juiciness	9.83 a	9.62 a	9.43 b	8.52 c	8.17 c
Mealy	1.40 b	1.61 b	1.38 bc	1.22 c	2.11 a
Skin Awareness	10.42 b	10.04 c	9.11 d	10.84 a	10.55 b
Seed Awareness	1.94	2.06	2.01	2.10	2.05
Fiber Awareness	1.78	1.83	1.74	1.85	2.13
Flavor					
Tomato ID	9.31 a	8.88 b	9.50 a	8.65 b	7.86 c
Ripeness	9.76 a	8.74 c	9.47 b	8.67 c	7.88 d
Green-Viney	3.78 c	4.46 a	3.42 d	4.07 bc	4.29 ab
Umami	1.19 ab	1.13 b	1.76 a	0.87 b	0.59 c
Fruity	2.70 ab	2.50 b	2.88 a	2.41 b	1.93 c
Cardboard	0.82 b	1.21 a	0.63 b	1.25 a	1.47 a
Fermented	0.29 a	0.04 b	0.27 a	0.09 b	0.00 b
Musty/Earthy	1.72	1.70	1.79	1.68	1.61
Sweet	2.49 ab	2.42 b	2.63 a	2.42 b	2.09 c
Sour	0.94 ab	0.89 b	1.11 a	0.95 ab	0.74 b
Salty	3.29	3.15	3.05	3.10	3.07
Bitter	1.16 b	1.09 bc	1.53 a	1.08 bc	1.01 c
Metallic	2.25	2.31	2.19	2.33	2.39
Astringent	0.13	0.11	0.13	0.10	0.12

a, b, c, d – Means with the same letter within a row are not significantly different at the 95% confidence level

Harvesting fresh tomatoes at different ripening stages (light-red, red-ripe, and red-soft) resulted in significant changes for all attributes evaluated, except musty/earthy, salty, metallic, and astringency (Table 7.3). Tomatoes harvested at different stages have been shown previously to differ significantly in flavor characteristics (Watada and Aulenbach 1979, Paull 1999, Causse and others 2003). Watada and Aulenbach (1979) found a significant impact of harvesting stage on several attributes including sweet, salty, and fruity-floral attributes. We also found that green-viney and bitter attributes were significantly different between different ripening stages.

Because there was an interaction of variety and stage of ripeness for many tomato sensory attributes, Tables 7.5 to 7.9 illustrate the trend of each attribute evaluation due to ripening stages for each tomato cultivar. It is important to note that the interaction effect often is the result of the degree of change noted in varieties for various ripeness levels and not a difference in the direction of change in a sensory attribute. The data showed that some attributes increased as fruit was allowed to ripen longer on vines, while some other attributes decreased significantly. For all five tomato cultivars, tomato ID (both aroma and flavor), ripeness, sweetness and juiciness increased when the fruit were allowed to ripen longer on vines. The increase of those characteristics was minimal for Red Agate compared to others. On the other hand, green-viney (both aroma and flavor) and firmness decreased with increased maturity, as expected. The firmness of Red Agate, the processing tomato in this study, seemed to decrease only slightly at riper stage, whereas a considerable decrease was observed in both Jet Star and Florida 91. The decrease in firmness is one of the critical issues related to limited shelf-life of vine-ripened fresh tomatoes (Auerswald and others 1999). Juiciness increased with maturity for all tomato cultivars, except Jet Star, which increased up to the red-ripe stage and then decreased significantly. Although cultivar differences certainly can be expected, some variation in data may be from the visual selection process used to determine stage of ripeness. One pattern that was noted is that textural changes were slight for Red Agate, a processing tomato, and were larger for fresh market tomatoes. Other attributes exhibited low intensity, but no specific pattern of change could be determined.

Because harvesting time in our study is confounded with replications, no definite conclusion on the effect of harvesting time can be made. However, the results suggest that tomatoes harvested early in the season would be more musty/earthy with higher skin awareness and be less green-viney, ripe, sweet, or juicy than tomatoes harvested later in the season.

Table 7.5 cv. Brandywine - Sensory characteristics by ripening stages

	Light-Red	Red-Ripe	Red-Soft
Aroma			
Tomato ID	7.59 b	8.28 a	7.97 ab
Green-Viney	5.29 a	4.19 b	4.17 b
Decaying Vegetation	0.00 b	0.17 b	0.44 a
Cardboard	1.00 a	0.67 b	0.83 a
Texture			
Firmness	3.82 a	3.42 b	3.67 ab
Juiciness	9.44 b	9.64 b	10.39 a
Mealy	1.94 a	1.17 b	1.11 b
Skin Awareness	9.85 c	10.47 b	10.92 a
Seed Awareness	2.15	1.83	1.86
Fiber Awareness	2.01 a	1.64 b	1.72 ab
Flavor			
Tomato ID	7.96 b	9.83 a	10.03 a
Ripeness	8.09 b	10.36 a	10.72 a
Green-Viney	4.67 a	3.50 b	3.25 b
Umami	0.84 b	1.22 ab	1.42 a
Fruity	2.43	2.81	2.81
Cardboard	1.38 a	0.47 b	0.67 b
Fermented	0.06 b	0.22 b	0.58 a
Musty/Earthy	1.50	1.86	1.78
Sweet	2.19 b	2.61 a	2.61 a
Sour	0.82	1.00	1.00
Salty	3.23 a	3.44 a	3.19 b
Bitter	1.17	1.17	1.14
Metallic	2.19	2.31	2.28
Astringent	0.18	0.06	0.17

a, b, c – Means with the same letter within a row are not significantly different at the 95% confidence level

Table 7.6 cv. Florida 91 - Sensory characteristics by ripening stages

	Light-Red		Red-Ripe		Red-Soft	
Aroma						
Tomato ID	7.71		7.86		8.00	
Green-Viney	5.26	a	4.42	b	4.35	b
Decaying Vegetation	0.00		0.06		0.00	
Cardboard	1.18	a	0.97	ab	0.76	b
Texture						
Firmness	5.62	a	4.58	b	3.88	c
Juiciness	8.74	b	9.89	a	10.21	a
Mealy	1.97	a	1.61	ab	1.24	b
Skin Awareness	9.13	c	10.64	a	10.22	b
Seed Awareness	2.03		2.25		1.88	
Fiber Awareness	2.11	a	1.75	b	1.62	b
Flavor						
Tomato ID	7.59	b	9.50	a	9.50	a
Ripeness	7.03	b	9.56	a	9.62	a
Green-Viney	5.47	a	4.17	b	3.74	c
Umami	0.56	c	1.17	b	1.62	a
Fruity	1.87	b	2.72	a	2.85	a
Cardboard	1.80	a	0.86	b	0.92	b
Fermented	0.00		0.06		0.06	
Musty/Earthy	1.62		1.75		1.74	
Sweet	1.88	b	2.67	a	2.66	a
Sour	0.65	b	1.03	a	1.03	a
Salty	3.17		3.19		3.03	
Bitter	1.00		1.11		1.14	
Metallic	2.43		2.36		2.17	
Astringent	0.26		0.06		0.00	

a, b, c – Means with the same letter within a row are not significantly different at the 95% confidence level

Table 7.7 cv. Jet Star - Sensory characteristics by ripening stages

	Light-Red	Red-Ripe	Red-Soft
Aroma			
Tomato ID	7.05 b	7.97a	7.75 a
Green-Viney	4.91 a	4.36b	3.28 c
Decaying Vegetation	0.09 b	0.12b	0.53 a
Cardboard	1.14 a	0.83b	1.33 a
Texture			
Firmness	4.91 a	3.67b	2.56 c
Juiciness	9.59 b	10.72a	7.91 c
Mealy	1.36 ab	1.42a	1.11 b
Skin Awareness	9.58 b	10.72a	7.06 c
Seed Awareness	2.09	2.19	1.47
Fiber Awareness	2.37 a	1.67b	1.28 c
Flavor			
Tomato ID	8.33 b	9.94a	10.11 a
Ripeness	8.08 b	10.00a	10.19 a
Green-Viney	3.84 a	3.44a	2.97 b
Umami	1.36	1.58b	2.17 a
Fruity	2.43 b	3.03a	3.11 a
Cardboard	1.11 a	0.39b	0.44 b
Fermented	0.00 b	0.22b	0.56 a
Musty/Earthy	1.91	1.75	1.72
Sweet	2.18 b	2.78a	2.89 a
Sour	0.98	1.11	1.22
Salty	2.84 b	3.08a	3.17 a
Bitter	1.14 b	1.22b	2.17 a
Metallic	2.08	2.17	2.33
Astringent	0.23	0.00	0.22

a, b, c – Means with the same letter within a row are not significantly different at the 95% confidence level

Table 7.8 cv. Juliet - Sensory characteristics by ripening stages

	Light-Red		Red-Ripe		Red-Soft	
Aroma						
Tomato ID	7.18	b	7.69	a	7.78	a
Green-Viney	5.38	a	3.81	b	4.11	b
Decaying Vegetation	0.06		0.22		0.00	
Cardboard	1.38	a	1.14	a	0.78	b
Texture						
Firmness	5.56	a	5.47	a	4.94	b
Juiciness	8.06	b	8.78	a	8.69	a
Mealy	1.29		1.19		1.17	
Skin Awareness	10.50	b	11.25	a	10.75	b
Seed Awareness	2.32		2.11		1.89	
Fiber Awareness	2.03	a	1.81	ab	1.72	b
Flavor						
Tomato ID	7.94	b	8.97	a	9.06	a
Ripeness	7.56	b	9.14	a	9.31	a
Green-Viney	5.26	a	3.61	b	3.33	b
Umami	0.62	b	0.92	ab	1.06	a
Fruity	1.98	b	2.61	a	2.58	a
Cardboard	1.52	a	1.28	ab	0.97	c
Fermented	0.06		0.11		0.11	
Musty/Earthy	1.50		1.89		1.64	
Sweet	2.05	b	2.47	a	2.69	a
Sour	0.81	b	1.11	a	0.94	ab
Salty	3.39	a	2.97	b	2.94	b
Bitter	0.97	b	1.11	ab	1.17	a
Metallic	2.52	a	2.22	b	2.28	ab
Astringent	0.26		0.06		0.00	

a, b, c – Means with the same letter within a row are not significantly different at the 95% confidence level

Table 7.9 cv. Red Agate – Sensory characteristics by ripening stages

	Light-Red		Red-Ripe		Red-Soft	
Aroma						
Tomato ID	7.54		7.28		7.62	
Green-Viney	4.79	a	4.17	b	4.00	b
Decaying Vegetation	0.00		0.00		0.00	
Cardboard	1.13	ab	1.17	a	0.85	b
Texture						
Firmness	5.46	a	5.25	a	4.68	b
Juiciness	7.79	b	8.42	a	8.65	a
Mealy	2.51	a	2.06	b	1.82	b
Skin Awareness	10.08	b	10.83	a	10.64	a
Seed Awareness	1.83		2.08		2.03	
Fiber Awareness	2.51	a	2.03	b	1.94	b
Flavor						
Tomato ID	7.33	c	7.86	b	8.30	a
Ripeness	7.01	c	7.89	b	8.68	a
Green-Viney	4.79	a	4.14	b	3.91	b
Umami	0.38	b	0.28	b	1.02	a
Fruity	1.78		1.83		2.15	
Cardboard	1.40		1.67		1.35	
Fermented	0.00		0.00		0.00	
Musty/Earthy	1.63		1.44		1.68	
Sweet	1.85	b	2.08	ab	2.30	a
Sour	0.72		0.67		0.84	
Salty	3.05		2.94		3.15	
Bitter	0.92		1.08		1.02	
Metallic	2.51		2.44		2.27	
Astringent	0.08		0.22		0.06	

a, b, c – Means with the same letter within a row are not significantly different at the 95% confidence level

Sensory Characteristics of Tomato Juice and Paste

In tomato juice, cultivar resulted in only two significant differences, browned and fruity flavor (Table 7.10). Juice made from cv. Florida 91 had the highest browned and fruity notes. All texture attributes for tomato juice samples, except skin awareness, changed significantly with different cultivars. These results indicated the importance of determining and differentiating the texture properties of various processed tomato products using descriptive sensory analysis, and possibly correlating this information with instrumental data, if available. Barrett and others (1998) indicated that understanding the textural properties of processed tomatoes is important to guarantee the product quality that meets consumer expectation. On average, tomato juice produced with Red Agate showed the highest intensity of those texture attributes evaluated. Tomato juice from Jet Star resulted generally in lowest intensity of the texture properties. Viscosity has been described as a key measure for processing yields and quality of processed tomato products (Claybon and Barringer 2002). Products with higher viscosity and thickness would mean lesser amounts of fresh tomatoes would be needed to fill the containers, thus reducing production costs (Thakur and others 1996). Seed awareness was significantly higher in Juliet than other cultivars because the seeds of Juliet are much smaller than those of the other cultivars and could not be completely filtered using the sieve we used in this research.

