SENSORY QUALITY AND CONSUMER ACCEPTABILITY OF SOUTHERN HIGHBUSH BLUEBERRY CULTIVARS

by

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(Under the Direction of Robert L. Shewfelt)

ABSTRACT

Southern highbush blueberries were evaluated for sensory quality and acceptability by a descriptive panel as well as consumer panels. Crisp-flesh and non-crisp flesh varieties were evaluated. Results from this study were used to validate mathematical models developed previously for predicting acceptability. In addition, the different varieties of blueberries were used in blueberry pie formulations to determine whether consumers could detect a difference in formulations. Sensory and consumer testing show that consumers will be accepting to the firmer flesh blueberries for fresh consumption. The mathematical model for predictive quality was validated. Also, consumers were unable to detect differences in pies baked with fresh berries from those with non-crisp flesh fruit.

INDEX WORDS: southern highbush blueberries, sensory evaluation, consumer acceptability, blueberry pies, crisp-flesh

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1

LITERATURE REVIEW

Introduction

Blueberries have become a very popular fruit over the last couple of decades for many reasons including health benefits, availability, and flavor. It is more efficient in most cases to mechanically harvest berries instead of hand harvesting, however this can be damaging to softer blueberry cultivars. New cultivars have been bred in order to better withstand mechanical harvesting, southern temperate conditions, and have earlier harvest dates for availability in the fresh market. There are crisp and non-crisp selections, in which the crisp tend to have a firmer, more durable texture and the non-crisp are softer textured. Consumers may or may not like the firmer flesh berries and is important for growers to understand which selections consumers would prefer. Also, it would be interesting to know whether these new cultivars will be appropriate in baking applications.

Blueberry Nutrition and Health-Related Compounds

Blueberries are a popular fruit choice among consumers, with an average of 1.11 pounds per capita consumption in America in 2010 (USDA 2011a), and they have been getting more attention due to their health-promoting characteristics (Crisoto and Kader 1999). Blueberries contain 80 calories (0% DV), 1 g lipid (0% DV), and 19 g of carbohydrates (14% DV) in a serving size of 146 g. They also are abundant in Vitamin C (3.9 mg/25% DV), Potassium (84 mg), Phosphorus (17 mg), and Calcium (12 mg/1%

DV) (Council 2012). Phenolic compounds have many other functions in nature as well, such as protectors against herbivores, attractants for pollinators, as well as agents of plant-plant competition and plant-microbe symbioses. Anthocyanins, flavonoids, and other polyphenols are all among the bioactive phenolics found in blueberries. Anthocyanins are considered secondary metabolites, meaning they have no direct role in photosynthesis, respiration, solute transport, translocation, protein synthesis, nutrient assimilation, or differentiation. Anthocyanins are responsible for the red, pink, purple, and blue pigments in blueberries, many of which are glycosylated (Taiz and Zeiger 2010). These compounds function as antioxidants, which have potential to inhibit cancer cell growth (Kähkäonen and Gosch 2003). Blueberries have a high ORAC value of 2,400 ORAC (Oxygen Radical Absorbance Capacity) units per 100 g (Prior *et al.* 1998, Council 2012b). When comparing values to other fruits and vegetables, strawberries have 1,540 units, pomegranates have 1,245 units, raw spinach has 1,260 units, and broccoli florets have 890 units (USDA 2010b). It is clear that blueberries are on the higher end of the spectrum when looking at ORAC values. Oxidative stress, which is caused by a negative balance between free radical oxidation and antioxidants, can play a major role in the development of chronic diseases. It has been reported by that oxidative stress decreases as fruit and vegetable intake increases (Fowke *et al.* 2006, Sanchez-Moreno *et al.* 2006). Many factors affect the nutritional components of blueberries, like ripening stage, climate, genotype, maturity, cultivation techniques, and cultivar (Häkkinen and Törrönen 2000).

