THE SENSORY EVALUATION AND THE EFFECT OF RADIO FREQUENCY APPLICATION ON SOUTHERN HIGHBUSH BLUEBERRIES

by

KYLAH C. SMITH

(Under the Direction of Robert L. Shewfelt)

ABSTRACT

With the increased in consumption of fresh blueberries in the last two decades, a new generation of cultivars has been released that were bred for mechanical harvesting. Sensory evaluation was conducted by trained panelists on various southern highbush blueberries (SHB) for taste, chemical feel, and texture characteristics. The only consistent finding at a significant difference level of $p < 0.05$ indicate that the "crispy" flesh selections were clearly crispier than the "melting" flesh counterparts and comparable in all other sensory The effects of radio frequency (RF) application on "melting" flesh and "crisp" flesh (SHB) on the improvement of juice yield and quality were investigated. The SHB were subjected to different radio frequency intensities. Juice yield increased for the both "melting" and "crisp" flesh SHB. When RF was applied to the SHB, it showed a statistically significant difference level of $p < 0.0001$ of total phenolic content of the juice and demonstrated strong radical-scavenging activity. However, there was a variation in percent inhibition among the different samples.

INDEX WORDS: Sensory evaluation; radio-frequency; phenolics; antioxidants; southern highbush blueberries; juice yield

THE SENSORY EVALUATION AND THE EFFECT OF RADIO FREQUENCY APPLICATION ON SOUTHERN HIGHBUSH BLUEBERRIES

by

KYLAH C. SMITH

B.S., Valdosta State University, 2007

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment

of the Requirements for the Degree

MASTERS OF SCIENCE

ATHENS, GEORGIA

2010

THE SENSORY EVALUATION AND THE EFFECT OF RADIO FREQUENCY APPLICATION ON SOUTHERN HIGHBUSH BLUEBERRIES

by

KYLAH C. SMITH

Major Professor: Robert L. Shewfelt

Committee: Jake H. Mulligan
Dan MacLean

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
August 2010

DEDICATION

To my Daddy, my Mommy who entered Heaven on December 6th 2009, my little brother Isiah, and Sister Kiara.

ACKNOWLEDGEMENTS

I would like to give thanks to God for giving me the strength needed for me achieve another goal in life despite the loss of my grandfather, aunt, and mother while working on this degree. Thank you to my family and friends who have supported me throughout this stage in my life. To my godmother Rethel and my best friend Kris, I thank you for always being there for me when it mattered most. Special thanks to my friend Katherine ‘Katie’ Erickson for all her help from academic to personal, advice, and many laughs that brought me to tears. I love you all.

My gratitude goes out to my amazing professor, Dr. Robert Shewfelt for every opportunity that he has given me to learn. I would also like to acknowledge Dr. Dan MacLean for being part of my educational experience and making it clear that field work will never beat my love for lab work. Dr. Jake Mulligan it has been an adventure working with you, many thanks for rescuing me from my graduate student office and allowing me to have a desk in your lab. My panel members, lab mates (3rd floor and 1st floor), and Anne Morrison, without you, I would not have made it.

I would also like to thank USDA National Institute of Food and Agriculture (GEO-2010-01605) for funding this research.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Blueberries in Georgia

In 2006, North America produced 85 % of world production of blueberries. Total production of blueberries in North America reached an estimated 536 million pounds. There has been a steady rise of production of highbush (*Vaccinium corymbosum*) blueberries, from approximately 90 million pounds in 1980 to 332 million pounds in 2006 (Council, 2010, Statistics, 2006). Blueberries are produced in 38 states of the United States. There are six states that are responsible for 90% of highbush varieties crops. These states are Michigan, New Jersey, Oregon, North Carolina, Washington, and Georgia.

Blueberry production dominates in the southeastern regions of Georgia. Blueberries, are the number one fruit crop in Georgia serve as a valuable fruit crop in Georgia (Scherm and Krewer, 2003). In 2009, it was reported by county agents in Georgia that there were 9,042 acres dedicated to blueberry crops with a value of $102 million(Agents, 2009). This acreage is a dramatic increase in production compared to 1955 when there was no production of blueberries in Georgia. An estimated 90% of the state's blueberry acreage is located in the southeastern and south-central Georgia, primarily in Appling, Bacon, Clinch, Pierce, Wayne, and Ware counties. Of that acreage, 90% is dedicated to rabbiteye (*Vaccinium viratum* Aiton, syn *V. ashei)* blueberries (Scherm and Krewer, 2003). There are two dominant types of blueberries grown in Georgia including rabbiteye and southern (*Vaccinium darrowii* Camp) (Strik and Yarborough, 2005). Rabbiteye blueberries can be grown throughout the entire state of Georgia. The rabbiteye blueberry has been in cultivation for more than 100 years. The southern highbush blueberry has been of great interest since the mid-1990s, due to its early harvest date and the economical benefits for the fresh market. Southern highbush do best in southern Georgia. However, there are some cultivars that bloom late and are not as well adapted in south Georgia (Council, 2010, Scherm and Krewer, 2003).

Dr. Tom Brightwell in Tifton, Georgia, started a breeding program in the 1940's producing rabbiteye blueberry cultivars. Dr. Brightwell worked with the United States Department of Agriculture (USDA) and the cultivars developed from the breeding program lead way to the success of the Georgia blueberry industry today (Krewer and Nesmith, 2006). There are many highbush cultivars in the industry today. Credit can be giving to Elizabeth White and Frederick Coville of New Jersey. They initiated a USDA-ARS breeding program in order to domesticate the wild blueberry producing desirable quality characteristics in the blueberry(Council, 2010). Georgia ranks 3rd in blueberry harvested acreage (7000 acres) and 7th in yield per acreage (4500lbs/ acres) in the United States (Statistics, 2006).

Growth and Development of the Southern Highbush Blueberry

There are great benefits for growing the southern highbush blueberry. Figure 1.1 shows a mature southern highbush blueberry plant. This type of blueberry is of higher quality and produces earlier than most blueberries. Depending on the variety of blueberry, the area of planting must be considered carefully. The blueberry fruit develops from a shrub that required a sandy high organic and acidic soil in order to develop properly. The pH of the soil should be between 4 and 5 and the organic matter should be >3 % (Scherm and Krewer, 2003, Wang et al., 2008, Krewer et al., 2007). The ambient temperature plays a key role in the fruit development of the plant. It must be in an environment in which the plant has enough cool weather to meet the chilling requirements of the cultivar. (Godoy et al., 2008). Planting is typically done on raised sandy beds to improve drainage. The width of the bed can be between 1.2 to 10.0 m and have approximately 1 to 6 rows per bed (Scherm and Krewer, 2003). The bed is about 14 inches deep not exceeding 30 inches above the surface. In Georgia, southern highbush blueberries are frequently grown in beds of only pine bark about six to eight inches deep (Krewer et al., 2007). Blueberries require 2.5-5 cm of water per week to be productive. However, excess water can be detrimental and proper drainage is important (Haman et al., 1988).

Figure 1.1. Sweet crisp southern highbush blueberry plant.

Chilling hours necessary are the number of winter temperature 45 ºF or lower that the plant must be exposed to for 90% of the buds to open and develop normally following a specific time period exposure to warm weather. Chilling hours varies depending on the cultivar. The estimated bloom date can be predicted from the chilling requirements. For bloom dates in South Georgia, chilling hours of 200-300 will bloom in mid February, 400-500 chill hours will bloom early March, and 600-800 chill hours will bloom late March. Chilling requirement information can be used to project relative bloom dates. For those cultivars needing less than 400 chill hours should not be planted in middle or north Georgia (Krewer and Nesmith, 2006).

Typical blueberry fields use fertilizers that make use of urea and ammonium sulfate as nitrogen fertilizers. One acre of land uses approximately 30 kg of nitrogen. The uptake of these chemicals comes about through the root system of the plants. The blueberry shrubs are also exposed to a variety of pre-emergent herbicides. Also, to control insects and pathogens, insecticides and fungicides are used that are approved by the U.S. Environmental Protection Agency(Wang et al., 2008).

There are many stages in the growth and development of southern highbush blueberries. The flower bud development stage initiates with bud scales on the stem and these buds begin to swell and separate and flowers are then visible. The leaf bud development begins when 1-5 mm of green leaf tissue in visible while still folded. Over time the leaves gradually unfold and grow to 6-13mm. Finally, the shoots expand and there is an increased size in the leaves (Williamson and Lyrene, 2004) .

The blueberry flower consists of corolla, a pistil and anthers. During the flower development stage, pinkish and white corolla tubes or petals are produced but are still closed.

The pistil extends to the end of the corolla with the anther is positioned in order for an insert, most commonly bees, to transfer the pollen to other flowers. After pollination it takes 45-120 days for the flower to develop (Williamson and Lyrene, 2004) .The individual flowers grow and separate while the corolla tubes expand. During early bloom some of the corolla tubes open. During full bloom, majority of the flowers on the plant are open. Soon after, the corollas begin to fall off revealing the small green fruit. The fruit development stage the green fruit begins to expand due to cell division followed by an increase in the embryo and endosperm growth. During this time the blueberry remains the same size. Finally, as shown in Figure 1.2 fruit begins ripen and change colors from a green to pink to blue.. Throughout the ripening stage, changes occur in acid, pH, sugar, and weight (Williamson and Lyrene, 2004)

Figure 1.2.Sweet Crisp blueberries at three different color phases; green, pink and blue.

A whole new generation of cultivars has been released that were bred for improved fruit quality, shelf stability, and extension of the fresh-market harvest season (Saftner et al., 2008). Highbush blueberry is a high priced small fruit crop increasingly cultivated because of its color, flavor and nutritional properties (Godoy et al., 2008). During the 1980s and 1990s, several blueberry cultivars with very firm texture were released from breeding programs. This texture can best be described as biting into an apple. In recent years, several other clones with crisp-textured berries have been planted in test plots in Florida (Padley, 2005). The perception of breeders at the start of these experiments led to a classification of "crispy" and "melting" flesh cultivars.

Nutritional Benefits of Blueberries

Knowledge about the health benefits of fruits has increased due to the widely publicized research findings and media. Research has shown that the consumption of foods that contain high amounts of phenolics may contribute to health and may decrease the risk of certain diseases such as cancer and heart disease (Brambilla et al., 2008, Gerard and Roberts, 2004, Schilling et al., 2007, Skrede et al., 2000) . Blueberries are distinguished by a high content in phenolic acids and their high antioxidant values (Brambilla et al., 2008, Strjanovic and Silva, 2007, Castrejon et al., 2008).