Table 7.11 illustrates texture differences among the cultivars of tomato pastes. Paste made from Florida 91 showed significantly higher browned and fruity notes, but lower tomato ID aroma compared to paste made from other cultivars. Paste made with Juliet had the highest green-viney character and lowest browned note. Pulp size, pulp amount and seed awareness attributes were different among the paste samples with Red Agate showing the most, but smaller size pulp and Florida 91 exhibiting less, but larger pulp. As for juice, seed awareness in tomato paste was higher for Juliet. Garcia and Barett (2006) indicated that cultivar, maturity stage, growing conditions and processing treatments principally influence the quality of processed tomatoes. In our study, only the effect of cultivars can be drawn, because other factors such as maturity of the tomatoes were similarly controlled. Although Thakur and others (1996) indicated that tomato cultivars may have the most impact of the quality of processed tomatoes; our results did not indicate such large differences. This may be due to the use of 4 fresh market tomato cultivars and only one processing tomatoes.

Table 7.10 Significant differences in the sensory characteristics of tomato juice by cultivars

	Brandywine	Florida 91	Jet Star	Juliet	Red Agate
Aroma					
Tomato ID	7.69	7.44	7.61	7.50	7.78
Green-Viney	2.44	2.47	2.28	2.47	2.42
Browned	1.22	1.28	1.17	1.17	1.17
Decaying Vegetation	0.39	0.44	0.47	0.53	0.50
Cardboard	0.92	1.08	1.14	1.14	1.25
Texture					
Viscosity	3.75 b	3.72 b	3.22 c	3.39 c	4.33 a
Thickness	3.75 b	3.75 b	3.14 c	3.50 b	4.67 a
Mealy	0.97 ab	0.97 ab	0.67 c	0.92 b	1.28 a
Skin Awareness	0.11	0.06	0.00	0.14	0.11
Seed Awareness	0.83 b	0.50 b	0.53 b	1.97 a	0.64 b
Fiber Awareness	1.50 b	1.42 b	0.92 c	1.39 b	2.00 a
Pulp Size	5.14 c	5.17 c	4.31 d	5.61 b	7.97 a
Pulp Amount	5.03 b	4.83 b	3.97 c	4.86 b	6.03 a
Flavor					
Tomato ID	10.11	10.22	10.08	10.00	10.22
Ripeness	10.00	10.22	10.11	10.17	10.14
Cooked	7.89	7.56	7.56	7.86	7.67
Browned	4.92 a	5.03 a	4.42 b	4.64 ab	4.47 ab
Green-Viney	2.81	2.39	2.58	2.78	2.86
Umami	1.61	1.89	1.78	1.97	1.72
Fruity	3.08 b	3.47 a	3.22 b	3.25 ab	3.11 b
Cardboard	0.50	0.61	0.42	0.61	0.64
Fermented	1.03	1.06	0.81	0.64	0.58
Musty/Earthy	1.83	1.72	1.89	1.83	1.78
Overall Sweet	3.08	3.19	3.19	3.31	3.03
Sweet	1.39	1.47	1.39	1.44	1.39
Sour	3.56	3.33	3.42	3.17	3.42
Salt	4.39	4.67	4.58	4.44	4.50
Bitter	2.44	2.28	2.47	2.14	2.31
Metallic	1.11	1.17	1.14	1.08	1.08
Chemical	0.06	0.11	0.06	0.17	0.17
Astringent	1.69	1.56	1.67	1.56	1.61

a, b, c – Means with the same letter within a row are not significantly different at the 95% confidence level

Table 7.11 Significant differences in the sensory characteristics of tomato paste by cultivars

	Florida 91		Jet Star		Juliet		Red Agate	
Aroma								
Tomato ID	7.14		7.22		7.22		7.28	
Green-Viney	2.31	ab	2.11	b	2.47	a	2.17	b
Browned	9.19	a	8.64	bc	8.36	c	8.97	b
Decaying Vegetation	2.83		3.06		2.81		3.31	
Cardboard	1.28		1.11		1.17		1.08	
Texture								
Thickness	13.86		14.00		13.67		13.88	
Mealy	1.97		1.69		1.89		1.89	
Skin Awareness	0.00		0.00		0.06		0.00	
Seed Awareness	0.47	c	0.86	b	3.81	a	0.36	c
Fiber Awareness	1.47		1.33		1.47		1.25	
Pulp Size	9.72	a	9.22	b	9.08	b	9.31	b
Pulp Amount	13.19	b	13.42	a	13.39	ab	13.56	a
Flavor								
Tomato ID	9.56	b	10.06	a	10.00	a	9.89	b
Ripeness	10.94		11.00		11.19		11.11	
Cooked	12.17		12.83		12.33		12.50	
Browned	10.92		11.36		11.03		10.92	
Green-Viney	2.69	a	2.25	b	2.28	b	2.08	b
Umami	0.83		0.64		0.75		0.47	
Fruity	3.00	a	2.81	b	2.89	b	2.64	b
Cardboard	1.08		1.03		1.08		1.00	
Fermented	2.89		3.06		2.78		2.58	
Musty/Earthy	2.17		2.31		2.33		2.36	
Overall Sweet	3.25		3.36		3.39		3.19	
Sweet	1.56		1.53		1.72		1.72	
Sour	4.31		4.28		4.31		4.14	
Salt	4.33		4.31		4.36		4.28	
Bitter	3.44		3.75		3.53		3.58	
Metallic	3.08		3.44		3.42		3.17	
Chemical	0.19		0.17		0.33		0.17	
Astringent	2.03		2.17		2.31		2.06	

a, b, c – Means with the same letter within a row are not significantly different at the 95% confidence level

Comparing Sensory Characteristics of Fresh and Processed Tomatoes

To help understand the differences and similarities of fresh tomatoes and their derivative juice and paste, principal component analysis (PCA) was performed. Because the data showed different effects for flavor and texture, the PCA was done separately for aroma/flavor and texture attributes. Figure 7.4 illustrates the PCA map for aroma and flavor characteristics of tomatoes and Figure 7.5 exhibits the texture map. For aroma and flavor, the first two principal components explained 96.31% of the variance. For texture attributes, the first two components accounted for 98.32% of the variance.

Three groups of tomatoes were identified using the cluster analysis. In general, products in each cluster had similar character, but differed in the intensity of several attributes. Cluster 1 included all fresh tomatoes, however, two sub-groups were observed, one that included tomatoes harvested at the red-ripe and red-soft stages and the other including those harvested at the light-red stage. Cluster 2 included all tomato juice samples and cluster 3 represented all the tomato paste. This indicates that degree of processing affected sensory properties much more than did variety. Cluster 1 exhibited higher green-viney, especially in those harvested at the red-pink stage. On the other hand, these red-pink tomatoes were lowest in tomato ID and ripeness characteristics. Those red-ripe and red-soft fresh tomatoes had higher tomato ID flavor, umami, and sweetness. Only a slight astringency was observed in fresh tomatoes. Firmness, juiciness, and skin awareness were apparent in all these fresh tomatoes. Cluster 2, tomato juice, exhibited the highest tomato ID, and higher ripeness, sourness, and fruity character than tomatoes in other clusters and had cooked, browned, and slight fermented notes. As anticipated, tomato paste, cluster 3, exhibited high levels of cooked and brown notes. Interestingly, fermented, decaying vegetation and astringent attributes also were more prominent in the tomato paste products.

Notably, tomato ID, ripeness and fruitiness were higher in tomato juice than in fresh tomatoes or tomato paste. This may suggest that the heat processing used to produce tomato juice is enough to preserve and intensify those characters of the product, without increasing cooked flavor notes that overwhelm those flavors with more intense processing. On the other hand, some attributes present in fresh tomatoes such as tomato ID, green-viney, and sweet were considerably decreased or essentially disappeared with high heat processes.

Figure 7.4 Principal Component Analysis (PCA) results for flavor and aroma attributes

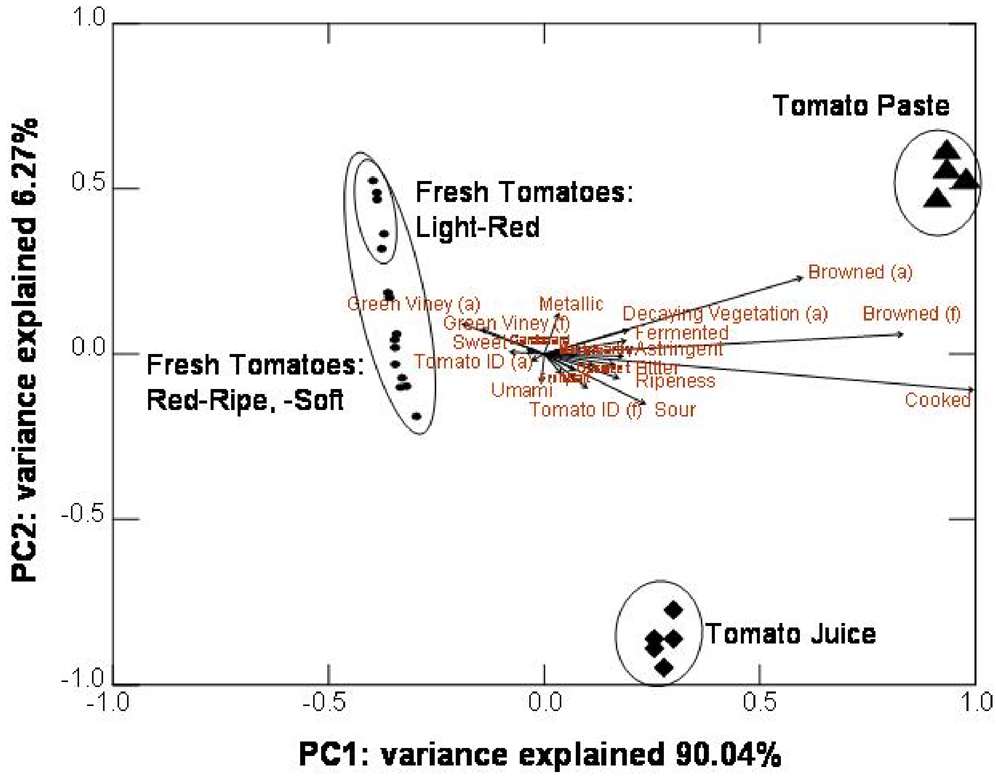
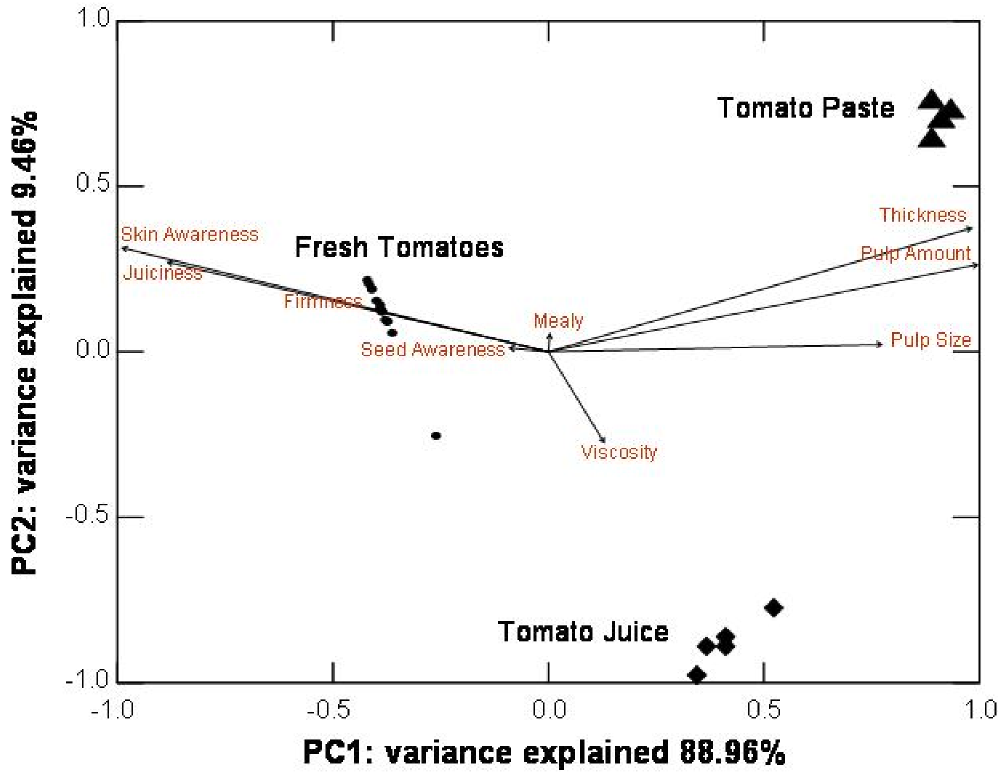