Southern Highbush Blueberries

Southern Highbush blueberries are a type of blueberry and the product of the crossbreeding of northern highbush blueberries, or *Vaccinium corymbosum*, and other *Vaccinium* species native to the southeastern region of the United States. Southern highbush blueberries have an earlier ripening period compared to Rabbiteye (*Vaccinium ashei),* allowing for them to be more popular among growers in the southern regions. Highbush blueberry farmers can have the advantage in the market because as the last part of harvesting of blueberries concludes in the southern hemisphere in the early spring months, harvesting of the highbush blueberries begins in the United States (Stringer 2012). In 2011, 533 million pounds of highbush blueberries were produced. According to the US Highbush Blueberry Council, people in the US consume 1.25 pounds of fresh berries and 1 pound of frozen blueberries per year. Also, there has been an increasing demand for blueberries internationally. In 2011, North America exported 116 million pounds to countries like Japan, South Korea, and China (Council 2012a).

Crossbreeding of blueberries began in the early 1900s with Dr. Frederick V. Coville. He researched optimal blueberry growth conditions and determined that this crop must be planted in a low pH, low nutrient wet soil, and required winter chilling for proper bud development. This stemmed research for the development of Southern highbush blueberries in 1948 in Florida. Researchers used *Vaccinium darrowi,* a blueberry species that provided a low chilling requirement, and combined that species with the Northern highbush species developed by Coville to have blueberries that could be bred in warmer climates. ‘Sharpblue’ and ‘Floridablue’ were the first Southern highbush blueberries released in 1976 out of The University of Florida (Mainland 2012).

Blueberry Growth

Southern highbush blueberry plants are different when compared with Rabbiteye plants when it comes to growing them. Optimal growth conditions are sandy, highly organic, and acidic soil with a pH between 4 and 5 (Scherm and Krewer 2003). There have been some growers who have used a pine bark culture that is poured on top of the soil (Williamson and Lyrene 2004). Using the bark method, there are such benefits like a lower pH, which creates an environment that is similar to wild blueberries that grow in the forest. The problems associated with this method are that irrigation and fertilization are more difficult due to the fact that bark has a low water storage capacity (Dourte 2010). Both methods are implemented on raised beds so that improved drainage occurs, which is vital to plant survival. Blueberry bushes require between 2.5 and 5 cm of water per week (Haman *et al.* 1988; Scherm and Krewer 2003).

Temperature is another factor that affects growth. Ambient temperatures allow for proper fruit development, but cultivation must take place in an area that has cold weather to meet chilling requirements of the cultivar that is being grown (Godoy *et al*. 2008). Southern highbush blueberries are low-chilling cultivars, meaning that they need 400 hours or less of exposure to temperatures lower than 45 °F, allowing for the buds to develop and open up. Blooming depends on the cultivar and the chilling hours associated with it as well as the location in which it is planted. For example, blueberries planted in south Georgia that have 200-300 required chilling hours will have bloom dates some time in mid February with harvest dates occurring in May (Krewer and NeSmith 2006). Overhead irrigation is used to protect flower buds from freezes (Williamson and Lyrene 2004).

Usually, five to eight flower buds can develop on a shoot growth and each flower bud can form five to ten flowers. This happens throughout the fall and into winter. Buds then open in the spring months, allowing for the blueberry fruit to develop over the next two months (Polomski and Reighard 1999). Blueberries are green when they first start to develop, then as cell division and the endosperm growth increase, the blueberry turns to pink and then finally to blue (Williamson and Lyrene 2004).

Harvesting and Postharvest Storage

Blueberries can either be hand harvested or mechanically harvested. They are a highly perishable berry and although they can sometimes be characterized as being firm, it is important to minimize mechanical harvesting damage in order to maintain berry quality (Mitcham 1999). Typically Southern highbush blueberries that are intended for the fresh market are hand harvested to reduce damage (Ehlenfeldt 2005). Hand harvesting is very time and labor intensive, requiring up to 1,300 workers an hour per hectare (Brown *et al.* 1983) and is very costly. Compared to hand harvesting, mechanical harvesting costs half as much (Takeda *et. al.* 2008). However, yields are generally higher with hand harvesting (Van Dalfsen and Gaye 1999). Mechanical harvesting can result in quality defects like incidental bruising, an unattractive appearance, and quicker decay and shriveling (Takeda *et al*. 2008; Ehlenfeldt 2005; Yu *et al*. 2011). Over the years, researchers have conducted field tests using new harvesters to improve blueberry fruit quality. Brown *et al*. (1996) found that 77% of the hand-picked berries were free of damage or only slightly bruised whereas the conventional mechanical harvesters had only 22% of berries damage free or slightly damaged. Peterson *et al*. (1999) in a subsequent study noted that “improved fruit quality over conventional harvesters was attributed to

reduced detachment bruising, less opportunity for falling berries to strike the bush, detached fruit falling shorter distances, and the use of cushioned catching surfaces.".