Antioxidants can stop or slow the oxidation process due to free radicals and reactive oxygen species in foods and biological systems (Heo et al., 2007). Phenolic compounds have been the main focus because they possess properties that can be related to human health. Phenolic compounds are second plant metabolites, which contributes to their antioxidant activities and free radical scavenging capabilities (Ma et al., 2008, Skrede et al., 2000, Strjanovic and Silva, 2007, Castrejon et al., 2008). Phenolic compounds are composed of an aromatic ring having one or more hydroxyl substituent. These compounds are effective antioxidants because the free radicals of these compounds are resonance stabilized by the aromatic rings (Mattila et al., 2006, Piljac-Zegarac et al., 2009, Hosseinian and Beta, 2007). Phenolic compounds consist of many organic and water soluble compounds shown in Figure 1.3, including anthocyanins, flavonols, and phenolic acids.

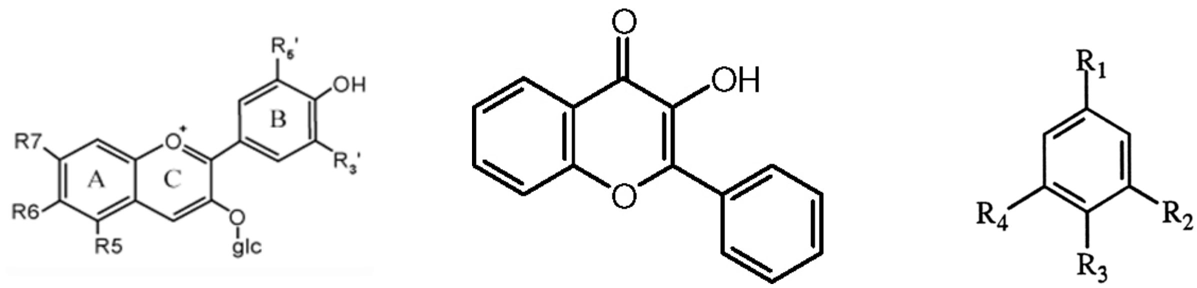


Figure 1.3. Basic chemical structures (left to right) of anthocyanin, flavonol, and phenolic acid

In fruit juices, ascorbic acid and water soluble polyphenols are the main antioxidants present that protect the components of the juice from oxidation (Su and Chien, 2007, Nicoue et al., 2007, Piljac-Zegarac et al., 2009).

Sensory Evaluation

Sensory evaluation has played a key role of any product that is to be consumed by humans. Sensory evaluation is involved in many stages in a products cycle including the research and development of the product, product maintenance, product improvement, and the assessment of the products market potential (Sidel and Stone, 1993) . The classical definition as described by (Sidel and Stone, 1993, Dijksterhuis, 1995) is as follows;

> "Sensory evaluation is a scientific discipline used to evoke, measure, analyze, and interpret reactions to those characteristics of products or materials as they are perceived by the senses of sight, smell, taste, touch and hearing."

Sensory evaluation is responsible for providing vital information in regards to the raw materials, design of the product and the manufacturing process (Zeng et al., 2008) . It also provides a service for the food industry. The service methods are separated by categories such as discriminative, descriptive, and consumer. Each of these methods has specific requirements for qualifying subjects and assessment of the responses (Sidel and Stone, 1993).

Sensory attributes of the evaluation of a food product is perceived by human subjects used as instrumentation in the order of appearance, aroma or odor, texture or consistency, and flavor profile that includes aromatics tastes, and chemical feel (Meilgaard *et al.*, 2007b). Using human subjects or panelist involves many factors including the variability in responses to the same stimulus, fatigue, and knowledge of certain attributes. In order to minimize these factors, a panel leader must train each panelist with the use of references and definitions (Elortonso *et al.*, 2007) . Panelists need detailed instructions in regards to how to handle the product, how to mark their responses, and what information is gained from the testing. There are three types of panelist; untrained, trained, and experienced. The type of testing methods used will determine which type of panelist will be used. An untrained panelist is those that have no exposure to specific training in sensory evaluation. Trained panelists are those that were recruiter to evaluate certain descriptors for a particular product. An experiences panelist has had previous training and receives less training time and is familiar with the sensory evaluation process (Meilgaard *et al.*, 2007b).

When evaluation a product, such as blueberries you must focus on the key factors that are important. These factors may vary depending on the overall goal of the study. In Cuneo Province, ONA. Frut primarily deals with fruit sensory evaluation. They use a panel of trained tasters to provide technical information to get a comprehensive descriptions and characterizations of a variety of fruits. The evaluations are useful to improve the value of the production and to inform the consumers of the fruit quality at harvest, storage, and shelf (Mellano *et al.*, 2009). Tasters develop a list of attributes by describing samples from different cultivars of blueberries and agree on a consensus list of attributes for profiling and on the definition. The descriptors are simple and definitions easy for the panel as a whole to fully understand. Typical qualities that are evaluated for blueberries include firmness, juiciness, and color. The firmness of blueberries is an important sensory characteristic in determining quality of the fruit. Color is another quality factor influencing fresh market value and the suitability of the blueberries for processing (Rosenfeld et al., 1999,(Silva *et al.*, 2005). The basic tastes of sweet, sour, and bitter and astringency are also important when determining blueberry flavor. (find more references)

Radio frequency

The application of radio frequency (RF) by the food industry has mainly been focused on cooking, defrosting, thawing, drying, pasteurization, and sterilization of food products (Marra *et al.*, 2009). During processing, RF has been used to improve time management, uniformity of heat, and quality. The mechanism behind radio frequency or dielectric heating function involves electromagnetic energy transmitted throughout a product. The product is passed through two metal capacitors which are alternatively charged positively and negatively by a high frequency alternating electrical field. As the electromagnetic energy enters the product friction is generated due to rapid molecular rotation of the polar molecules aligning themselves with the polarity of the electrical field within the product The polarity of electric field changes about 27 million times in a second for 27.12 MHz causing fluctuation of ions in the product and produces heat (Marra *et al.*, 2007). RF falls in the electromagnetic spectrum between 1-300MHz (Figure 1.5). Although the main frequencies for radio frequency used for industrial, scientific, medical, and domestic heating purposes are restricted to13.56, 27.12 and 40.68MHz (Awuah *et al.*, 2007).

The dielectric properties can explain the absorption and distribution of electromagnetic energy. Given that foods are non-magnetic materials, permittivity (ε, complex permittivity) is the parameter that differentiates their interface with the electromagnetic field. Permittivity can be expressed as

$$\varepsilon = \varepsilon' - j\varepsilon'' \qquad (1.1)$$

when , j = √-1 and where, ε′ represents the dielectric constant of individual materials and remains the same regardless at a specific frequency under constant conditions. Dielectric constant is the ability of a material to store energy from the electric field. Dielectric loss factor (ε″, the imaginary part of the complex permittivity) is a measure of energy loss due to energy absorption and heat generation in the material moving through the electrical energy field. Materials with high values of dielectric loss factor will absorb energy at a quicker rate than materials with lower loss factors. The tangent of the dielectric loss angle (tan δ) is called loss tangent or dissipation factor of the material. It is represented by the following equation:

$$\tan\delta = \varepsilon''/\varepsilon' \qquad (1.2)$$

This is defined as the ratio of dielectric loss factor (ε″) and dielectric constant (ε′) (Birla *et al.*, 2008).

The dielectric properties (DP) of food materials effects how it is heated using the radio frequency. RF heating characteristics of fruits are not only influenced by DPs but also by fruit shape and size, the surrounding medium, and relative distance between fruit and the two electrodes (Birla et al., 2008). Radio frequency heating is more appropriate for materials of regular shapes of great dimensions and offering high loss factor (Awuah et al., 2007). In foodstuff, water and salt are the two major ingredients that influence dielectric properties. Other food components usually have an insignificant influence on the dielectric properties. The dielectric properties are also conditional on whether the electric field is oriented perpendicular or parallel to the fibrous matrix of a food matter. Arcing is an electrostatic discharge as charges jump from one point to another point via dielectric breakdown (Parker *et al.*, 2004). Arching is a major problem that could arise during RF processing.

Research Objectives

The objective of the research is to determine the effect of “melting” and “crisp” flesh types as well as hand and machine harvest methods on the sensory quality of southern highbush blueberries. In addition, the evaluate the effect of radio frequency treatment of southern highbush blueberries on juice yield, total phenolic content, and antioxidant capacity .

REFERENCES

AGENTS, G.C.E.C. 2009. 2009 Georgia Farm Gate Value Report. In pp. 1-187, University of Georgia.

AWUAH, G.B., RAMASWAMY, H.S. and ECONOMIDES, A. 2007. Thermal Processing and Quality: Principles and Overview. *Chemical Engineering and Processing* **46**, 584-602.

BIRLA, S.L., WANG, S., TANG, J. and TIWARI, G. 2008. Characterization of Radio Frequency Heating of Fresh Fruits Influenced by Dielectric Properties. *Journal of Food Engineering* **89**, 390-398.

BRAMBILLA, A., LO SCALZO, R., BERTOLO, G. and TORREGGIANI, D. 2008. Steam-Blanched Highbush Blueberry (*Vaccinium corymbosum* L.) Juice:Phenolic Profile and Antioxidant Capacity in Relation to Cultivar Selection. *Journal of Agricultural and Food Chemistry* **56**, 2643-2648.

CASTREJON, A., EICHHOLZ, I., ROHN, S., KROH, L. and HUYSKENS-KEIL, S. 2008. Phenolic Profile and Antioxidant Activity of Highbush Blueberry (*Vaccinium corymbosom* L.) During Fruit Maturation and Ripening. *Food Chemistry* **109**, 564-572.

COUNCIL, B.$_{T.}$U.S.H.B. 2010. <http://www.blueberrycouncil.com/about-production.php> (accessed March 18, 2010).

DIJKSTERHUIS, G. 1995. Multivariate Data Analysis in Sensory and Consumer Science: An Overview of Developments. *Trends in Food Science & Technology* **6**, 206-211.

ELORTONSO, F.J.P., OJEDA, M., ALBISU, M., SALMERON, J., ETAYO, I. and MOLINA, M. 2007. Food Quality Certification: An Approach for the Development of Accredited Sensory Evaluation Methods. *Food Quality and Preference* **18**, 425-439

GERARD, K.A. and ROBERTS, J.S. 2004. Microwave Heating of Apple Mash to Improve Juice Yield and Quality. *Lebensm Wiss Technology* **37**, 551-557.