Figure 7.5 Principal Component Analysis (PCA) for texture attributes



Conclusions

The sensory characteristics and compositional data of five fresh tomatoes differed significantly due to cultivar and ripening stage differences, with fresh-market tomatoes showing higher levels of tomato ID, green-viney, ripeness, fruity, sweet and umami than a tomato developed for processing. Not surprisingly, sensory characteristics of processed tomatoes differed substantially from those of fresh tomatoes and differences in flavor caused by variety became smaller or disappeared at high levels of processing. At a low level of processing, i.e. tomato juice, some characterizing tomato attributes were intensified, but processing to a higher degree, i.e. tomato paste, significantly decreased those attributes. Differences in texture attributes based on variety did carry through or intensify as tomatoes were processed, with the texture of the tomato bred for processing maintaining mealiness, pulp and fiber awareness, and thickness of the products.

References

Auerswald H, Peters P, Bruckner B, Krumbein A, Kuchenbuch R. 1999. Sensory analysis and instrumental measurements of short-term stored tomatoes (*Lycopersicon esculentum Mill.*) Postharvest Biol. Technol. 15: 323–34.

Barrett DM, Garcia E, Wayne JE. 1998. Textural modification of processing tomatoes. Crit. Rev. Food Sci. Nutr. 38: 173–258.

Batu A. 2004. Determination of acceptable firmness and colour values of tomatoes. J. Food Eng. 61: 471-475.

Bedford LV. 1989. Sensory quality of fresh tomatoes: comparison of tomatoes grown in nutrient media of different conductivities. Camden Food and Drink Research Association/Technical Memorandum No. 531.

Bruhn CM, Feldmann N, Gartitz C, Harwood J, Ivans E, Mashall M, Riley A, Thurber D, Willamson E. 1991. Consumer perceptions of quality: apricots, cantaloupes, peaches, pears, strawberries, and tomatoes. J. Food Qual. 14: 187–195.

Boukobza F, Taylor A. 2002. Effect of postharvest treatment on flavour volatiles of tomatoes. Postharvest Biol. Technol. 25: 321–331.

Claybon KT, Barringer SA. 2002. Consumer acceptability of viscosity in processed tomato products by African-American, Latino, and prototypical consumer groups. J. Food Sci. 67: 2380-2384.

Causse M, Buret M, Robini K, Verschave P. 2003. Inheritance of nutritional and sensory quality traits in fresh market tomato and relation to consumer preferences. J. Food Sci. 68: 2342-2350.

Garcia E, Barrett DM. 2006. Evaluation of processing tomatoes from two consecutive growing seasons: Quality attributes, peelability and yield. J. Food Process. Preserv. 30: 20-36.

Gould WA. 1992. Tomato Production, Processing and Technology, 3rd Ed., CTI Publishers, Baltimore, MD.

Ho L. 1996. The mechanism of assimilates partitioning and carbohydrate compartmentation in fruit in relation to the quality and yield of tomato. J. Exp. Bot. 47: 1239–1243.

Hobson G. 1988. How the tomato lost its taste. New Scientist. 1632: 46–50.

Johansson L, Haglund A, Berglund L, Lea P, Risvik E. 1999. Preference for tomatoes, affected by sensory attributes and information about growth conditions. Food Qual. Pref. 10: 289-298.

Kader AA, Stevens MA, Albright-Holton M, Morris LL, Algizi M. 1977. Effect of fruit ripeness when picked on flavor and composition in fresh market tomatoes. J. Am. Soc. Hortic. Sci. 102: 724–731.

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

Ketelaere BD, Lammertyn J, Molenberghs G, Desmet M, Nicolaï B, Baerdemaeker JD. 2004. Tomato cultivar grouping based on firmness change, shelf life and variance during postharvest storage. Postharvest Biol. Technol. 34: 187-201.

Krumbein A, Peters P, Brückner B. 2004. Flavor compounds and a quantitative descriptive analysis of tomatoes (Lycopersicon esculentum Mill.) of different cultivars in short-term storage. Postharvest Biol. Technol. 32: 15-28.

Lana MM, Tijskens LMM, Kooner O. 2005. Effect of storage temperature and fruit ripening on firmness of fresh cut tomatoes. Postharvest Biol. Technol. 35: 87-95.

Lee SY, Luna-Guzmán I, Chang S, Barrett DM, Guinard JX. 1999. Relating descriptive analysis and instrumental texture data of processed diced tomatoes. Food Qual. Pref. 10: 447-455.

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

Maul F, Sargent SA, Sims CA, Baldwin EA, Balaban MO, Huber DJ. 2000. Tomato flavor and aroma quality as affected by storage temperature. J. Food Sci. 65: 1228-1237.

Meilgaard MC, Civille GV, Carr BT. 1991. Sensory Evaluation Techniques. CRC Press, Boca Raton, Florida.

Monti LM. 1980. The breeding of tomatoes for peeling. Acta Hortic. 100: 341–349.

Paull RE. 1999. Effect of temperature and relative humidity on fresh commodity quality. Postharvest Biol. Technol. 15: 263–277.

Picha D. 1986. Effect of harvest maturity on the final fruit composition of cherry and large-fruited tomato cultivars. J. Am. Soc. Hort. Sci. 111: 723-727.

Ratanachinakorn B, Klieber A, Simons DH. 1997. Effect of short-term controlled atmospheres and maturity on ripening and eating quality of tomatoes. Postharvest Biol. Technol. 11: 149-154.

Saltveit ME. 2005. Fruit ripening and fruit quality. In: Heuvelink E, editor. Tomatoes. Massasusett: CABI Publishing. p 145-170.

Serrano-Megías M, López-Nicolás JM. 2006. Application of agglomerative hierarchical clustering to identify consumer tomato preferences: influence of physicochemical and sensory characteristics on consumer response. J. Sci. Food Agri. 86: 493-499.

Stevens MA. 1972. Citrate and malate concentrations in tomato fruits: Genetic control and maturational effects. J. Am. Soc. Hortic. Sci. 97: 655–658.

Thakur BR, Singh RK, Nelson P. 1996. Quality attributes of processed tomato products: A review. Food Rev. Int. 12: 375–401.

United States Department of Agriculture. 1976. United States standards for grade of fresh tomatoes. US Dept. Agric., Mktg., Serv., Washington DC. pp. 10.

Watada AE, Aulenbach BB. 1979. Chemical and sensory qualities of fresh market tomatoes. J. Food Sci. 44: 1013–1016.

Yilmaz E. 2002. The chemistry of fresh tomato flavour. Turk J. Agric. Forest. 25: 149-155.

Appendix A - Descriptive Sensory Analysis for Green Odor in Foods and Chemicals

Table A.1 Orientation Schedule for Chemical Evaluation

Day	Chemical	Concentration (ppm)	Code	Serve Time
April 18, 2006	Cis-3-Hexen-1-Ol	1,000	853	9:05 am
	Cis-3-Hexen-1-Ol	100	178	9:05 am
	Cis-3-Hexen-1-Ol	10	206	9:05 am
	Hexanal	1,000	593	9:05 am
	Hexanal	100	421	9:05 am
	Hexanal	10	974	9:05 am

Figure A.1 Serial Dilution Technique Used for Chemical Solution Preparation

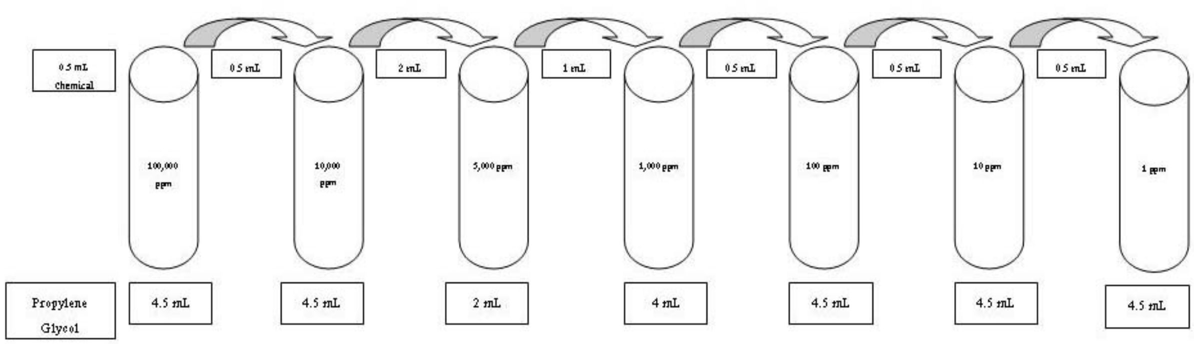


Table A.2 Testing Schedule for Chemical Evaluation

Chemicals	SAFC Catalog Number	Concentration (ppm)	Date Evaluated
Hexanal (Hexyl aldehyde)	w25571-8	1-100,000 ppm	19-Apr
cis-3-Hexen-1-ol	w25630-7	1-100,000 ppm	20-Apr
1-Penten-3-ol	w35840-1	1-100,000 ppm	21-Apr
2-isobutylthiazole	w31340-8	1-100,000 ppm	21-Apr
2-Pentanol	w33160-0	1-100,000 ppm	24-Apr
3-Heptanone	w25450-9	1-100,000 ppm	24-Apr
b-Cyclocitral	w36392-8	1-100,000 ppm	24-Apr
Citronellal	w23070-7	1-100,000 ppm	25-Apr
Geranyl formate	w25140-2	1-100,000 ppm	25-Apr
Heptyl butyrate	w25490-8	1-100,000 ppm	26-Apr
Hexyl benzoate	w36910-1	1-100,000 ppm	26-Apr
Hexyl formate	w25700-1	1-100,000 ppm	26-Apr
Hexyl hexanoate	w25720-6	1-100,000 ppm	27-Apr
Hexyl octanoate	w25750-8	1-100,000 ppm	27-Apr
Hexyl phenylacetate	w34570-9	1-100,000 ppm	28-Apr
Hexyl propionate	w25760-5	1-100,000 ppm	28-Apr
Hexyl tiglate	w50090-9	1-100,000 ppm	2-May
Hexyl-2-furoate	w25710-9	1-100,000 ppm	2-May
Hexyl-2-methylbutanoate	w34990-9	1-100,000 ppm	3-May
trans-2-Hexen-1-ol	w25621-8	1-100,000 ppm	3-May
trans-2-Hexenal	w25600-5	1-100,000 ppm	4-May
trans-2-Pentenal	w32181-8	1-100,000 ppm	4-May

Appendix B - Descriptive Sensory Analysis for Tomato Lexicon

Table B.1 Aroma and Texture Intensity Scores for Tomato Products Based on 15-Point Scale