Postharvest quality is typically defined by describing the flavor and texture of fruits and vegetables (Chiabrando 2009). Blueberries are a climacteric fruit, meaning they continue to ripen after they are harvested at a higher respiration rate while also producing ethylene gas (Pech *et al.* 2008). However, it is recommended that the blueberry fruit be allowed to remain on the bush until nearly ripened since quality and flavor do not improve appreciably after harvest. It is best to store blueberries at a relative humidity of 90-95% at 3±1°C for no longer than one to two weeks (Mitcham *et al*. 1999). It is recommended by the Highbush Blueberry Council to store the berries in plastic clam shells or cello packs cartons (Council 2012b). Researchers are also trying to find new methods to improve the shelf-life of these highly perishable fruits. Ozonation can be employed to slow decay (Forney *et al.* 2001).

Crisp and Non-Crisp Selections

In the 1980's and 1990's, new selections of Southern highbush blueberries were released through various breeding programs. These new berries had a "firm" texture. Currently, Southern highbush blueberries can now be categorized into crisp and non-crisp varieties. "Crisp" texture can be described as the sensation of biting into an apple (Padley 2005). The crisp classification used to be called "Crispy" flesh and the softer breeds were called "melting" flesh before they were renamed (Smith 2010). These crisp berries have better fruit quality and a longer shelf life, making them more available to the market longer compared to the non-crisp flesh berries (Saftner 2008). 'Duke', 'Chanticleer', and 'Hannah's Choice' are all examples of crisp cultivars (Hancock 2001, Adelaja and

Knipling 2000). There has been difficulty in defining the "crisp" terminology and trying to define it in literature, but Padley found that consumers could differentiate this texture descriptor (Padley and Lyrene 2006). In previous studies, the crisp blueberries can be described by descriptive panels as "bursting energy" (Saftner 2008), or by "texture/firmness" (Smith 2010).

Florida – According to the US Highbush Blueberry Council, Florida produced 15 million pounds of fresh blueberries in 2010 (Council 2010). In the 1980's, Ralph Sharpe, a horticulturist from the Florida Agricultural Experiment Station, began crossbreeding Florida evergreen lowbush wild blueberries with northern highbush cultivars (Lyrene 1988). At the time, North Carolina Southern Highbush blueberries were being harvested in late May, but with this new breed of blueberry, harvesting of Southern highbush blueberries could begin in March (Sharpe 1971). Florida has very mild weather conditions and thus has the opportunity to have early access to the fresh blueberry market before other states. There has been research conducted in Florida to further promote early harvest using covered polyethylene tunnels. These covers were employed in the beginning of January, after the chilling requirements of the buds had been reached and removed in towards the end of March. This method allowed for early budding of flowers, thus permitting growers to harvest about one month earlier than usual "early" harvesting dates (Baptista 2006).

'Sweetcrisp' is a crisp variety of highbush blueberry grown in Florida. The berries of this type of bush are considered sweet and have a firm texture. Berries vary in size but tend to be smaller in size compared to other Florida cultivars like 'Star'. The plant has low chilling requirements around 200 hours, which is within the range of normal

blueberry chilling requirements of 200-400 hours. With a firm texture and long pedicels, or branches that connect the flower bud to the main vertebral body of the bush, and a low detachment force, 'Sweetcrisp' is considered an appropriate berry for mechanical harvesting (Miller Nursery 2012).