GODOY, C., MONTERUBBIANESI, G. and TOGNETTI, J. 2008. Analysis of Highbush Blueberry (*Vaccinium corymbosum* L.) Fruit Growth with Exponential Mixed Models. *Scientia Horticulturae* **115**, 368-376.

HAMAN, D.Z., SMAJSTRLA, A.G. and LYRENE, P.M. 1988. Blueberry Response to Irrigation and Ground Cover. *Selected Proceedings of the Florida State Horticultural Society* **101**, 238-241.

HEO, H.J., KIM, Y.J., CHUNG, D. and KIM, D. 2007. Antioxidant capacities of individual and combined phenolics in a model system. *Food Chemistry* **104**, 87-92.

HOSSEINIAN, F. and BETA, T. 2007. Saskatoon and Wild Blueberries Have Higher Anthocyanin Contents than Other Manitoba Berries. *Journal of Agricultural and Food Chemistry* **55**, 10832-10838.

KREWER, G., CLINE, B. and NESMITH, D.S. 2007. Southeast Regional Blueberry Horticulture and Growth Regulator Guide. In, The Southern Region Small Fruit Consortium.

KREWER, G. and NESMITH, D.S. 2006. Blueberry Cultivars for Georgia. In, The Southern Region Small Fruit Consortium.

MA, Y., CHEN, J., LIU, D. and YE, X. 2008. Effects of Ultrasonic Treatment of Total Phenolic and Antioxidant Activity of Extracts from Citrus Peel. *Journal of Food Science* **73**, T115-T120.

MARRA, F., LYNG, J., ROMANO, V. and MCKENNA, B. 2007. Radio Frequency Heating of Foodstuff: Solution and Validation of a Mathematical Model. *Journal of Food Engineering* **79**, 998-1006

MARRA, F., ZHANG, L. and LYNG, J. 2009. Radio Frequency Treatment of Foods: Review of Recent Advances. *Journal of Food Engineering* **91**, 497-508.

MATTILA, P., HELLSTROM, J. and TORRONEN, R. 2006. Phenolic Acids in Berries, Fruits and Beverages. *Journal of Agricultural and Food Chemistry* **54**, 7193-7199.

MEILGAARD, M.C., CIVILLE, G.V. and CARR, B.T. 2007. *Sensory Evaluation Techniques*. CRC Press, Boca Raton.

MELLANO, M.G., CARLI, C., FOLINI, L., DRAICCHIO, P. and BECCARO, G. 2009. Training of Two Groups of Tasters for the Creation of Sensory Profiles of Highbush Blueberry Cultivars Grown in Northern Italy. *Acta Horticulturae* **810**, 835-840.

NICOUE, E., SAVARD, S. and BELKACEMI, K. 2007. Anthocyanins in Wild Blueberries of Quebec: Extraction and Identification. *Journal of Agricultural and Food Chemistry* **55**, 5

PADLEY, L. 2005. Firmness and Storage Characteristics of Crisp-Textured Blueberries. In *Horticulural Science*, Vol Master of Science pp. 88, University of Florida, Gainesville.
626-5635.

PARKER, J., REATH, M., KRAUSS, A. and CAMPBELL, W. 2004. Monitoring and Preventing Arc-Induced Wafer Damage in 300mm Manufacturing. *Intergrated Circuit Design and Technology*, 131-134.

PILJAC-ZEGARAC, J., VALEK, L., MARTINEZ, S. and BELSCAK, A. 2009. Fluctuations in the Phenolic Conrent and Anitioxidant Capacity of Dark Fruit Juices in Refrifgerated Storage. *Food Chemistry* **113**, 394-400.

SAFTNER, R., POLASHOCK, J., EHLENFELDT, M. and VINYARD, B. 2008. Instrumental and Sensory Qualities Characteristics of Blueberry Fruit from Twelve Cultivars. . *Postharvest Biology & Technology* **49**, 19-26.

SCHERM, H. and KREWER, G. 2003. Blueberry Production in Georgia: Historical Overview and Recent Trends. *Small Fruits Review* **2**, 83-91.

SCHILLING, S., ALBER, T., TOEPFL, S., NEIDHART, S., KNORR, D., SCHIEBER, A. and CARLE, R. 2007. Effects of Pulsed Electric Field Treatment of Apple Mash on Juice Yield and Qulaity Attributes of Apple Juices. *Innovative Food Science and Emerging Technologies* **8**, 127-134.

SIDEL, J.L. and STONE, H. 1993. The Role of Sensory Evaluation in the Food Industry. *Food Quality and Preference* **4**, 65-73.

SILVA, J.L., MARROQUIN, E., MATTA, F.B., GARNER JR, J.O. and STOJANOVIC, J. 2005. Physicochemical, Carbohydrate and Sensory Characteristics of Highbush and Rabbiteye Blueberry Cultivars. *Journal of Science of Food and Agriculture* **85**, 1815-1821.

SKREDE, G., WROLSTAD, R.E. and DURST, R.W. 2000. Changes in Anthocyanins and Polyphenolics During Juice Processing of Highbush Blueberries (*Vaccinium corymbosum* L.) *Journal of Food Science* **65**, 357-364.

STATISTICS, U.N.A. 2006. 2006 Blueberry Statistics. http://www.nass.usda.gov/Statistics_by_State/New_Jersey/Publications/Blueberry_Statistics/2006Blueberries.pdf (accessed March 18, 2010).

STRIK, B. and YARBOROUGH, D. 2005. Comprehensive Crop Report. *Horticulture Tecnology* **15**, 391-398.

STRJANOVIC, J. and SILVA, J. 2007. Influence of Osmotic Concentration, Continuous High Frequency Ultrasound and Dehydration on Antioxidants, Colour and Chemical Properties of Rabbiteye Blueberries. *Food Chemistry* **101**, 898-906.

SU, M. and CHIEN, P. 2007. Antioxidant Activity, Anthocyanins, and Phenolics of Rabbiteye Blueberries (*Vaccinium ashei)* Fluid Products as Affected by Fermentation. *Food Chemistry* **104**, 182-187

WANG, S., CHEN, C., SCIARAPPA, W., WANG, C. and CAMP, M. 2008. Fruit Quality, Antioxidant Capacity, and Flavonoid Content of Organically and Conventionally Grown Blueberries. *Journal of Agricultural and Food Chemistry* **56**, 5788-5794.

WILLIAMSON, J.G. and LYRENE, P.M. 2004. Reproductive Growth and Development of Blueberry. edis.ifas.ufl.edu/pdffiles/HS/HS22000.pdf (accessed.

ZENG, X., RUAN, D. and KOEHL, L. 2008. Intelligent Sensory Evaluation: Concepts, Implementations, and Applications. *Mathematics and Computer Simulation* **77**, 443-452.

CHAPTER 2

SENSORY EVALUATION OF SOUTHERN HIGHBUSH BLUEBERRIES[1]

[1] [1] Smith, K.C. and Shewfelt, R.L.To be submitted to *Journal of Food Quality*

Abstract

Sensory quality characteristics were evaluated by trained sensory panelists on blueberry fruit from several highbush (*V. corymbosum* interspecific hybrid) cultivars 'Sweet Crisp', 'Farthing' , FL-98-325, FL-05-290, 'Meadowlark' described as "crisp flesh" , and 'Star', 'Scintilla', 'Primadonna', FL-05-486, and FL-01-234 describes as "melting flesh" grown in Florida.. The descriptors include sweetness, sourness, bitterness, blueberry-like flavor, astringency, firmness, crispness, and juiciness (moisture release). Cultivars varied in sensory intensity of different descriptors. The only consistent finding across treatments was that the "crispy" flesh selections were clearly crispier than the "melting" flesh counterparts. These results suggest that consumer acceptability of "crisp" blueberries will be on the basis of texture.

Introduction

There has been an increased in consumption of fresh blueberries in the last two decades. Consumers demand high quality fruit, which is dependent on cultivar characteristics as well as the postharvest handling of the fruit (Allan-Wojtas et al., 2001). Differences in cultivar, environment, and handling methods can result in a range of flavor and texture profiles. The performance level of a descriptive panel of assessors and the quality of the data they provide is of vital importance for making appropriate research and business decisions.

There is a vast amount of research on instrumental quality characteristics of highbush and rabbiteye blueberries. However, there limited publications regarding their sensory characteristics. More recent sensory evaluations of fresh highbush and rabbiteye blueberries found no differences in fruit color, flavor or skin toughness between three rabbiteye and two highbush cultivars (Silva *et al.*, 2005). A previous study established that temperature and packaging film type affected sensory scores for texture and blueberry flavor of stored fruit from the highbush cultivar (Rosenfeld *et al.*, 1999). For a successful analysis, it is important to have a set of strong tools for monitoring individual assessor performances as well as the panel as a whole (Kermit and Leugard, 2006). The objective of the study was to determine the effect of “melting” and “crisp” flesh types as well as hand and machine harvest methods on the sensory quality of southern highbush blueberries.

Materials and Methods

Panel Training

Sensory panel training was performed twice in 2009 and 2010. In 2009, nine panelists from the University of Georgia Food Science and Technology Department were trained to evaluate descriptive characteristics over a period of nine training sessions over 12 weeks lasting between 1- 3 hours. The panelists were given lexicons of pre-determined descriptors developed by the panel leader. These attributes included the followings: blue color intensity, blueberry like flavor, sweetness, sourness, bitterness, astringency, crispness, firmness, and moisture release. The clarification of blueberry like flavor was agreed within the panel to establish a standard with the use of store bought blueberries. The other attributes were defined based on previous studies (Chauvin *et al.*, 2008, Meilgaard *et al.*, 2007a, Childs *et al.*, 2007, Murray *et al.*, 2001). In 2010, eight panelists were trained over 7 training. There were 6 new and 2 returning panelists. The same attributes were used except for moisture release which was changed to juiciness.

The quantitative descriptive testing utilized sensory sheets for evaluation shown in Figure 2.1 (Saftner *et al.*, 2008). The reference solutions prepared included cane sugar (Walmart Stores, Inc, Bentonville, AR) for sweetness, citric acid (Science Lab.com, Inc, Houston, TX) for sourness, caffeine (Science Lab.com, Inc, Houston, TX) for bitterness, and alum (McCormick and Co., Inc., Huntvalley, MD) for astringency (Meilgaard *et al.*, 2007a, Okayasu and Naito, 2001). Blueberry-like flavor standard was developed by the panel. They agreed that a mark of 7 on the scale would indicate the typical blueberry-like flavor. Table 2.1 indicates the descriptors, definitions, and references.