	Tomato ID	Green-Viney	Browned	Decay. Veg.	Viscos.	Thick	Firm	Juicy	Mealy	Skin	Seed	Fiber	Pulp Amo.	Pulp Size
Fresh Tomatoes														
Emeril's - Cherry	8.5	5.0	0.0	0.0	0.0	0.0	6.5	7.5	2.5	11.5	5.0	4.0	0.0	0.0
Nature Sweet - Cherry	10.0	5.0	0.0	0.0	0.0	0.0	5.0	8.5	1.5	10.5	5.0	2.5	0.0	0.0
Grape (Mexico)	7.0	3.0	0.0	0.0	0.0	0.0	6.0	9.0	2.5	12.0	2.5	5.0	0.0	0.0
Dillon's Vine Ripe - Round	7.5	6.0	0.0	0.0	0.0	0.0	4.0	8.5	5.0	8.0	6.5	5.0	0.0	0.0
KS Grown Hydro - Round	9.0	5.0	0.0	0.0	0.0	0.0	5.0	7.5	3.0	9.5	4.0	5.0	0.0	0.0
AK Grown - Round	9.0	4.0	0.0	0.0	0.0	0.0	4.5	7.5	5.5	9.0	3.5	5.0	0.0	0.0
Del Monte - Round	6.0	6.0	0.0	0.0	0.0	0.0	6.0	7.0	6.0	9.0	4.0	5.0	0.0	0.0
Dillon's - Plum	5.0	4.0	0.0	0.0	0.0	0.0	3.5	6.5	5.5	10.0	3.0	3.0	0.0	0.0
Dillon's - Round	7.0	4.0	0.0	0.0	0.0	0.0	5.0	7.5	5.0	10.0	4.0	5.5	0.0	0.0
Canned Tomatoes														
Hunt's Whole	9.0	2.0	3.0	1.5	5.0	0.0	1.5	13.0	3.0	0.0	4.0	3.5	3.0	4.0
SanMWhole	10.5	2.5	3.0	3.5	4.0	0.0	3.0	10.0	2.5	0.0	4.0	4.0	3.0	4.0
Great Value Whole	8.5	2.0	2.0	2.5	4.0	0.0	5.0	10.5	1.5	0.0	4.0	8.0	3.0	4.0
FMV Whole	7.0	2.0	3.0	3.5	0.0	0.0	5.0	9.0	1.0	0.0	3.5	6.0	0.0	0.0
Kroger Whole	8.5	2.5	2.0	2.5	4.0	0.0	5.0	10.0	2.5	0.0	4.5	8.5	3.0	4.0
Linguria Crushed	9.5	2.5	3.0	2.0	11.0	11.5	0.0	0.0	0.0	2.0	10.5	0.0	12.0	11.0
Hunt's Crushed	7.5	2.5	4.0	5.0	12.0	11.0	0.0	0.0	0.0	9.0	3.5	3.5	13.0	12.5
Hunt's Diced	9.0	2.5	2.0	2.0	3.0	0.0	4.5	10.0	1.5	1.0	2.5	7.0	3.0	4.0
Del Monte Diced	8.5	2.5	3.0	3.5	2.5	0.0	3.5	11.0	3.0	0.0	2.0	4.5	1.5	2.5
GV Diced	6.0	1.5	4.0	5.0	2.0	0.0	5.0	8.0	1.0	2.0	2.0	8.5	1.5	2.5
Kroger Diced	8.0	2.5	2.5	2.5	4.0	0.0	6.0	9.0	2.0	0.0	5.0	8.5	3.0	4.5
Tomato Juices														
Campbell Regular	9.0	2.5	4.0	2.0	3.5	3.5	0.0	0.0	0.0	0.0	0.0	0.0	4.0	2.0
Campbell Low Sodium	10.5	1.5	4.5	2.0	5.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	4.0	2.0
Kroger Regular	7.0	3.0	4.0	2.0	5.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	2.5
Concentrated Tomatoes														
Amore Paste	9.0	1.0	7.5	5.5	14.5	13.5	0.0	0.0	1.5	0.0	0.0	0.0	14.0	9.0
Hunt's Paste	8.0	1.5	7.5	4.5	0.0	14.0	0.0	0.0	1.5	0.0	0.0	0.0	14.0	8.5
Kroger Paste	9.0	1.5	7.5	5.0	0.0	14.5	0.0	0.0	1.5	0.0	0.0	0.0	14.0	8.5
Contadina Paste	9.0	2.0	7.5	4.5	0.0	14.0	0.0	0.0	1.5	0.0	0.0	0.0	14.0	8.5
Contadina Sauce	6.0	1.5	5.0	2.0	6.5	6.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	1.0
Del Monte Organic Sauce	6.5	1.5	5.5	3.0	7.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	8.0	4.0
GV Sauce	10.0	1.5	3.5	2.0	8.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	8.0	5.0
Hunt's Sauce	8.5	3.5	4.0	3.5	7.5	7.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	6.0

Table B.1 (Continued)

	Tomato ID	Green-Viney	Browned	Decay. Veg.	Viscos.	Thick	Firm	Juicy	Mealy	Skin	Seed	Fiber	Pulp Amo.	Pulp Size
Dried Tomatoes														
Great Lakes Sun Dried	9.5	1.0	10.5	11.5	0.0	0.0	15.0	0.0	0.0	15.0	0.0	0.0	0.0	0.0
California Sun Dried	9.0	1.5	10.0	11.0	0.0	0.0	13.0	0.0	0.0	14.0	1.0	0.0	0.0	0.0
Melissa's Dreid	2.0	0.0	14.0	14.0	0.0	0.0	15.0	0.0	0.0	15.0	0.0	0.0	0.0	0.0
Tomato-Based Products														
Hunt's Ketchup	6.0	1.0	5.5	2.5	13.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	9.0	2.0
Del Monte Ketchup	6.0	0.0	5.0	3.0	11.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5	1.5
Heinz Ketchup	6.5	0.0	5.5	3.0	13.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	9.0	2.5
Prego Pasta Suace	7.0	1.0	5.5	2.0	8.5	8.5	0.0	0.0	1.5	0.0	0.0	0.0	10.0	10.0
Hunt Pasta Sauce	7.0	1.5	5.0	1.5	8.5	8.5	0.0	0.0	1.5	0.0	0.0	0.0	9.5	9.0
Ragu Pasta Sauce	5.5	0.0	7.5	2.5	8.5	8.0	0.0	0.0	1.0	0.0	0.0	0.0	9.0	6.0

Table B.2 Flavor Intensity Scores for Tomato Products Based on 15-Point Scale

	Tomato ID	Ripe	Cooked	Browned	Green-Viney	Fruity	Ferment	Musty	Sweet	Chem-ical	Sour	Salt	Bitter	Metallic
Fresh Tomatoes														
Emeril's - Cherry	8.0	7.0	0.0	0.0	4.0	2.0	0.0	2.0	2.5	0.0	3.0	1.5	2.0	0.0
Nature Sweet - Cherry	9.5	8.0	0.0	0.0	3.5	2.5	0.0	2.0	3.0	0.0	3.0	1.5	1.5	0.0
Grape (Mexico)	8.5	9.5	0.0	0.0	4.5	2.5	0.0	2.0	2.0	0.0	3.5	2.0	3.0	0.0
Dillon's Vine Ripe - Round	7.0	6.0	0.0	0.0	5.0	1.5	0.0	3.0	2.0	0.0	3.0	2.0	2.5	0.0
KS Grown Hydro - Round	8.5	7.5	0.0	0.0	4.0	2.0	0.0	2.0	2.5	0.0	3.0	1.5	1.5	0.0
AK Grown - Round	9.0	8.5	0.0	0.0	3.5	2.0	0.0	2.0	2.0	0.0	2.5	1.5	1.5	0.0
Del Monte - Round	6.5	7.0	0.0	0.0	6.0	1.5	0.0	2.0	2.0	0.0	2.5	1.0	2.0	0.0
Dillon's - Plum	5.5	4.5	0.0	0.0	5.0	1.0	0.0	3.5	1.0	0.0	2.5	1.0	2.0	0.0
Dillon's - Round	7.0	5.0	0.0	0.0	4.0	1.0	0.0	2.0	1.5	0.0	2.5	1.0	2.0	0.0
Canned Tomatoes														
Hunt's Whole	11.0	10.0	8.5	2.5	2.0	4.0	1.5	2.0	2.5	0.0	3.5	4.5	2.5	1.5
SanMWhole	11.0	10.5	8.5	3.0	2.5	3.0	1.5	2.0	2.5	0.0	3.5	4.5	2.5	2.5
Great Value Whole	10.5	10.0	7.5	3.0	2.5	2.5	1.0	2.0	2.5	0.0	3.5	5.0	2.0	1.5
FMV Whole	9.5	10.0	7.0	3.5	3.0	2.0	1.0	2.0	2.0	0.0	3.0	5.0	2.0	2.0
Kroger Whole	9.5	9.5	7.0	3.0	3.0	2.0	1.0	2.5	2.0	0.0	3.0	3.5	2.0	2.0
Linguria Crushed	11.0	10.0	8.0	4.0	2.5	2.5	1.0	2.0	2.5	0.0	3.0	4.5	2.5	2.0
Hunt's Crushed	11.0	11.5	9.0	6.5	3.5	1.0	2.0	2.5	2.0	0.0	3.5	6.0	3.0	3.5
Hunt's Diced	11.0	10.0	7.5	2.5	3.0	2.5	1.0	2.0	2.5	0.0	3.5	5.5	2.0	1.5
Del Monte Diced	8.5	11.0	7.5	3.5	3.0	2.5	2.0	2.0	2.0	0.0	3.5	3.0	3.0	2.5
GV Diced	8.0	12.0	7.0	4.0	2.5	1.5	4.0	2.0	1.5	0.0	3.0	4.0	3.0	2.5
Kroger Diced	7.0	9.0	7.0	3.0	3.5	1.5	1.0	2.5	2.0	0.0	3.5	3.5	3.0	2.0
Tomato Juices														
Campbell Regular	8.5	10.0	9.5	5.5	2.5	2.0	1.0	1.5	2.5	0.0	3.0	5.5	2.5	1.0
Campbell Low Sodium	9.0	9.5	10.0	8.5	3.0	2.5	1.0	2.0	2.0	0.0	4.0	3.5	3.0	3.0
Kroger Regular	9.0	10.0	10.5	5.0	4.0	3.0	1.5	2.0	1.5	0.0	3.5	6.0	3.0	5.0
Concentrated Tomatoes														
Amore Paste	9.5	10.0	12.0	9.5	1.5	2.5	2.0	2.0	2.0	0.0	3.5	4.5	3.0	4.5
Hunt's Paste	10.0	10.0	12.0	10.5	1.5	2.0	2.0	2.5	2.5	0.0	3.5	4.5	3.0	3.0
Kroger Paste	9.5	10.5	11.0	9.0	2.5	2.0	3.0	2.5	2.0	0.0	4.0	2.5	3.0	5.0
Contadina Paste	10.0	10.5	12.5	11.0	2.0	2.0	2.0	3.0	2.5	0.0	3.5	4.0	3.0	3.5
Contadina Sauce	9.0	10.5	11.0	9.0	2.0	1.5	0.0	1.0	3.0	0.0	3.0	4.5	2.0	1.0
Del Monte Organic Sauce	6.0	10.5	11.5	9.0	2.0	0.0	2.0	2.5	2.0	3.0	3.0	7.0	3.0	3.5
GV Sauce	11.0	10.5	11.5	8.5	2.0	1.5	0.0	2.0	2.5	0.0	3.0	7.0	2.0	2.5
Hunt's Sauce	9.5	9.5	10.0	8.0	3.0	2.0	1.0	2.0	2.0	0.0	3.5	3.0	3.5	3.0

Table B.2 (Continued)