Sensory Evaluation

In 2009, southern highbush blueberries were hand and machine harvested from Alto Straughn Farms and Chip and Dale Farm in Waldo, FL during April. The blueberries were transported in a refrigerated trailer 14º C for approximately 160 miles then to be hand sorted using an air blower, slant table, and evaluation table at the UGA Alapaha Blueberry Research

Farm, Alapaha, GA. Fruit were then packaged into clamshells before being returned to the refrigerated trailer for subsequent transport to the testing location. Panel evaluation was conducted in a controlled sensory panel room (20°C) containing partitioned booths equipped with fluorescent lights at the Food Processing Research and Development Laboratory of the Department of Food Science and Technology at the University of Georgia, Athens, GA. The blueberries were divided into flesh types, "crisp" ('Sweet Crisp', 'Farthing', FL-98-325, FL-05-290,) and melting ('Star', 'Primadonna', 'Scintilla', and FL-05-486.) and harvest types (hand and machine). In 2010, southern highbush blueberries were hand and machine harvested in Waldo, FL during May. Harvest and transport were similar to the 2009 crop. The blueberries were divided into two categories "crisp" flesh ('Sweet Crisp', 'Farthing', 'Meadowlark' and "melting" flesh ('Star', 'Scintilla', and FL-01-234) and harvest types (hand and machine).

Statistical Analysis

Analysis of Variance (ANOVA) was performed to determine significant difference between treatments for each of the assays performed. An alpha level p-value <0.05 was used in 'the analysis.

Results

The 2009 results (Table 2.2) within the "crispy" flesh type indicate that 'Sweet Crisp' was the darkest, firmest berry when compared with the other "crisp" flesh types. FL 98-325 was the least sour but also demonstrated the least moisture release while 'Farthing 'showing the greatest moisture release. Within the "crisp" flesh blueberries the descriptors of sweetness, bitterness, astringency, blueberry-like flavor, and crispness there were no significant differences. Within the "crisp" flesh type, the hand-harvested fruit exhibited more blueberry-like flavor, crispness and firmness when compared to the mechanically harvested blueberries. There were no significant differences in the other descriptors when comparing harvest methods.

Within the “melting” flesh type results show that ‘Primadonna’ was the least sour of the four selections but was also least blueberry-like in flavor, least crispy, and released the least moisture. The greatestt moisture release was found in ‘Scintilla’, but this cultivar along with FL05-486 had the least blue color intensity. All other descriptors between the “melting” flesh types showed that there were no significant differences. The mechanically harvested, “melting” flesh blueberries were darker in color and less firm than hand-harvested fruit.

There were only significant differences between the “melting” group and the “crisp” group with respect to color and firmness. The “crisp” flesh blueberries were darker and firmer than their “melting” flesh counterparts. The-hand harvested blueberries were firmer with a higher moisture release, but the mechanically harvested blueberries were darker in blue color (Table 2.3). For the response crisp (Table 2.4), the interaction was significant. The “crisp” flesh blueberry when hand harvested was significantly crispier compared with mechanical harvesting. The “melting” flesh showed no significant difference in crispness from either harvest method, but the “crisp” flesh fruit was clearly crispier than the “melting” selections.

Results from 2010 (Table 2.5) indicate that within the “crisp” flesh type that ‘Sweet Crisp’ was sweeter, fuller in flavor, crispier and firmer than the other crispy flesh types. ‘Meadowlark’ was the least sweet and demonstrated the least blueberry-like flavor the least firm and least crisp. There were no significant differences for the additional descriptors for the “crisp” flesh types. When comparing harvest methods, the mechanically harvested berries were darker in color than the hand-harvested.

Within the “melting” flesh type, ‘Star’ was the darkest, sweetest but was lower in blueberry-like flavor while ‘Scintilla’ having the most blueberry-like flavor. There was no indication of any significant difference within the “melting” flesh type in regards to the other descriptors. Evaluation of the harvest methods showed the hand-harvested berries were crispier and firmer compared with the mechanically harvested berries.

There was significant difference between the melting group and the crisp group in 2010 with respect to firmness. The “crisp” flesh blueberries were firmer in comparison to the “melting” flesh. The harvest methods did show any significant differences. (Table 2.6). For the response crisp and color (Table 2.7), the interaction effect was significant. The difference between the two harvest types is not significant for the crispy group for color or crisp descriptors. The “melting” flesh blueberries when hand harvested were crispier than mechanically harvested, and the “crisp” flesh berries were clearly crispier than the “melting” type.

Discussion

Harvest methods in both years demonstrated different scores of the descriptors from season to season. The “crisp” flesh blueberries mechanically harvested resulting tin better quality than its counterpart “melting flesh” blueberries each year. When looking at the blueberries in one group, the blueberries within the “crisp” flesh group showed during the 2009 season blueberry-like flavor, crispness, and firmness were affected most by the machine harvester. This observation indicates that the characteristics of the blueberry were not of equal measures to those blueberries hand-picked. The 2010 season results indicate that sweetness, blueberry-like flavor, crispness, and firmness also varied between the cultivars similar to the

2009 season. However, the 2010 harvest methods indicate a difference in the blueberry-like flavor and no difference in the other descriptors the blueberries from the crisp group. The 2010 harvest indicated that the “crisp” flesh blueberries mechanically harvested were comparable to those hand-picked.

The blueberries within the “melting” flesh group showed during the 2009 season color, and firmness were affected most by the machine harvester indicating that the characteristics of the blueberry were not of equal measures to those blueberries hand-picked. The hand-picked blueberries were firmer than the machine harvested. The 2010 season results indicate that crispness and firmness also varied between the cultivars similar to the 2009 season. It was shown that the “melting” flesh blueberries are not able to be mechanically harvested and maintain the same textural quality as if hand harvested.

The panel was able to successfully confirm the difference in the textural characteristics of firmness and crispness that distinguishes certain blueberries to be known as a “crisp” or “melting” flesh blueberry. These descriptors should be useful for the selection of superior blueberries. This is important with the increase rise in labor cost of blueberry production. The development of a blueberry that is equivalent to traditional blueberries that will be able to withstand a machine harvest will reduce the cost and time of blueberry production to keep up with consumer demand for fresh blueberries. The most significant finding was that the “crispy” flesh selections were clearly crispier than the “melting” flesh counterparts and comparable in all other sensory characteristics. These results suggest that if crispness of these new selections is acceptable to consumers, they should be able to replace other popular selections.

Table 2.1. Sensory descriptors, definitions and reference used for evaluation of southern highbush blueberries.

Descriptor	Definition	Reference
Sweetness	The taste stimulated by sucrose, glucose, or fructose.	Cane Sugar (Walmart Stores, Inc, Bentonville, AR) Intensity 5
Sourness	The taste stimulated by acids such as citric, malic, and phosphoric	Citric Acid (Science Lab.com, Inc, Houston, TX) Intensity 2
Bitterness	The taste stimulated by substances such as caffeine and hops	Caffeine (Science Lab.com, Inc, Houston, TX) Intensity 2
Blueberry Like Flavor	The expected flavor associated when consuming a blueberry	NA
Astringency	The shrinking or puckering of the tongue surface caused by substances such as tannins or alum	Alum (McCormick and Co., Inc., Huntvalley, MD) Intensity 2
Crispness	The force and sound (pitch)with which a sample breaks and fractures on the 1st and 2nd chew	Club Cracker Intensity 5
Firmness	The force required to fracture sample between molars	Hard Boiled Egg White Intensity 2.5 (2009) Queen Size Olives without pimento Intensity 6 (2010)
Moisture Release (Juiciness)	The quantity of juice released by the sample when chewed up to 5 times	Cucumber Intensity 8
Blue Color	The blue color intensity from light to very dark	Light=1 Light Medium=4 Medium= 7.5 Medium Dark= 11 Dark= 14

Panelist_______________ Sample____________________

Please rinse mouth with water and cracker between each sample. Taste the blueberry and mark the line for intensity of each characteristic below. The middle line is the standard.

Sweetness

____

| | |

slight intense

Please evaluate the blueberry texture and mark the line that best describes the product from each characteristic below. The middle line is the standard.

Crispness

____

| | |

soggy very crisp

Please evaluate the blueberry appearance and mark the line that best describes the product from the characteristic below.

Color Intensity

____

| |

light dark

Figure 2.1. Example of a quantitative descriptive ballot

Table 2.2. 2009 Summary of quantitative descriptive analysis means for a variety of southern highbush blueberry selections.

Crisp Selections	Color	Sweet	Bitter	Sour	Astringent	Flavor	Crisp	Firm	Moisture
Sweet Crisp	9.78 [a]	4.09 [a]	1.53 [a]	3.90 [a]	1.31 [a]	6.94 [a]	3.44 [a]	4.08 [a]	6.83 [ab]
Farthing	7.90 [b]	3.40 [a]	1.43 [a]	3.83 [a]	1.21 [a]	6.74 [a]	3.01 [a]	3.29 [ab]	7.61 [a]
FL 98-325	8.03 [b]	4.40 [a]	1.21 [a]	1.22 [b]	0.74 [a]	5.29 [a]	3.18 [a]	3.44 [ab]	6.12 [b]
FL-05-290	9.12 [ab]	3.57 [a]	1.58 [a]	2.93 [a]	1.18 [a]	5.43 [a]	2.82 [a]	3.07 [b]	6.67 [ab]
Harvest Type									
Crisp Cultivars	Color	Sweet	Bitter	Sour	Astringent	Flavor	Crisp	Firm	Moisture
Hand	8.96 [a]	3.90 [a]	1.47 [a]	3.15 [a]	1.17 [a]	6.62 [a]	3.49 [a]	3.74 [a]	7.15 [a]
Mechanical	8.46 [a]	3.83 [a]	1.40 [a]	2.97 [a]	1.04 [a]	5.58 [b]	2.74 [b]	3.18 [b]	6.46 [a]
Melting Selections	Color	Sweet	Bitter	Sour	Astringent	Flavor	Crisp	Firm	Moisture
Star	9.28 [a]	4.34 [a]	1.09 [a]	3.46 [a]	1.10 [a]	7.40 [a]	2.11 [ab]	3.21 [a]	7.12 [ab]
Primadonna	8.61 [a]	4.12 [a]	1.14 [a]	1.78 [b]	0.861 [a]	4.72 [b]	1.97 [b]	2.39 [a]	5.94 [b]
Scintilla	7.28 [b]	4.35 [a]	1.24 [a]	3.69 [a]	1.22 [a]	7.06 [a]	2.33 [ab]	3.01 [a]	7.57 [a]
FL 05-486	7.28 [b]	3.58 [a]	1.22 [a]	2.69 [ab]	0.972 [a]	6.08 [ab]	2.82 [a]	2.93 [a]	6.78 [ab]
Harvest Type									
Melting Cultivars	Color	Sweet	Bitter	Sour	Astringent	Flavor	Crisp	Firm	Moisture
Mechanical	8.49 [a]	4.23 [a]	1.20 [a]	2.76 [a]	1.03 [a]	6.19 [a]	2.27 [a]	2.56 [b]	6.61 [a]
Hand	7.73 [b]	3.96 [a]	1.15 [a]	3.05 [a]	1.04 [a]	6.44 [a]	2.35 [a]	3.21 [a]	7.10 [a]

Means for each descriptor within a column not followed by the same letter are significantly different ($p<0.05$)

Table 2.3. 2009 Quantitative descriptive analysis of southern highbush blueberry selection by flesh type and harvest method.