	Tomato ID	Ripe	Cooked	Browned	Green-Viney	Fruity	Ferment	Musty	Sweet	Chemical	Sour	Salt	Bitter	Metallic
Dried Tomatoes														
Great Lakes Sun Dried	11.0	12.0	14.0	10.0	4.0	2.0	9.0	4.0	2.5	0.0	3.5	2.5	3.0	0.5
California Sun Dried	10.5	10.0	11.5	9.0	4.5	4.0	8.0	3.0	2.5	0.0	3.0	1.5	3.0	1.0
Melissa's Dreid	2.0	13.5	15.0	15.0	1.0	2.0	6.0	2.0	2.5	0.0	3.0	1.5	3.5	1.5
Tomato-Based Products														
Hunt's Ketchup	7.0	10.0	11.0	11.0	0.0	2.5	2.0	1.0	4.0	0.0	4.5	6.5	3.0	2.5
Del Monte Ketchup	6.5	10.0	11.0	11.0	0.0	3.0	2.0	0.0	4.5	0.0	4.0	7.0	2.5	2.5
Heinz Ketchup	6.5	10.0	11.0	11.0	0.0	2.0	2.0	1.5	4.0	0.0	4.5	7.5	3.0	3.0
Prego Pasta Suace	9.0	10.0	11.0	9.0	2.0	1.5	1.0	1.5	3.0	0.0	3.0	5.0	2.5	1.5
Hunt Pasta Sauce	9.0	10.0	11.0	9.5	1.5	2.0	1.0	2.0	3.0	0.0	3.0	6.0	3.0	2.0
Ragu Pasta Sauce	7.5	10.0	12.0	11.0	1.0	1.5	0.0	3.0	3.0	0.0	3.0	6.5	3.0	2.0

Table B.3 Pearson Correlation for All Sensory Attributes

	Tomato ID A	Green-Viney A	Browned A	Decay. Veg. A	Card-board	Viscos.	Thick	Firm	Juicy	Mealy	Skin	Seed	Fiber
Aroma													
Tomato ID	1.00												
Green-Viney	0.23	1.00											
Browned	-0.24	-0.78	1.00										
Decaying Vegetation	-0.17	-0.57	0.88	1.00									
Cardboard	-0.39	-0.10	0.21	0.40	1.00								
Texture													
Viscosity	-0.07	-0.51	0.20	-0.03	-0.26	1.00							
Thickness	-0.01	-0.50	0.43	0.09	-0.29	0.63	1.00						
Firmness	-0.14	0.14	0.18	0.53	0.44	-0.60	-0.68	1.00					
Juiciness	0.17	0.53	-0.68	-0.40	0.22	-0.48	-0.75	0.30	1.00				
Mealy	-0.02	0.70	-0.63	-0.50	0.13	-0.51	-0.47	0.16	0.65	1.00			
Skin Awareness	-0.16	0.42	-0.05	0.24	0.17	-0.53	-0.49	0.76	0.14	0.32	1.00		
Seed Awareness	0.24	0.62	-0.64	-0.39	0.02	-0.22	-0.42	0.19	0.62	0.47	0.26	1.00	
Fiber Awareness	0.06	0.46	-0.62	-0.32	0.32	-0.40	-0.67	0.32	0.88	0.54	0.12	0.60	1.00
Pulp Size	0.20	-0.35	0.27	0.07	-0.15	0.54	0.72	-0.57	-0.40	-0.31	-0.50	-0.08	-0.29
Pulp Amount	0.06	-0.51	0.41	0.09	-0.26	0.65	0.96	-0.71	-0.66	-0.46	-0.58	-0.37	-0.57
Flavor													
Tomato ID	0.80	0.01	-0.09	-0.05	-0.43	0.08	0.12	-0.20	0.08	-0.18	-0.24	0.15	0.03
Ripeness	-0.05	-0.75	0.72	0.68	0.18	0.31	0.30	0.04	-0.37	-0.74	-0.28	-0.45	-0.29
Cooked	-0.08	-0.87	0.87	0.67	0.03	0.48	0.57	-0.18	-0.68	-0.78	-0.46	-0.66	-0.62
Browned	-0.27	-0.84	0.90	0.64	0.05	0.47	0.67	-0.16	-0.82	-0.72	-0.30	-0.75	-0.74
Green-Viney	0.21	0.80	-0.52	-0.23	-0.06	-0.64	-0.63	0.43	0.44	0.58	0.58	0.48	0.45
Fruity	0.37	-0.14	0.13	0.19	-0.10	0.01	-0.09	0.14	0.15	-0.16	-0.05	0.04	-0.08
Cardboard	-0.30	0.18	0.18	0.35	0.47	-0.46	-0.19	0.49	-0.09	0.23	0.63	-0.06	-0.06
Fermented	-0.06	-0.48	0.77	0.92	0.19	-0.11	0.00	0.59	-0.32	-0.43	0.32	-0.33	-0.27
Musty/Earthy	0.15	0.18	0.14	0.28	0.10	-0.45	-0.20	0.39	0.06	0.23	0.38	0.12	0.09
Overall Sweet	-0.09	-0.46	0.28	0.06	-0.29	0.48	0.41	-0.19	-0.33	-0.43	-0.22	-0.26	-0.41
Sweet	-0.12	-0.44	0.25	0.02	-0.38	0.52	0.49	-0.35	-0.47	-0.51	-0.35	-0.40	-0.50
Sour	0.14	-0.50	0.32	0.19	-0.21	0.46	0.50	-0.29	-0.26	-0.51	-0.41	-0.36	-0.27
Salty	-0.05	-0.63	0.25	-0.02	-0.30	0.76	0.56	-0.62	-0.40	-0.62	-0.72	-0.38	-0.32
Bitter	-0.24	-0.56	0.69	0.58	0.07	0.31	0.43	-0.06	-0.52	-0.50	-0.17	-0.50	-0.44
Metallic	0.07	-0.55	0.47	0.28	-0.03	0.51	0.68	-0.53	-0.48	-0.55	-0.65	-0.45	-0.38
Chemical	-0.12	-0.09	0.07	0.00	-0.10	0.10	0.06	-0.13	-0.14	-0.15	-0.11	-0.14	-0.14
Astringent	-0.04	-0.40	0.38	0.43	0.18	0.17	0.17	0.17	-0.08	-0.25	0.00	-0.12	-0.04

Table B.3 (Continued)

	Pulp Size	Pulp Amo.	Tomato ID	Ripe	Cooked	Browned	Green-Viney	Fruity	Cardboard	Ferment	Musty/ Earthy	Overall Sweet	Sweet	Sour	Salty	Bitter	Metallic	Chem.	Astring.
Texture																			
Pulp Size	1.00																		
Pulp Amount	0.85	1.00																	
Flavor																			
Tomato ID	0.42	0.24	1.00																
Ripeness	0.36	0.36	0.20	1.00															
Cooked	0.48	0.61	0.13	0.80	1.00														
Browned	0.39	0.63	-0.12	0.67	0.92	1.00													
Green-Viney	-0.38	-0.62	0.10	-0.56	-0.69	-0.73	1.00												
Fruity	-0.10	-0.10	0.39	0.21	0.15	0.02	-0.10	1.00											
Cardboard	-0.26	-0.25	-0.43	-0.13	-0.15	0.00	0.32	-0.37	1.00										
Fermented	-0.05	-0.03	0.03	0.57	0.55	0.51	-0.10	0.27	0.25	1.00									
Musty/Earthy	0.05	-0.16	0.15	-0.12	-0.05	-0.10	0.49	-0.22	0.42	0.33	1.00								
Overall Sweet	0.06	0.33	-0.04	0.27	0.37	0.49	-0.69	0.29	-0.41	0.07	-0.56	1.00							
Sweet	0.04	0.38	-0.04	0.22	0.41	0.49	-0.57	0.31	-0.49	0.08	-0.55	0.78	1.00						
Sour	0.22	0.45	0.12	0.42	0.48	0.47	-0.54	0.38	-0.38	0.22	-0.29	0.50	0.63	1.00					
Salty	0.47	0.61	0.17	0.48	0.62	0.52	-0.71	-0.02	-0.51	-0.07	-0.38	0.50	0.57	0.48	1.00				
Bitter	0.37	0.43	-0.16	0.56	0.66	0.66	-0.35	0.07	0.08	0.52	0.15	0.04	0.16	0.50	0.26	1.00			
Metallic	0.62	0.73	0.18	0.54	0.68	0.58	-0.50	0.07	-0.26	0.17	-0.10	0.03	0.31	0.58	0.59	0.60	1.00		
Chemical	0.02	0.10	-0.23	0.08	0.13	0.12	-0.09	-0.44	0.19	0.03	0.09	-0.10	-0.12	-0.09	0.25	0.13	0.19	1.00	
Astringent	0.32	0.23	-0.01	0.39	0.33	0.31	-0.36	-0.09	0.13	0.41	0.15	0.18	-0.11	0.09	0.19	0.29	0.20	0.27	1.00

Figure B.1 Cluster Tree Diagram for Aroma and Flavor Attributes

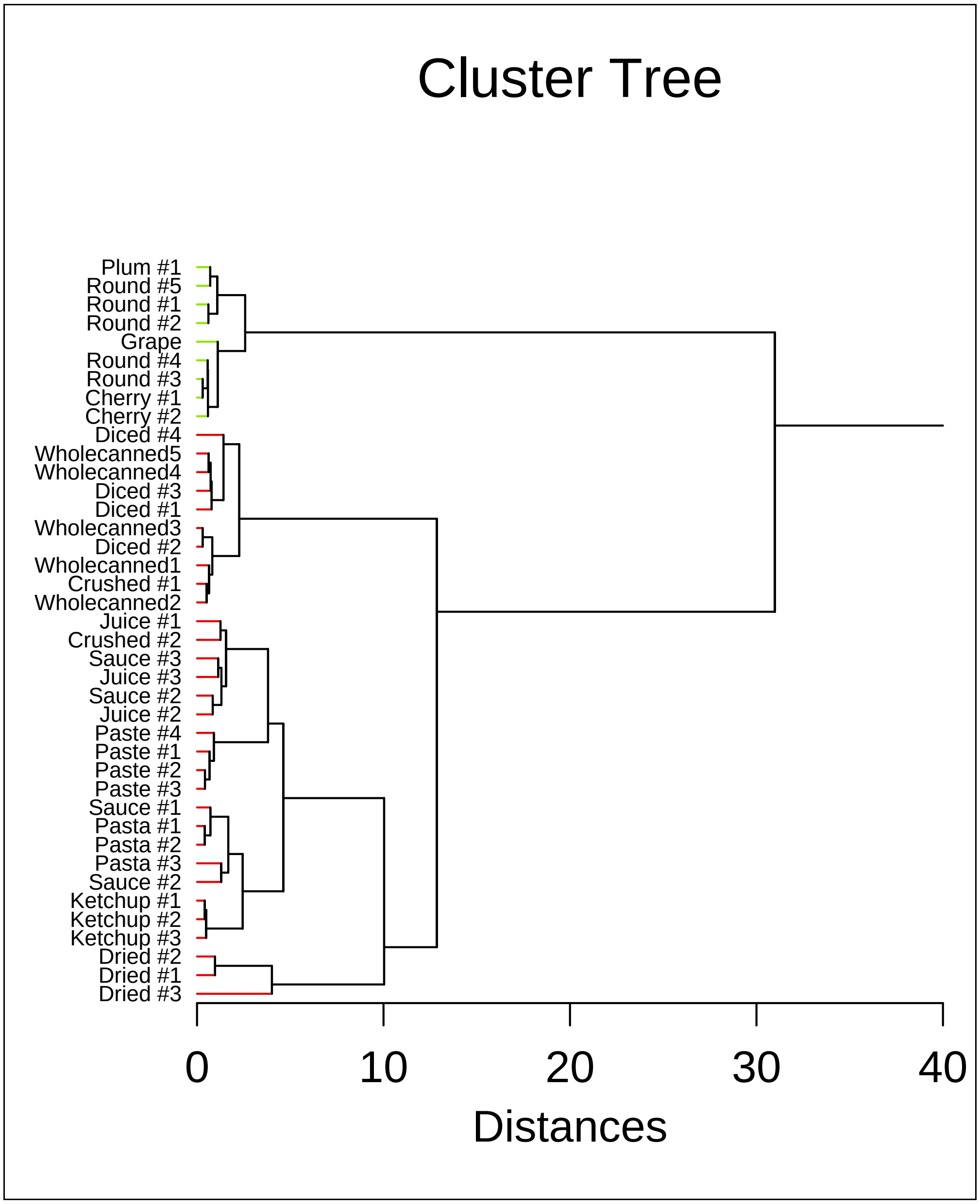
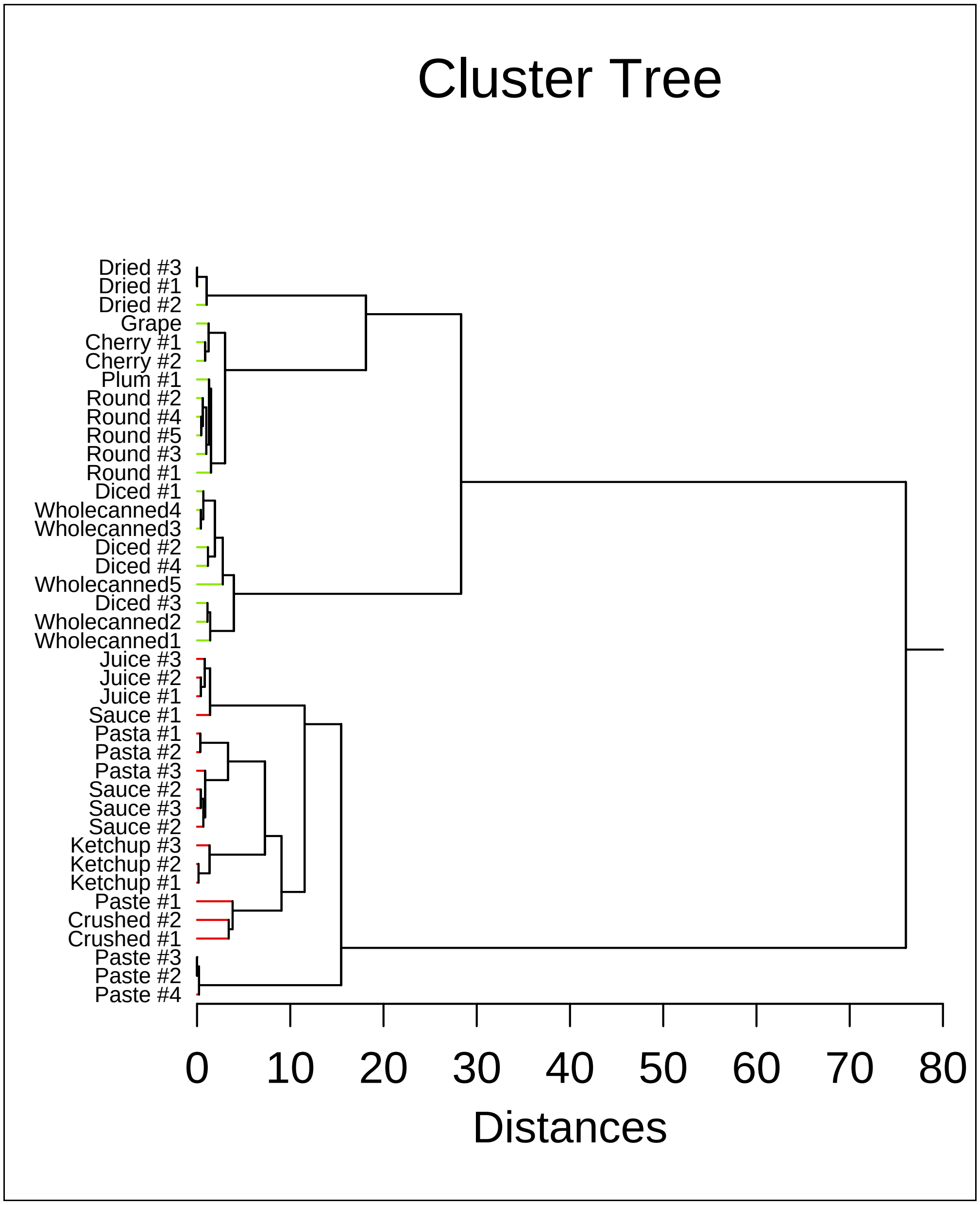


Figure B.2 Cluster Tree Diagram for Texture Attributes



Appendix C - Tomato Planting and Planning for Evaluation

Figure C.1 Plotting Design for Tomato Planting in High Tunnel Greenhouse

	Plot 1					Plot 2				
Row 1	Florida 91	Jet Star	Brandy wine	Juliet	Red Agate	Brandy wine	Florida 91	Red Agate	Jet Star	Juliet
	Plot 3					**Plot 4**				
Row 2	Juliet	Red Agate	Jet Star	Brandy wine	Florida 91	Red Agate	Brandy wine	Juliet	Florida 91	Jet Star

Figure C.2 Tomato Yield

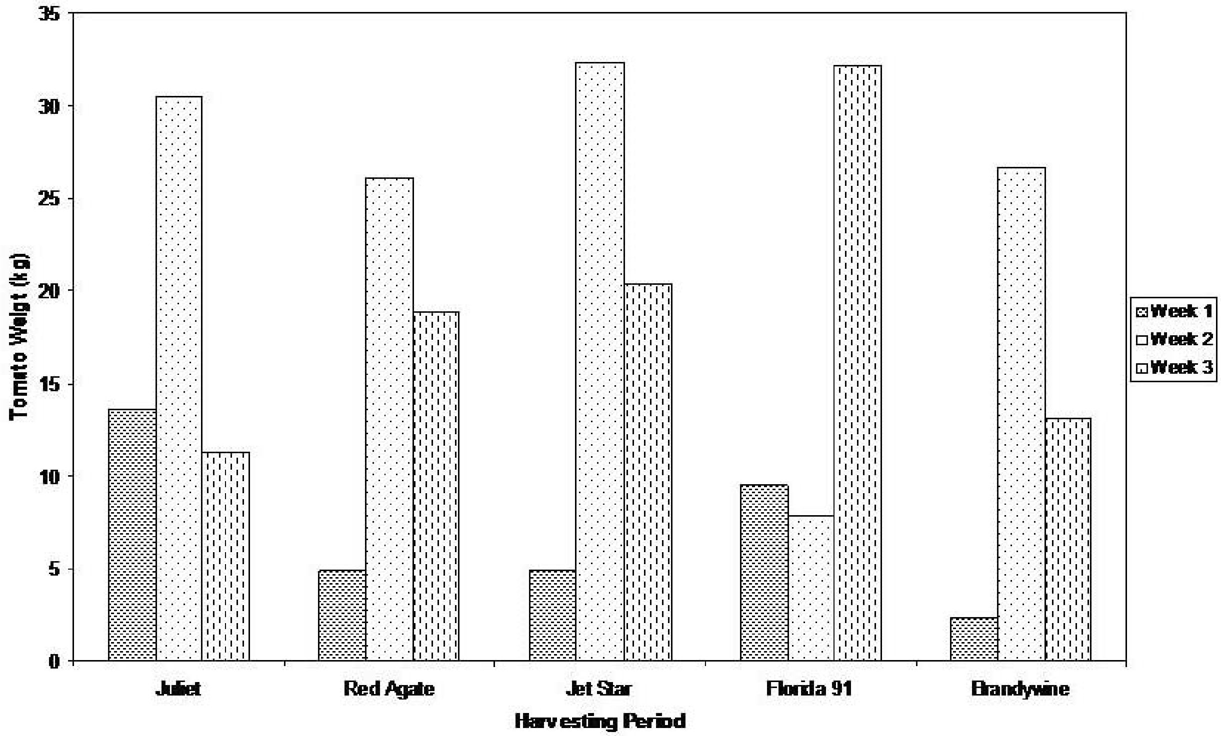


Table C.1 Compositional Worksheet for pH, Total Soluble Solids and Titratable Acidity

Tomato	Rep	Sample pH	°Brix	Initial NaOH ml read	Final NaOH ml read	ml NaOH used
Brandywine	1					
Brandywine	2					
Brandywine	3					
Florida 91	1					
Florida 91	2					
Florida 91	3					
Jet Star	1					
Jet Star	2					
Jet Star	3					
Juliet	1					
Juliet	2					
Juliet	3					
Red Agate	1					
Red Agate	2					
Red Agate	3					

Appendix D - Tomato Juice Processing Instruction

Ingredients

- About 2 kg (2000 g) of tomatoes
- ½ tsp Pickling Salt
- 1 tsp Lemon juice

1. Wash tomatoes in lukewarm water.
2. Remove stems and trim off bruised or discolored portions.
3. Cut the fruits into large pieces (~1.5" thick) and place directly in a stock pot.
4. Heat the cut tomatoes immediately to boil while crushing.
5. Then, simmer on setting 4 for 5 minutes before juicing.
6. Press heated tomatoes through a food mill to remove skins and seeds. Place the juice back into a stock pot.
7. Heat the juice again to boiling.
8. Meanwhile, prepare the jars for canning.
    a. Bring water to boil in a large pot.
    b. Place jars in the boiling water for 5 minutes.
    c. Add lemon juice and salt to the jars.
9. Fill the jars with hot tomato juice, leaving about ½ inch headspace. Adjust the metal lids.
10. Process in a boiling water canner for 35 minutes.

Tomato Juice Canning:

- Fill canner halfway with water and preheat on a gas stove to 180 ºF.
- Load sealed jars onto canner rack (5 cans limit) and lower with handles into the canner.
- Make sure the water level is 1 inch above jars. Cover the canner.
- Turn heat to high and bring water to boil. When water boils vigorously, lower heat to maintain a gentle boil and process jars for the given time.

Modified from "The National Center for Home Food Preservation" (http://www.uga.edu/nchfp/).

Appendix E - Tomato Paste Processing Instruction

Ingredients

- About 4 kg (4,000 g) of tomatoes
- ¼ tsp Pickling Salt

1. Bring enough water (~2/3), in a stock pot, to boil.
2. Wash tomatoes with lukewarm water.
3. Dip tomatoes in boiling water for about 60 seconds (or until skins split).
4. Then, dip in cold water. Slip off skins.
5. Remove cores and chop tomatoes into pieces (~ 1.5" thick).
6. Combine tomatoes and salt in a stock pot and cook slowly on stove using setting 4 for 1 hour.
7. Press cooked tomatoes through food mill and place back in the stock pot. Continue cooking slowly (using stove setting 3) until the product is thick enough to round up on a spoon (approximately 4 hours). Stir frequently to prevent sticking. Monitor ºBrix of the mixture using a handheld refractometer – tomato paste should contain at least 24% of tomato total soluble solids.
8. Immediately before the paste is ready, prepare glass jars for canning by:
    a. Bring water to boil in a large pot.
    b. Place jars in the boiling water for 5 minutes and remove the jars.
9. Pour boiling hot paste into hot jars, leaving about ¼ inch headspace.
10. Remove air bubbles using a spatula and adjust headspace if necessary.
11. Wipe off rims of jars with a dampened clean paper towel; adjust two-piece metal canning lids.
12. Process in a boiling water canner for 50 minutes.

Tomato Paste Canning:

- Fill canner halfway with water and preheat on a gas stove to 180 ºF.
- Load sealed jars onto canner rack (5 cans limit) and lower with handles into the canner.
- Make sure the water level is 1 inch above jars. Cover the canner.
- Turn heat to high and bring water to boil. When water boils vigorously, lower heat to maintain a gentle boil and process jars for the given time.

Modified from "The National Center for Home Food Preservation" (http://www.uga.edu/nchfp/).