Blueberry Flesh Type	Color	Sweet	Bitter	Sour	Astringent	Flavor	Firm	Crisp	Moisture
Crisp	8.71 [a]	3.87 [a]	1.44 [a]	2.97 [a]	1.11 [a]	6.31 [a]	3.47 [a]	N/A	6.85 [a]
Melting	8.11 [b]	4.10 [a]	1.17 [a]	2.91 [a]	1.04 [a]	6.10 [a]	2.88 [b]	N/A	6.81 [a]
Harvest Method									
Hand	8.09 [b]	4.07 [a]	1.31 [a]	3.10 [a]	1.11 [a]	6.53 [a]	3.49 [a]	N/A	7.12 [a]
Mechanical	8.73 [a]	3.90 [a]	1.30 [a]	2.78 [a]	1.04 [a]	5.88 [a]	2.87 [b]	N/A	6.54 [b]

N/A: Due to the significance of the interaction. Therefore these effects were examined with other variables

Table 2.4. 2009 Descriptor crispness by blueberry flesh type and harvest methods.

Crisp		
	Melting Group	Crisp Group
Harvest Method		
Hand	2.34 [a]	3.49 [a]
Mechanical	2.27 [a]	2.74 [b]

Table 2.5. 2010 Summary of quantitative descriptive analysis means for a variety of southern highbush blueberry selections.

Crisp Selections	Color	Sweet	Bitter	Sour	Astringent	Flavor	Crisp	Firm	Moisture
Sweet Crisp	9.22 ^{a}	4.39 ^{a}	0.734 ^{a}	2.23 ^{a}	1.67 ^{a}	7.50 ^{a}	4.25 ^{a}	4.45 ^{a}	6.69 ^{a}
Farthing	9.14 ^{a}	3.89 ^{ab}	1.02 ^{a}	1.89 ^{a}	1.41 ^{a}	6.73 ^{ab}	3.03 ^{b}	3.84 ^{ab}	6.81 ^{a}
Meadowlark	8.84 ^{a}	3.09 ^{b}	1.02 ^{a}	1.47 ^{a}	1.48 ^{a}	6.11 ^{b}	2.48 ^{b}	3.45 ^{b}	6.69 ^{a}
Harvest Type									
Crisp Cultivars	Color	Sweet	Bitter	Sour	Astringent	Flavor	Crisp	Firm	Moisture
Hand	8.59 ^{b}	3.68 ^{a}	0.927 ^{a}	1.91 ^{a}	1.44 ^{a}	6.72 ^{a}	2.95 ^{a}	3.89 ^{a}	6.82 ^{a}
Mechanical	9.52 ^{a}	3.91 ^{a}	0.917 ^{a}	1.82 ^{a}	1.59 ^{a}	6.84 ^{a}	3.56 ^{a}	3.94 ^{a}	6.63 ^{a}
Melting Selections	Color	Sweet	Bitter	Sour	Astringent	Flavor	Crisp	Firm	Moisture
Star	9.27 ^{a}	4.31 ^{a}	0.75 ^{ab}	1.91 ^{a}	1.31 ^{a}	6.67 ^{b}	1.84 ^{a}	2.91 ^{a}	6.16 ^{a}
Scintilla	8.28 ^{b}	3.61 ^{b}	0.66 ^{b}	1.67 ^{a}	1.67 ^{a}	8.06 ^{a}	1.95 ^{a}	2.78 ^{a}	6.50 ^{a}
FL 01-234	9.75 ^{ab}	3.67 ^{b}	1.23 ^{a}	1.50 ^{a}	1.98 ^{a}	6.28 ^{b}	1.81 ^{a}	2.39 ^{a}	5.81 ^{a}
Harvest Type									
Melting Cultivars	Color	Sweet	Bitter	Sour	Astringent	Flavor	Crisp	Firm	Moisture
Mechanical	8.94 ^{a}	4.23 ^{a}	0.802 ^{a}	1.74 ^{a}	1.56 ^{a}	7.02 ^{a}	1.62 ^{b}	2.37 ^{b}	6.30 ^{a}
Hand	9.26 ^{a}	3.96 ^{a}	0.958 ^{a}	2.00 ^{a}	1.75 ^{a}	6.99 ^{a}	2.11 ^{a}	3.01 ^{a}	6.01 ^{a}

Means for each descriptor within a column not followed by the same letter are significantly different ($p<0.05$)

Table 2.6. 2010 Compared quantitative descriptive analysis of southern highbush blueberry selection by flesh type and harvest method.

Blueberry Flesh Type	Color	Sweet	Bitter	Sour	Astringent	Flavor	Firm	Crisp	Juiciness
Crisp	N/A	3.79 [a]	0.922 [a]	1.86 [a]	1.52 [a]	6.78 [a]	3.91 [a]	N/A	6.73 [a]
Melting	N/A	4.03 [a]	0.880 [a]	1.87 [a]	1.66 [a]	7.00 [a]	2.69 [b]	N/A	6.15 [a]
Harvest Method									
Hand	N/A	3.97 [a]	0.943 [a]	1.95 [a]	1.60 [a]	6.85 [a]	3.45 [a]	N/A	6.56 [a]
Mechanical	N/A	3.85 [a]	0.859 [a]	1.78 [a]	1.58 [a]	6.93 [a]	3.16 [a]	N/A	6.32 [a]

N/A: Due to the significance of the interaction. Therefore these effects were examined with other variable

Table 2.7. 2010 descriptor crispness by blueberry flesh type and harvest methods.

Crisp			Color	
	Melting Group	Crisp Group	Melting Group	Crisp Group
Harvest Method				
Hand	2.11 [a]	2.95 [a]	9.26 [a]	8.59 [a]
Mechanical	1.62 [b]	3.56 [a]	8.94 [a]	9.52 [a]

REFERENCES

ALLAN-WOJTAS, P.M., FORNEY, C.F., CARBYN, S.E. and NICHOLAS, K.U.K.G. 2001. Microstructural Indicators of Quality-Related Characteristics of Blueberries-An Intergrated Approach. *Lebensm Wiss Technology* **34**, 23-32.

CHAUVIN, M., YOUNCE, F., ROSS, C. and SWANSON, B. 2008. Standard Scales for Crispness, Crackliness, and Crunchiness in Dry and Wet Foods: Relationship with Acoustical Determination. *Journal of Texture Studies* **39**, 345-368.

CHILDS, J., YATES, M. and DRAKE, M. 2007. Sensory Properties of Meal Replacement Bars and Beverages Made from Whey and Soy Proteins. . *Journal of Food Science* **72**, S425-S434.

GODOY, C., MONTERUBBIANESI, G. and TOGNETTI, J. 2008. Analysis of Highbush Blueberry (*Vaccinium corymbosum* L.) Fruit Growth with Exponential Mixed Models. *Scientia Horticulturae* **115**, 368-376.

KERMIT, M. and LEUGARD, V. 2006. *Assessing the Preformance of Sensory Panel Panelist Monitoring and Tracking*. CAMO Process AS, Oslo.

MEILGAARD, M., CIVILLE, G. and AND CARR, B. 2007a. *Sensory Evaluation Techniques*. CRC Press LLC, Boca Rotan.

MEILGAARD, M.C., CIVILLE, G.V. and CARR, B.T. 2007b. *Sensory Evaluation Techniques*. CRC Press, Boca Raton.

MURRAY, J., DELAHUNTY, C. and BAXTER, I. 2001. Descriptor Sensory Analysis:Past, Present, and Future. . *Food Research International* **34**, 461-471.

OKAYASU, H. and NAITO, S. 2001. Sensory Characteristics of Apple Juice Evaluated by Consumer and Trained Panels. *Journal of Food Science* **66**, 1025-1029.

PADLEY, L. 2005. Firmness and Storage Characteristics of Crisp-Textured Blueberries. In *Horticulural Science*, Vol Master of Science pp. 88, University of Florida, Gainesville.

ROSENFELD, H.J., MEBERG, K.R., HAFFNER, K. and SUNDELL, H.A. 1999. MAP of Highbush Blueberries: Sensory Quality in relation to Storage Temperature, Film Type, and Initial High Oxygen Atmosphere. *Postharvest Biology & Technology* **16**, 27-36.

SAFTNER, R., POLASHOCK, J., EHLENFELDT, M. and VINYARD, B. 2008. Instrumental and Sensory Qualities Characteristics of Blueberry Fruit from Twelve Cultivars. . *Postharvest Biology & Technology* **49**, 19-26.

SILVA, J.L., MARROQUIN, E., MATTA, F.B., GARNER JR, J.O. and STOJANOVIC, J. 2005. Physicochemical, Carbohydrate and Sensory Characteristics of Highbush and Rabbiteye Blueberry Cultivars. *Journal of Science of Food and Agriculture* **85**, 1815-1821.