Appendix F - SAS Code for ANOVA for pH, TSS (ºBrix) and TA Data

```
Option ps=57 ls=95;
Title 'Compositional Analysis for Raw tomatoes';

data set1;
input tomato$ rep week brix pH TA;
datalines;
FL91   1     1     5.0    4.26   0.400
FL91   2     1     4.8    4.24   0.448
FL91   3     1     4.8    4.25   0.464
. . .

;
run;
proc sort data=set1;
        by tomato harvest;
run;
********Obtain the mean table by tomato cultivars********;
proc means data=set1;
        var brix pH TA;
        by tomato;
        output out=means1;
run;
********Obtain the ANOVA for each variable********;
proc mixed data=set1;
        class tomato;
        model brix = tomato;
        lsmeans tomato/ diff;
run;
proc mixed data=set1;
        class tomato;
        model pH = tomato;
        lsmeans tomato/ diff;
run;
proc mixed data=set1;
        class tomato;
        model TA = tomato;
        lsmeans tomato/ diff;
run;
quit;
```

Appendix G - SAS Code for ANOVA for Dry Matter Data

```
Option ps=57 ls=95;
Title 'Dry Matter Analysis';

data set1;
input tomato$ week$ dryG dry;
datalines;
BW    wk2    12.4    6.20
BW    wk1    10.3    5.15
BW    wk3    12.8    6.40
…
;
run;
proc sort data=set1; by tomato harvest;
run;
proc means data=set1;
        var dryG dry;
        by tomato;
        output out=means1;
run;
proc sort; by tomato; run;
proc mixed data=set1;
        class tomato;
        model dryG = tomato;
        lsmeans tomato/ diff;
run;
proc mixed data=set1;
        class tomato;
        model dry = tomato;
        lsmeans tomato/ diff;
run;
```

Appendix H - SAS Code for ANOVA for Fresh Tomatoes

```
DM 'LOG;CLEAR;OUTPUT;CLEAR;';
options ps=65 ls=80 nodate pageno=1;
options symbolgen;
data step1;
INPUT  tomato$ week stage$ pa code IDAroma VineyA DecayVA CrbdA Firmness Juiciness
Mealy Skin Seed Fiber IDFlavor Ripeness Viney Umami Fruity Crbd Fermented MustyEarthy
Sweet Sour Salt Bitter Metallic Astringent;
datalines;

[Data has been removed]

;

/*********Check if the data was read*********;
proc print;*/
title 'Fresh Tomato Analysis';
*********Check the frequency according to the test design***********;
proc sort; by tomato stage; run;
proc freq;
tables Code Tomato week Pa; by tomato;
run;
*********Check Means and Standard Deviations************;
data step2; set step1;
Proc sort; by tomato;
proc means;
 var IDAroma--Astringent;
 by Tomato;
 output out=means;
run;
Proc sort; by tomato;
proc means;
 var IDAroma--Astringent;
 by Tomato stage;
 output out=meanstage;
run;

******* Data Analysis - ANOVA and Mean Separation (Pa treated as Random Effect) *****;
proc mixed data=step1;
        Class tomato week pa stage;
        model IDAroma = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model VineyA = tomato|week|stage/ ddfm=satterth;
```

```
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model CrbdA = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model DecayVA = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Firmness = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Juiciness = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Mealy = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Skin = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Seed = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
```

```
        Class tomato week pa stage;
        model Fiber = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato*week stage tomato*stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model IDFlavor = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Ripeness = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Viney = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Umami = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Fruity = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Crbd = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Fermented = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
```

```
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model MustyEarthy = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Sweet = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Sour = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Salt = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Bitter = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Metallic = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
proc mixed data=step1;
        Class tomato week pa stage;
        model Astringent = tomato|week|stage/ ddfm=satterth;
        random pa pa*tomato pa*week pa*week*tomato pa*week*stage pa*tomato*stage;
        lsmeans tomato|week|stage /pdiff;
run;
```

Appendix I - SAS Code for ANOVA for Tomato Juice and Paste

```
DM 'LOG;CLEAR;OUTPUT;CLEAR;';
options ps=65 ls=80 nodate pageno=1;
options symbolgen;
data step1;
INPUT  Tomato$ Week Type$ Pa$ Code IDAroma VineyA BrownedA DecayVA CrbdA
Viscosity Thickness Mealy Skin Seed Fiber PulpSize PulpAmount IDFlavor Ripeness Cooked
Browned Viney Umami Fruity Cardboard Fermented MustyEarthy OVSweet Sweet Sour Salt
Bitter Metallic Chemical Astringent;
datalines;
(data has been removed)
;
/*********Check if the data was read**********;
title 'Tomato Juice and Paste Analysis';
*********Check the frequency according to the test design************;
proc sort; by type; run;
proc freq;
tables Code Tomato Week Pa; by type;
run;
*********Check Means and Standard Deviations*************;
data step2; set step1;
Proc sort; by Tomato;
proc means;
 var IDAroma--Astringent;
 by Tomato type;
 output out=means;
run;
*******Data Analysis - ANOVA and Mean Separation (Pa treated as a Random Effect) *****;
proc mixed data=step1;
	Class tomato week pa;
	model IDAroma = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model VineyA = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	/*lsmeans tomato|rep/pdiff;*/
run;
```

```
proc mixed data=step1;
	Class tomato week pa;
	model BrownedA = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model DecayVA = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model CrbdA = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Viscosity = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Thickness = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Mealy = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
```

```
proc mixed data=step1;
        Class tomato week pa;
        model Skin = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model Seed = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model Fiber = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model PulpSize = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model PulpAmount = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model IDFlavor = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
```

```
proc mixed data=step1;
	Class tomato week pa;
	model Ripeness = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Cooked = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Browned = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Viney = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Umami = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Fruity = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
```

```
proc mixed data=step1;
	Class tomato week pa;
	model Cardboard = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Fermented = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model MustyEarthy = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model OVSweet = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Sweet = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
	Class tomato week pa;
	model Sour = tomato|week/ ddfm=satterth;
	random pa tomato*pa week*pa;
	by type;
	lsmeans tomato|week/pdiff;
run;
```

```
proc mixed data=step1;
        Class tomato week pa;
        model Salt = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model Bitter = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model Metallic = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model Chemical = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
proc mixed data=step1;
        Class tomato week pa;
        model Astringent = tomato|week/ ddfm=satterth;
        random pa tomato*pa week*pa;
        by type;
        lsmeans tomato|week/pdiff;
run;
```

Appendix J - Additional Tomato Juice and Paste Data

Figure J.1 Total Soluble Solid Plot for Tomato Juice

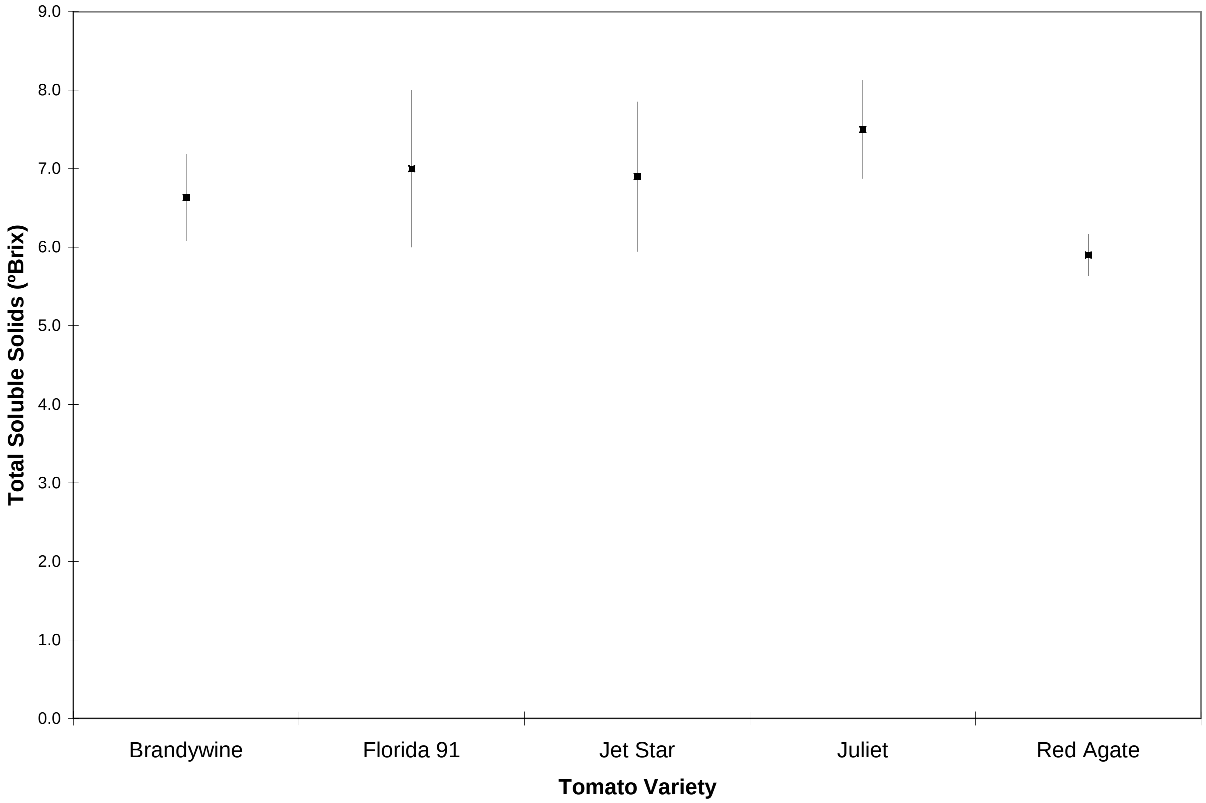
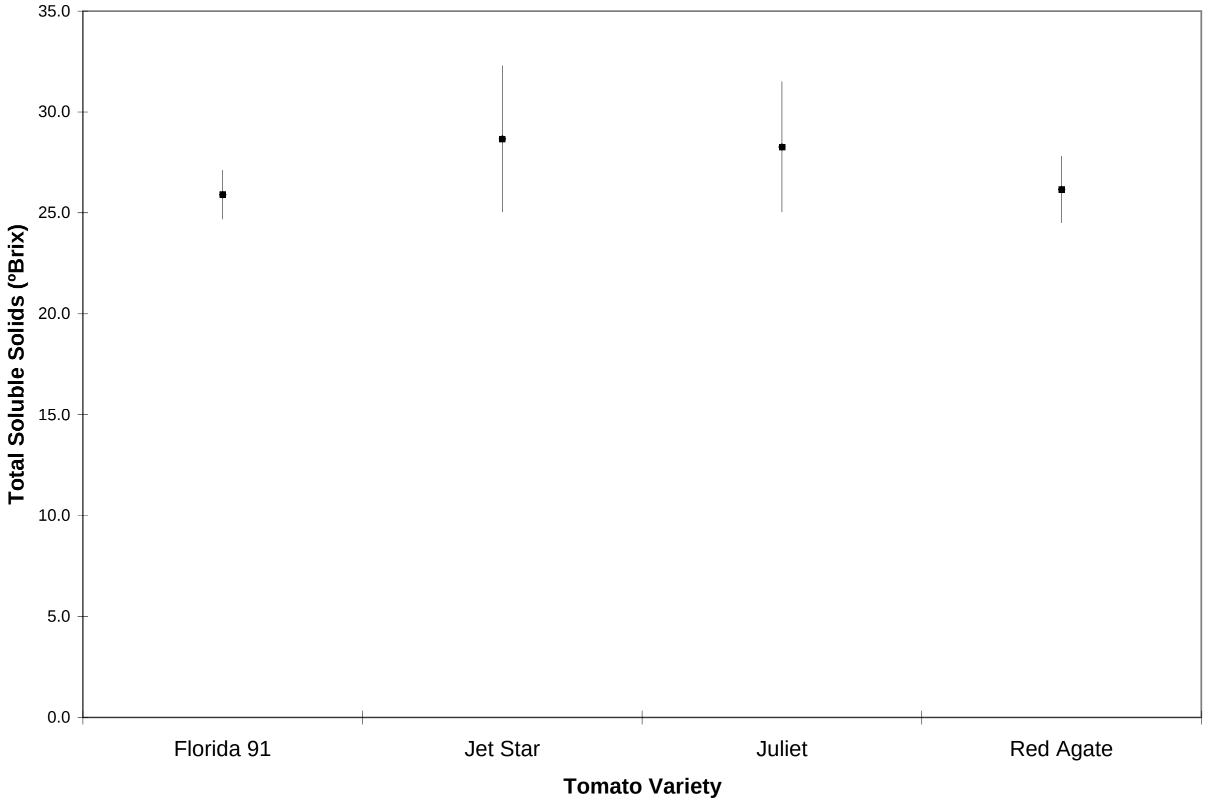


Figure J.2 Total Soluble Solid Plot for Tomato Paste



Appendix K - Code of Federal Regulations for Tomato Juice

(a) *Identity*--(1) *Definition.* **tomato juice** is the food intended for direct consumption, obtained from the unfermented liquid extracted from mature tomatoes of the red or reddish varieties of *Lycopersicum esculentum* P. Mill, with or without scalding followed by draining. In the extraction of such liquid, heat may be applied by any method which does not add water thereto. Such juice is strained free from peel, seeds, and other coarse or hard substances, but contains finely divided insoluble solids from the flesh of the tomato in accordance with current good manufacturing practice. Such juice may be homogenized, may be seasoned with salt, and may be acidified with any safe and suitable organic acid. The juice may have been concentrated and later reconstituted with water and/or **tomato juice** to a tomato soluble solids content of not less than 5.0 percent by weight as determined by the method prescribed in 156.3(b). The food is preserved by heat sterilization (canning), refrigeration, or freezing. When sealed in a container to be held at ambient temperatures, it is so processed by heat, before or after sealing, as to prevent spoilage.

(2) *Labeling.* (i) The name of the food is:

(*a*) "Tomato juice" if it is prepared from unconcentrated undiluted liquid extracted from mature tomatoes of reddish varieties.

(*b*) "Tomato juice from concentrate" if the finished juice has been prepared from concentrated **tomato juice** as specified in paragraph (a)(1) of this section or if the finished juice is a mixture of **tomato juice** and **tomato juice** from concentrate.

(ii) *Label declaration.* Each of the ingredients used in the food shall be declared on the label as required by the applicable sections of parts 101 and 130 of this chapter.

(b) *Quality.* (1) The standard of quality for **tomato juice** is as follows:

(i) The strength and redness of color is not less than the composite color produced by spinning the Munsell color discs in the following combination: 53 percent of the area of Disc 1; 28 percent of the area of Disc 2; and 19 percent of the area of either Disc 3 or Disc 4; or 9 1/2 percent of the area of Disc 3 and 9 1/2 percent of the area of Disc 4, whichever most nearly matches the appearance of the tomato juice.

(ii) Not more than two defects for peel and blemishes, either singly or in combination, in addition to three defects for seeds or pieces of seeds, defined as follows, per 500 milliliters (16.9 fluid ounces):

(*a*) Pieces of peel 3.2 millimeters (0.125 inch) or greater in length.

(*b*) Blemishes such as dark brown or black particles (specks) greater than 1.6 millimeters (0.0625 inch) in length.
(*c*) Seeds or pieces of seeds 3.2 millimeters (0.125 inch) or greater in length.
(2) *Methodology.* (i) Determine strength and redness of color as specified in 156.3(a).
(ii) Examine a total of 500 milliliters for peel, blemishes, and seeds. Divide the 500-milliliter sample into two 250-milliliter aliquots and pour each aliquot onto separate 30.5 * 45.7 centimeters (12 * 18 inches) white grading trays. Remove defects and evaluate for color and size as defined in paragraph (b)(1)(ii) of this section.
(3) Determine compliance as specified in 156.3(d).
(4) If the quality of the **tomato juice** falls below the standard prescribed in paragraph (b)(1) and (3) of this section, the label shall bear the general statement of substandard quality specified in 130.14(a) of this chapter, in the manner and form therein specified, but in lieu of such general statement of substandard quality when the quality of the **tomato juice** falls below the standard in one or more respects, the label may bear the alternative statement, "Below Standard in Quality ___", the blank to be filled in with the words specified after the corresponding paragraph (s) under paragraph (b)(1) of this section which such **tomato juice** fails to meet, as follows:
(i) "Poor color".
(ii)(*a*) "Excessive pieces of peel".
(*b*) "Excessive blemishes".
(*c*) "Excessive seeds" or "excessive pieces of seed".

(c) *Fill of container.* (1) The standard of fill of container for tomato juice, as determined by the general method for fill of container prescribed in 130.12(b) of this chapter, is not less than 90 percent of the total capacity, except when the food is frozen. (2) Determine compliance as specified in 156.3(d).
(3) If the **tomato juice** falls below the standard of fill prescribed in paragraph (c)(1) and (2) of this section, the label shall bear the general statement of substandard fill specified in 130.14(b) of this chapter, in the manner and form therein prescribed.
[48 FR 3957, Jan. 28, 1983, as amended at 58 FR 2883, Jan. 6, 1993]

Appendix L - Code of Federal Regulations for Tomato Paste

(a) *Identity*--(1) *Definition.* Tomato concentrates are the class of foods each of which is prepared by concentrating one or any combination of two or more of the following optional tomato ingredients:

(i) The liquid obtained from mature tomatoes of the red or reddish varieties (*Lycopersicum esculentum* P. Mill).

(ii) The liquid obtained from the residue from preparing such tomatoes for canning, consisting of peelings and cores with or without such tomatoes or pieces thereof.

(iii) The liquid obtained from the residue from partial extraction of juice from such tomatoes.

Such liquid is obtained by so straining the tomatoes, with or without heating, as to exclude skins (peel), seeds, and other coarse or hard substances in accordance with good manufacturing practice. Prior to straining, food-grade hydrochloric acid may be added to the tomato material in an amount to obtain a pH no lower than 2.0. Such acid is then neutralized with food-grade sodium hydroxide so that the treated tomato material is restored to a pH of 4.2+/-0.2. Water may be addedto adjust the final composition. The food contains not less than 8.0 percent tomato soluble solids as defined in 155.3(e). The food is preserved by heat sterilization (canning), refrigeration, or freezing. When sealed in a container to be held at ambient temperatures, it is so processed by heat, before or after sealing, as to prevent spoilage.

(2) *Optional ingredients.* One or any combination of two or more of the following safe and suitable ingredients may be used in the foods:

(i) Salt (sodium chloride formed during acid neutralization shall be considered added salt).

(ii) Lemon juice, concentrated lemon juice, or organic acids.

(iii) Sodium bicarbonate.

(iv) Water, as provided for in paragraph (a)(1) of this section.

(v) Spices.

(vi) Flavoring.

(3) *Labeling.* (i) The name of the food is:

(*a*) "Tomato puree" or "tomato pulp" if the food contains not less than 8.0 percent but less than 24.0 percent tomato soluble solids.

(*b*) "Tomato paste" if the food contains not less than 24.0 percent tomato soluble solids.

(*c*) The name "tomato concentrate" may be used in lieu of the name "tomato puree," "tomato pulp," or "tomato paste" whenever the concentrate complies with the requirements of such foods; except that the label shall bear the statement "for remanufacturing purposes only" when the concentrate is packaged in No. 10 containers (3.1 kilograms or 109 avoirdupois ounces total water capacity) or containers that are smaller in size.

(*d*) "Concentrated tomato juice" if the food is prepared from the optional tomato ingredient described in paragraph (a)(1)(i) of this section and is of such concentration that upon diluting the food according to label directions as set forth in paragraph (a)(3)(iii) of this section, the diluted article will contain not less than 5.0 percent by weight tomato soluble solids.

(ii) The following shall be included as part of the name or in close proximity to the name of the food:

(*a*) The statement "Made from" or "Made in part from," as the case may be, "residual tomato material from canning" if the optional tomato ingredient specified in paragraph (a)(1)(ii) of this section is present.

(*b*) The statement "Made from" or "Made in part from," as the case may be, "residual tomato material from partial extraction of juice" if the optional tomato ingredient specified in paragraph (a)(1)(iii) of this section is present.

(*c*) A declaration of any flavoring that characterizes the product as specified in 101.22 of this chapter and a declaration of any spice that characterizes the product, e.g., "Seasoned with ___," the blank to be filled in with the words "added spice" or, in lieu of the word "spice," the common name of the spice.

(iii) The label of concentrated tomato juice shall bear adequate directions for dilution to result in a diluted article containing not less than 5.0 percent by weight tomato soluble solids; except that alternative methods may be used to convey adequate dilution directions for containers that are larger than No. 10 containers (3.1 kilograms or 109 avoirdupois ounces total water capacity).

(iv) Label declaration. Each of the ingredients used in the food shall be declared on the label as required by the applicable sections of parts 101 and 130 of this chapter; except that water need not be declared in the ingredient statement when added to adjust the tomato soluble solids content of tomato concentrates within the range of soluble solids levels permitted for these foods.

(v) Determine percent tomato soluble solids as specified in 155.3(e). Determine compliance as specified in 155.3(b). A lot shall be deemed to be in compliance for tomato soluble solids as follows:

(*a*) The sample average meets or exceeds the required minimum.

(*b*) The number of sample units that are more than 1 percent tomato soluble solids below the minimum required does not exceed the acceptance number in the sampling plans set forth in 155.3(c)(2).

(b) *Quality.* (1) The standard of quality for tomato concentrate (except for concentrated tomato juice, which when diluted to 5.0 percent tomato soluble solids shall conform to the standard of quality for tomato juice set forth in 156.145 of this chapter) is as follows:

(i) The strength and redness of color of the food, when diluted with water (if necessary) to 8.1+/-0.1 percent tomato soluble solids is not less than the composite color produced by spinning the Munsell color discs in the following combination:

53 percent of the area of Disc 1;

28 percent of the area of Disc 2; and

19 percent of the area of either Disc 3 or Disc 4; or

9 1/2 percent of the area of Disc 3 and 9 1/2 percent of the area of Disc 4, whichever most nearly matches the appearance of the sample.

(ii) Not more than one whole seed per 600 grams (21 ounces).

(iii) Not more than 36 of the following defects, either singly or in combination, per 100 grams (3.5 ounces) of the product when diluted with water to 8.1+/-0.1 percent tomato soluble solids:

(*a*) Pieces of peel 5 millimeters (0.20 inch) or greater in length (without unrolling).

(*b*) Pieces of seed (seed particles) 1 millimeter (0.039 inch) or greater in length.

(*c*) Blemishes, such as dark brown or black particles (specks)--not more than four exceed 1.6 millimeters (0.0625 inch) in length of which not more than one exceeds 3.2 millimeters (0.125 inch) and none exceed 6.4 millimeters (0.25 inch).

(2) *Methodology.* Dilute with water, if necessary, to 8.1+/-0.1 percent tomato soluble solids. (i) Determine strength and redness of color as prescribed in 155.3(d).

(ii) Whole seeds--Weigh out 600 grams (21 ounces) of the well-mixed, diluted concentrate; place a U.S. No. 12 screen (1.68 millimeters (0.066 inch) openings) over the sink drain; transfer the

product sample onto the screen; rinse container thoroughly with water and pour through screen; flush sample through screen by using an adequate spray of water; check screen for whole seeds; apply the appropriate allowance.
(iii) Peel, pieces of seed, and blemishes--Spread the prepared concentrate evenly on a large white tray and remove the individual defects, identify, classify, and measure.
(3) *Sampling and acceptance.* Determine compliance as specified in 155.3(b).
(4) If the quality of the tomato concentrate falls below the standard prescribed in paragraph (b)(1) and (3) of this section, the label shall bear the general statement of substandard quality specified in 130.14(a) of this chapter, in the manner and form therein specified, but in lieu of such general statement of substandard quality when the quality of the tomato concentrate falls below the standard in one or more respects, the label may bear the alternative statement, "Below Standard in Quality ___," the blank to be filled in with the words specified after the corresponding paragraph(s) under paragraph (b)(1) of this section which such tomato concentrate fails to meet, as follows:
(i) "Poor color."
(ii) "Excessive seeds."
(iii)(*a*) "Excessive pieces of peel."
(*b*) "Excessive pieces of seed."
(*c*) "Excessive blemishes."

(c) *Fill of container.* (1) The standard of fill of container for tomato concentrate, as determined by the general method for fill of container prescribed in 130.12(b) of this chapter, is not less than 90 percent of the total capacity, except when the food is frozen.
(2) Determine compliance as specified in 155.3(b).
(3) If the tomato concentrate falls below the standard of fill prescribed in paragraph (c) (1) and (2) of this section, the label shall bear the general statement of substandard fill specified in 130.14(b) of this chapter, in the manner and form therein prescribed.
[48 FR 3954, Jan. 28, 1983, as amended at 49 FR 15073, Apr. 17, 1984; 58 FR 2883, Jan. 6, 1993; 58 FR 17104, Apr. 1, 1993]