CHAPTER 3

THE EFFECTS OF RADIO FREQUENCY APPLICATION ON JUICE YIELD AND QUALITY[3]

[3] Smith, K.C., Mulligan, J.H., and Shewfelt, R.L. To be submitted to *Journal of Food Science*

Abstract

The effects of radio frequency (RF) application on "melting" flesh and "crisp" flesh southern highbush blueberries on the improvement of juice yield and quality were investigated. These two types of blueberries were subjected to radio frequency intensities of 20 MHz, 40 MHz, and 60 MHz. Juice yield increased for the melting flesh blueberries at 40 MHz and 60MHz and for the crisp flesh blueberry an increase in juice yield for all treatments. The crisp and melting flesh blueberries when RF was applied showed a statistically significant difference of total phenolic content of the juice expressed as mg/ml gallic acid equivalent. Blueberry juice also showed strong radical-scavenging activity

Introduction

Compared to whole fruit, fruit juice has lower amounts of total phenolics and antioxidant values. Minute levels can be extracted from the fruit skins during the beginning stage of juice processing, while the bulk of the compounds remain in the skins and seeds. (Gerard and Roberts, 2004, Pinelo *et al.*, 2006). Blueberry juice abundance in bioactive phenolic compounds is attributed to two factors: the first related with the synthesis of secondary metabolites by the plant, and the second connected with the processing juice technology (Brambilla *et al*., 2008). There is great interest in the likely health benefits of blueberries and blueberry products, because of their high antioxidant capacity, which is highly correlated to their total phenolic content (Lee *et al.*, 2002). The use of pre-treatments, such as microwave heating, has been investigated in increasing the juice yield and quality of the juice (Gerard and Roberts, 2004, Schilling *et al.*, 2007, Wang and Sastry, 2002, Ma *et al.*, 2008). The use of radio frequency as a pre-treatment has not been studied as intensively. Radio frequency (RF) and microwave heating (MW) are both types of radiated heating processes. Microwave heating has a higher frequency range than RF of 300 MHz-300 GHz. Since RF uses longer wavelengths than MW, the electromagnetic waves in the RF spectrum can enter deeper into the foodstuffs so there is no surface overheating, or hot or cold spots, general problems with MW heating (Piyasena et al., 2003). The objective of this study is to the evaluate the effect of radio frequency treatment of southern highbush blueberries on juice yield, total phenolic content , and antioxidant capacity of juice processed from radio frequency exposed southern highbush blueberries.

Materials and Methods

Radio frequency juice processing

A combination of three varieties of crisp flesh southern highbush blueberries were separated into four 2.5 kg batches at 20 º C (‘Farthing’, ‘Meadowlark’, and ‘Sweet Crisp’). In addition, a combination of three varieties of melting flesh southern highbush blueberries were also separated into four 2.5 kg batches at 20 º C (Fl-01-234,’ Scintilla’, and ‘Star’) . Each batch was treated with either no exposure to radio frequency as the control, 20 MHz of radio frequency, 40 MHz of radio frequency, or 60 MHz of radio frequency using a Strayfield 6kW Radio Frequency Heater . The blueberries were placed on a polymeric tray evenly to prevent arching. After the blueberries were treated, they were then processed into juice using a commercial juicer (Breville Juice Fountain Plus JE95XL, Denver, Co.) , vacuum filtered, followed by juice collection to calculate juice yield .

Total Phenolics

The total phenolic determination were measured using an adapted Folin-Ciocalteu’’s phenol reagent assay (Slinkard and Singleton, 1997). A gallic acid stock solution was prepared to have an approximate concentration of 0.32 mg/mL in a methanol/water solution. A standard curve was prepared using different concentrations of the stock solutions. The working stock solution of the juice sample was prepared to have an approximate concentration of 1% volume in deionized water. The blank was also prepared (5% methanol-95% water solution).

To the blueberry juice samples from each batch, blank and standard curve test tubes, 6.5 ml of water and 0.5 ml of Folin-Ciocalteu’s phenol reagent was added to each tube followed by vortex. After vortexing and waiting 5 minutes, 1ml of saturated sodium carbonate was added. Solutions were vortexed and after 35 minutes, their absorbance was measured with a Genesy 20 spectrophotometer (Model 4001/4 Thermo Electron Scientific, Madison, WI) at at λ= 750 nm.

Each juice sample was prepared in triplicate. To determine the corresponding gallic acid concentration in gallic acid equivalents (GAE) the standard curve was used.

DPPH Radical Scavenging Capacity

The DPPH method was used from an adapted and modified (Burda and Oleszek, 2001) was used to determine radical-scavenging potential of each sample. A solution of 1, 1'-Diphenyl-2-picrl-hydrazyl reagent was prepared to yield a concentration on 2mM in 70% v/v methanol. A blank was also prepared (70% v/v methanol).

The control and the samples from the blueberry juice that underwent radio frequency processing were prepared for DPPH radical scavenging analysis. A 2mL aliquot of blueberry juice from each of the previous from each batch along with 8 mL of 70% (v/v) methanol was added to a test tube and vortex for approximately 15 seconds. Further dilutions of the samples were prepared by pipetting 2mL from the proceeding step into test tubes and add 8mL of 70% v/v methanol and vortex. Then there was an addition of 1mL of 2mM DPPH solution and vortex for approximately 15 seconds. The samples sat for 15 min before the absorbance readings were taken at λ= 517 nm on a Genesys 20 spectrometer (Model 4001/4 Thermo Electron Scientific, Madison, WI). The absorbance readings were done every 30 seconds over a time frame of 5 minutes. Each processing method was analyzed in triplicate. The calculation of the % inhibition of the DPPH for each sample was as follows:

$$\% \text{ Inhibition} = [1- (A_{517} \text{ sample} / A_{517} \text{ DPPH}\bullet \text{ blank})] \times 100$$

Statistical Analysis

Analysis of Variance (ANOVA) was performed to determine significant difference between treatments for each of the assays performed. An alpha level p-value <0.0001 was used for the analysis.

Results

As shown in Table 3.1, the crisp flesh blueberries that were exposed to increasing intensities of radio frequency showed an increase of juice yield compared to the control batch. The control batch of crisp flesh blueberries produced a juice yield of 38.9 % recovery. As the application of radio frequency increased to 20 MHz, 40 MHz and 60 MHz the recovery of juice increased .The melting flesh blueberries in which the same intensity of RF applied as the crisp flesh, generally yielded an increase in juice yield as relative to the control batch. The control batch of melting flesh blueberries generated a juice yield of 37.6 %. As the melting flesh blueberries were exposed to the lower intensity of radio frequency of 20 MHz, there was a slightly less juice yield recovery of only 35.2 %. However, as the radio frequency treatment increased to 40 MHz and 60 MHz the juice yield also increased to 42.0 % and 45.6%.

Total phenolic content of the blueberry juice was expressed in gallic acid equivalents (GAE) instead of the dominate chlorogenic acid typically found in blueberries due to cost and availability. The total phenolic of juice extracted from the crisp flesh and melting flesh blueberries were found to be a significant factor of ($p<0.0001$). Table 3.2 indicates that the crisp flesh blueberries exposed to radio frequency affected the total phenolics within the juice. The crisp flesh blueberries that were not exposed to RF juice had 1.54 µg/ml GAE. Radio frequency intensities of 20 MHz, 40 MHz, and 60 MHz produced juice that contained 2.99 mg/ml GAE , 2.59 mg/ml GAE, and 3.46 mg/ml GAE . The significant increase of radio frequency exposure led to higher recovery total phenolic compounds. The melting flesh blueberries that were not exposed to RF juice expressed 2.36 mg/mL GAE. As the RF increased to 20 MHz and 40 MHz there was an increased amount of total phenolics; however, the higher intensity of 60 MHz led to lower recovery .

The blueberry juice from the crisp flesh and melting flesh blueberries showed a very strong radical-scavenging activity before and after radio frequency. The values are reported of percent inhibition of DPPH after 5 min of reaction. Over time all the blueberries illustrated an increase inhibition (Table 3.3). The blueberry juice from the crisp flesh blueberries unprocessed with RF indicated an initial inhibition of 74.6 %. The crisp flesh blueberry juice subjected to 20 MHz and 40 MHz of RF had inhibition values of 88.4 % and 86.9 %. Crisp flesh blueberry juice exposure to 60 MHz of RF indicated lower inhibition than the unprocessed juice with 60.7 %. The blueberry juice from the melting flesh blueberries unprocessed with RF indicated an initial inhibition of 67.8 %. The crisp flesh blueberry juice belonged to the melting flesh blueberries subjected to 40 MHz and 60 MHz of RF of 73.6 % and 78.8 %. Melting flesh blueberry juice exposure to 20 MHz of RF indicated a % inhibition lower than from untreated juice of 63.7 %.

Discussion

Radio frequency likely penetrated the cell walls and membrane of the blueberry fruit samples. Within the cells are vacuoles that contain the extracellular fluids and their contents include the juice, phenolic compounds, vitamins, minerals, and other essential components found in plants (Pinelo et al., 2006). This application of radio frequency wave's vibration within the blueberries initiated the breakdown of the cells structure creating pores (Geveke et al., 2007). The breakdown of the structure allows for a release of more juice. The traditional melting flesh and the nontraditional crisp flesh showed similar juice release (difference of 1.1 % juice yield) when they were not subjected to radio frequency. The melting flesh blueberries were less affected by radio frequency exposure when compared to the crisp flesh blueberries. The effects of the different RF treatment on juice yield for the melting flesh juice yields in the ranges of a lost of 1.4 % to increase of up to 8%. The application of RF to the crisp flesh blueberries increased juice yields in the range of 1.1 to 19.7%. There have been other processing methods to improve juice yield. Previous studies from (Gerard and Roberts, 2004, Wang and Sastry, 2002) used microwave heating and ohmic heating to improve juice yield of apple and apple mash. Their observations indicate that the use of those processing methods showed similar results as radio frequency exposure by demonstrating an increase in juice yield. Similar studies by (Schilling *et al.*, 2007) used pulsed electric field (PEF) as a treatment on apple mash in order to amplify juice yield production. The use of PEF also increased the amount of juice extracted. Nevertheless, it must be taken into consideration that juice yield is only one portion, even though the most important, influencing the profitability of juice production.

Juice processing methods affects the distribution and composition of the phenolic compounds of the juice. Processing, such as radio frequency application, also affects the rupture of the vacuoles and cell walls (Bengoechea *et al.*, 1997). The crisp and melting flesh blueberries when RF was applied showed a statistically significant difference of total phenolic content of the juice. Since, RF processing breaks through the structure in the skin which is the location of many phenolics, the increased intensity of RF exposure to the surface of the blueberries would elevate the amount of phenolics released from the structure of the skin and found in the final product. The crisp flesh blueberries when exposed to RF at higher intensity showed the highest amount of total phenolics in the juice product. The melting flesh blueberry when RF was applied at lower intensities showed an increase in total phenolic content. At the higher exposure to RF the juice yielded lower quantities of phenolic compounds in the juice. The lower intensities were enough to release the maximum amount of cell wall and non cell wall phenolics. Total phenolics degradation and lost was seen with the over exposure from the higher intensity of RF (Schilling *et al.*, 2007). The melting flesh blueberry the highest intensity indicated that RF could be most effective at lower frequency with melting flesh blueberries for minimizing nutrient losses

Blueberry juice showed an exceptionally strong radical-scavenging activity. However, there was a variation in antioxidant activities or % inhibition among the different samples. Factors that may impact antioxidant activity and change the phenolic composition of the fruit materials include maturity at harvest, season of maturity, genetic differences, pre-harvest environmental conditions, postharvest storage conditions, and processing(Lui *et al.*, 2007, Connor *et al.*, 2002). There is a strong correlation (r= 0.9887) between the antioxidant activity as it relates to the total phenolic of the melting flesh blueberries (Figure 3.1). There was a weak correlation (r=0.2138) between the antioxidant activity as it relates to the total phenolic of the crisp flesh blueberries (Figure 3.2). The crisp flesh blueberries that had a RF treatment of 60 Mhz had more total phenolics, which are more susceptible to oxidation which leads to decrease in inhibition. However, from Figure 3.3, taking into account this and the removal of that treatment the correlation was strong (r=0.9816). Several studies including works of (Lohachoompol *et al.*, 2008, Connor *et al.*, 2002, Cho *et al.*, 2004, Ehlenfeldt and Prior, 2001) showed results of the correlation of antioxidant activity as it relates to phenolic compounds.

Table 3.1. Blueberry juice yield from southern highbush blueberries with the application of radio frequency.

Treatment Type	**Blueberry Selection**	**Whole Blueberry Weight (kg)**	**Juice Weight (kg)**	**Mash Weight (kg)**	**Lost (kg)**	**Juice Yield (%)[a]**
Control	Melting (M)	2.50	0.940	1.43	0.130	37.6
	Crisp (C)	2.50	0.973	1.51	0.017	38.9
RF 20MHz	Melting	2.50	0.880	1.48	0.130	35.2
	Crisp	2.50	1.00	1.37	0.130	40.0
RF 40MHz	Melting	2.50	1.05	1.35	0.100	42.0
	Crisp	2.50	1.29	1.04	0.170	51.6
RF 60MHz	Melting	2.50	1.14	1.34	0.020	45.6
	Crisp	2.50	1.46	1.00	0.040	58.4

[a] *% Juice Yield = (Juice Weight / Whole Blueberry Weight) * 100*

Table 3.2. Total phenolics of southern highbush blueberries treated with radio frequency.

Radio Frequency Intensity	Gallic acid equivalent (GAE) (mg/mL) Melting Flesh Blueberry	Gallic acid equivalent(GAE) (mg/mL) Crisp Flesh Blueberry
Control	2.36 [b]	1.54 [c]
20 MHz	2.74 [a]	2.99 [ab]
40 MHz	2.89 [a]	2.59 [b]
60 MHz	1.91 [c]	3.46 [a]

Means for each within a column not followed by the same letter are significantly different (p-value <0.0001)

Table 3.3. Antioxidant activity of southern highbush blueberries treated with radio frequency.

RF Treatment	% DPPH radical quenched
Control (C)	**74.6**
(M)	**67.8**
20 MHz (C)	**88.4**
(M)	**63.7**
40 MHz (C)	**86.9**
(M)	**73.6**
60MHz (C)	**60.7**
(M)	**78.8**

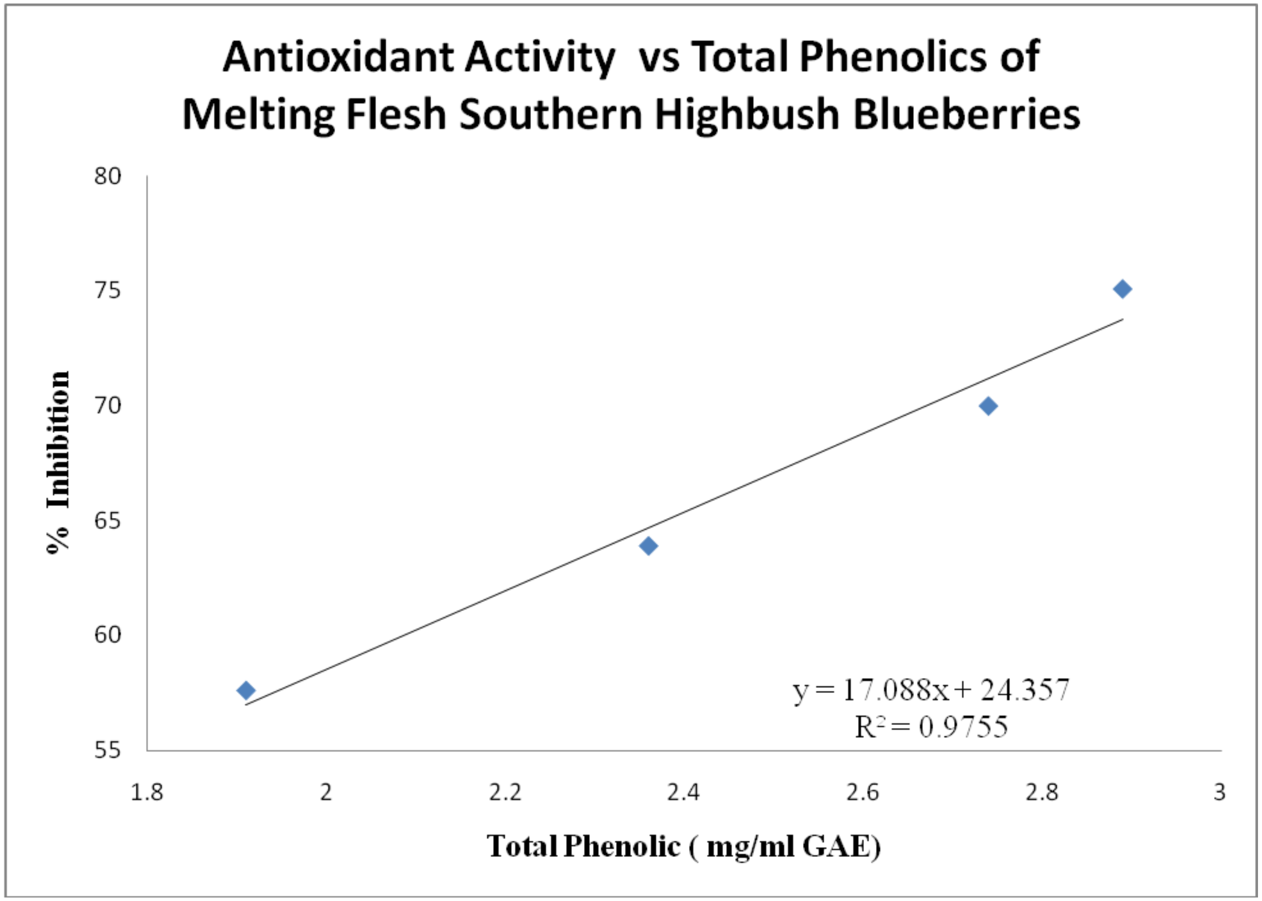


Figure 3.1 Antioxidant activity vs total phenolics of 4 treatments of RF on" melting" flesh southern highbush blueberries

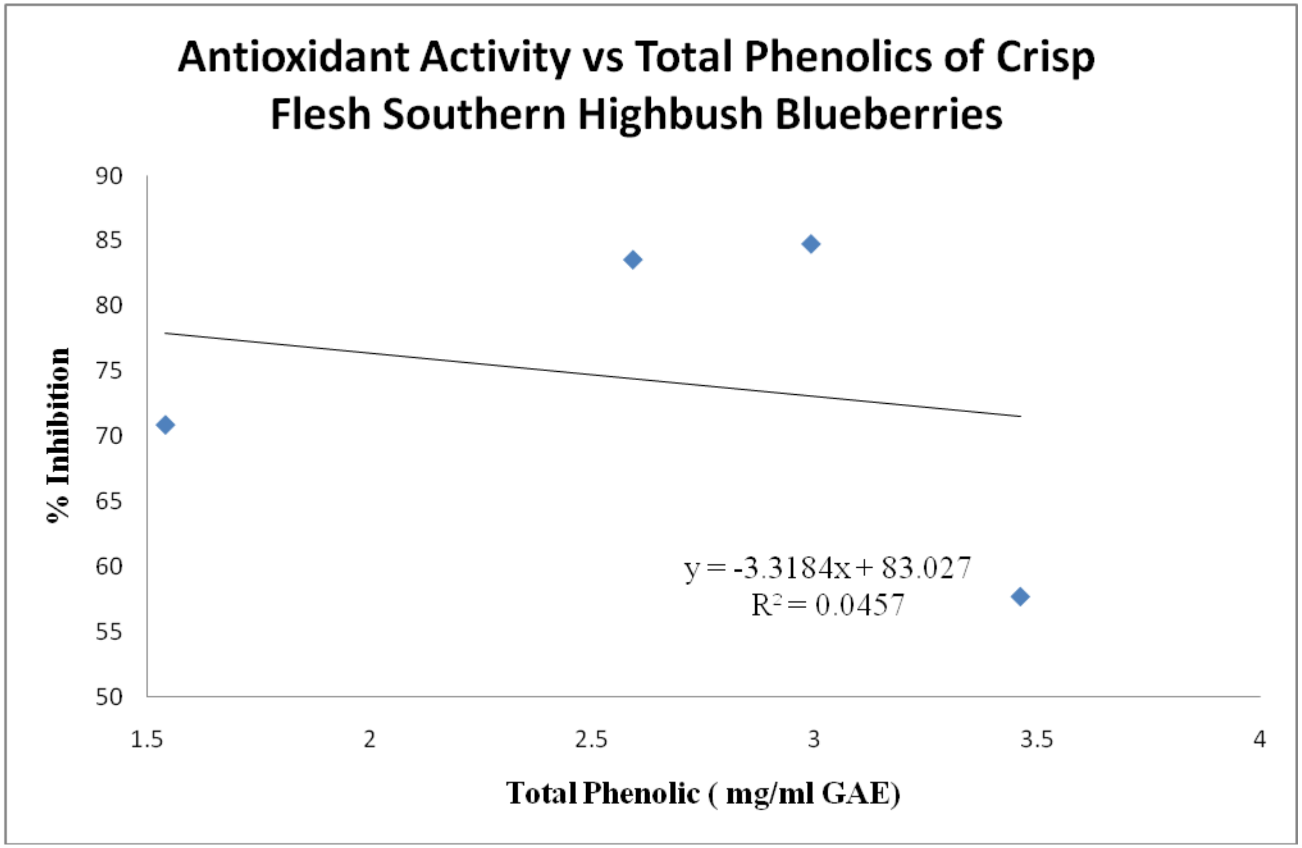
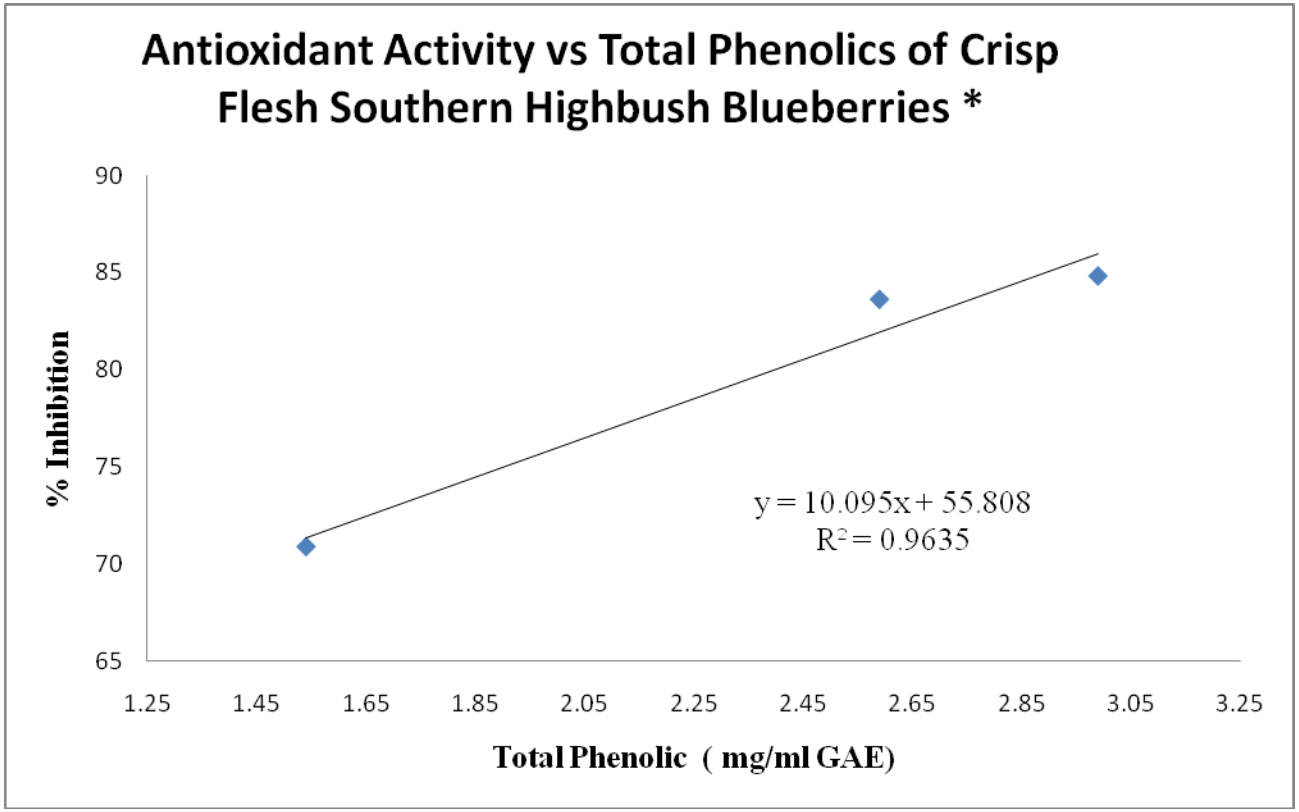


Figure 3.2 Antioxidant activity vs total phenolics of 4 treatments of RF on “crisp” flesh southern highbush blueberries



*Data does not include RF 60 MHz treatment

Figure 3.3 Antioxidant activity vs total phenolics of 3 treatments of RF on “crisp” flesh southern highbush blueberries

REFERENCES

BENGOECHEA, M., SANCHO, A., BARTOLOME, B., ESTRELLA, I., GOMEZ-CORDOVES, C. and HERNANDEZ, M. 1997. Phenolic Composition of industrially Manufactured Puree and Concentrates from Peach and Apple Fruits. *Journal of Agricultural and Food Chemistry* **45**, 4071-4075.

BRAMBILLA, A., LO SCALZO, R., BERTOLO, G. and TORREGGIANI, D. 2008. Steam-Blanched Highbush Blueberry (*Vaccinium corymbosum* L.) Juice:Phenolic Profile and Antioxidant Capacity in Relation to Cultivar Selection. *Journal of Agricultural and Food Chemistry* **56**, 2643-2648.

BURDA, S. and OLESZEK, W. 2001. Antioxidant Effects of Flavonoids. *Journal of Agricultural and Food Chemistry* **49**, 2774-2779.

CHO, M.J., HOWARD, L.R., PRIOR, R.L. and CLARK, J.R. 2004. Flavonoid Glycosides and Antioxidant Capacity of Various Blackberry, Blueberry, and Red Grape Genotyoes Determined by High Performance Liquid Chromatography/Mass Spectrometry. *Journal of the Science of Food and Agriculture* **84**, 1771-1782.

CONNOR, A.M., LUBY, J.J., HANCOCK, J., BERKHEIMER, S. and HANSON, E. 2002. Changes in Fruit Anitoxidant Activity Among Blueberry Culitivars During Cold Temperature Storage. *Journal of Agricultural and Food Chemistry* **50**, 893-898.

EHLENFELDT, M. and PRIOR, R.L. 2001. Oxygen Radical Absorbance Capacity (ORAC) and Phenolic and Anthocyanin Concentrations in Fruit and Leaf Tissue of Highbush Blueberry. *Journal of Agricultural and Food Chemistry* **49**, 2222-2227.

GERARD, K.A. and ROBERTS, J.S. 2004. Microwave Heating of Apple Mash to Improve Juice Yield and Quality. *Lebensm Wiss Technology* **37**, 551-557.

GEVEKE, D.J., BRUNKHORST, C. and FAN, X. 2007. Radio Frequency Electric Fields Processing of Orange Juice. *Innovative Food Science and Emerging Technologies* **8**, 549-554.

LEE, J., DURST, R.W. and WROLSTAD, R.E. 2002. Impact of Juice Processing on Blueberry Anthocyanins and Polyphenolics: Comparison of Two Pretreatments. *Journal of Food Science* **67**, 1660-1667.

LOHACHOOMPOL, V., MULHOLLAND, M., SRZEDNICKI, G. and CRASKE, J. 2008. Determination of Anthocyanins in Various Cultivars of Highbush and Rabbiteye Blueberries. *Food Chemistry* **111**, 249-254.

MA, Y., CHEN, J., LIU, D. and YE, X. 2008. Effects of Ultrasonic Treatment of Total Phenolic and Antioxidant Activity of Extracts from Citrus Peel. *Journal of Food Science* **73**, T115-T120.

PINELO, M., ARNOUS, A. and MEYER, A.S. 2006. Upgrading of Grape Skins: Significance of Plant Cell Wall Structural Components and Extraction Techniques for Phenol Release. *Trends in Food Science & Technology* **17**, 579-590.

PIYASENA, P., DUSSAULT, C., KOUTCHMA, T., RAMASWAMY, H.S. and AWUAH, G.B. 2003. Radio Frequency Heating of Foods: Principles, Applications and Related Properties-A Review. *Critical Review in Food Science and Nutrition* **43**, 587-606.

SCHILLING, S., ALBER, T., TOEPFL, S., NEIDHART, S., KNORR, D., SCHIEBER, A. and CARLE, R. 2007. Effects of Pulsed Electric Field Treatment of Apple Mash on Juice Yield and Qulaity Attributes of Apple Juices. *Innovative Food Science and Emerging Technologies* **8**, 127-134.

SLINKARD, K. and SINGLETON, V.L. 1997. Total Phenol Analysis: Automation and Comparison with Manual Methods. *Americal Journal of Enology and Viticulture* **28**, 49-55.

WANG, W. and SASTRY, S.K. 2002. Effects of Moderate Electrothermal Treatments on Juice Yield from Cellular Tissue. *Innovative Food Science and Emerging Technologies* **3**.

CHAPTER 4

CONCLUSIONS

Over the past few decades, the southern highbush blueberry has been studied with great interest because of its harvest season and the positive economical benefits for the fresh market. With the increase in demand from consumers for the fresh market, new creations of cultivars have been bred. There has been minimum information available regarding the sensory characteristics of highbush blueberries. Sensory evaluation of "crisp" and "melting" flesh southern highbush blueberries was conducted by trained panelists to determine the differences among the various blueberries. Also, sensory analysis was able to determine if these characteristics changed due to harvest methods. It was concluded that there are many differences among the blueberries and the harvest method rather it hand-picked or mechanically harvested had diverse outcomes. The panel was able to successfully distinguish the dissimilarities in the textural characteristics of firmness and crispness that were able to validate certain blueberries to be categorized as "crisp" or "melting" flesh blueberry. The only consistent difference across the two years, harvest method and flesh type was that the "crispy" flesh berries were than the "melting" flesh fruit. The success of these new selections in the marketplace will depend on the consumers" willingness to accept the fruit. Based on these results, "crispy" flesh type southern highbush blueberries may be able to endure storage, harvesting, shipping and handling better than "melting" flesh southern highbush blueberries resulting in a better quality fruit. Additional research will be needed to better understand the relationship of these characteristics to be able to predict consumer acceptability as a function of these critical sensory notes of the new "crisp" flesh blueberries.

The use of radio frequency as a pre-treatment achieved a higher juice yield recovery in the southern highbush blueberries when the method was applied at different frequencies. In addition, RF increased the extraction of phenolics resulting in a juice with increased 56 concentration of total phenolics. The application of RF also had a positive effect on the antioxidant activity of the juice as well. It was observed that the antioxidant activity values were correlated to the total phenolics of the blueberry juice. Results for the juice quality and yield varied for “melting” flesh and “crisp” flesh southern highbush blueberries. Therefore, further research would be needed to see the effects of RF treatments on blueberries of different varieties. This RF process can serve as a promising technology in the food industry as an addition to conventional juice processing if incorporated into the process of products of similar nature.