Advanced selection FL98-325 and other genotypes of crisp and non-crisp blueberry cultures were examined for their ability to be mechanically harvested (USDA 2009c). Research was conducted by Fumiomi Takeda at the USDA-ARS in Kearneysville, West Virginia and Gerard Krewer at the University of Georgia in Tifton, Georgia by running trials on crop maturity, harvest efficiency, ground loss, and drop/impact damage (Smith 2010). In another research project conducted by Les Padley at The University of Florida, FL FL98-325 was evaluated among other crisp and non-crisp blueberries for relative firmness, firmness changes during fruit development, consumer and sensory characteristics, and postharvest storage testing. Results showed that with the use of an Instron8600 firmness tester, FL FL98-325 was the firmest out of the 99 highbush clones (Padley 2005).

'Star' is a non-crisp variety of highbush blueberry grown in Florida. It was created by crossbreeding 'O'Neal' with FL. 80-31 and was released in 1996 by the University of Florida in Gainesville, Florida. This commercial cultivar is harvested in late April to early May and is known for its high fruit quality and its ability to endure a growing season. It requires 400 chilling hours below 7°C. The 'Star' berries are described as large and firm with a sweet and slightly acidic taste. Some limitations to this cultivar are that it only produces a medium yield and can be unreliable in areas where winter temperatures average higher than 14°C (Lyrene 2000).

‘Jewel’ is a non-crisp variety of highbush blueberry grown in Florida and Georgia. Like most Southern Highbush varieties, ‘Jewel’ has low chilling requirements. Its harvest dates in Florida begin around mid April and go until mid May for commercial use. This berry is known for its high berry quality and sour flavor (Williamson and Lyrene 2004).

Georgia - Georgia was the lead producer of blueberries in the Southern states in 2010 with 36 million pounds of fresh blueberries harvested (Council 2010). Georgia blueberries have only been grown commercially for about twenty years and are harvested for April and May markets. Most Southern highbush blueberry farming takes place in the Southern regions of Georgia, like Alma, Baxley, and Homerville (Krewer and NeSmith 2006).

‘Bluecrisp,’ sometimes called ‘Crunchy,’ is a crisp Southern highbush variety grown in Georgia but was released by Florida in 1997. Its harvest dates typically fall during the month of May after the bush has had approximately 400 chilling hours. ‘Bluecrisp’ berries are considered to be very firm with medium to large berry size ad light blue coloring (Krewer and NeSmith 2006).

‘Emerald’ is a non-crisp cultivar grown in Florida and Georgia. It was released from Florida in 1999. ‘Emerald’ berries have very low chilling requirements of about 200-300 hours and therefore blooms early. Berry size is large to very large and has a moderately firm texture and a medium to dark blue coloring (Krewer and NeSmith 2006). They are said to have a mild and sweet flavor (Lyrene 2008).

‘Rebel’ is a relatively new, non-crisp cultivar that was released by The University of Georgia in 2006. This cultivar has slightly higher chilling requirements when

compared with most Southern highbush of between 400 to 450 hours. ‘Rebel’ berries are large with medium to light blue coloring and are reported to have a bland flavor on average (Krewer and NeSmith 2006). This cultivar is harvested very early in the year and forces the growers to use potentially expensive methods for frost protection, thus increasing the price in the market (NeSmith 2008).

North Carolina - North Carolina produced 27.5 million pounds of fresh blueberries in 2010 (Council 2010). Commercial production usually occurs in southeastern North Carolina due to more ideal growth conditions found in this region. Harvesting occurs throughout the state from mid May to early July (Mainland and Cline 2002).

‘O’Neal’ is a non-crisp Southern highbush cultivar grown typically in the coastal plain regions of North Carolina and is commercially harvested during mid May to mid June (Mainland and Cline 2002). This cultivar of Southern highbush blueberry was named after James M. O’Neal who played a big role in the breeding programs at North Carolina State University for over 20 years. It was released in 1987 by the North Carolina Agricultural Research Service and the USDA. The berries are said to be very large but are not appropriate for mechanical harvesting due to their softer characteristics (Ballington 1990). Its chilling requirements are between 400 and 500 hours (Krewer and NeSmith 2006).

‘Reveille’ is a crisp Southern highbush cultivar grown in the coastal plains regions of North Carolina (Mainland and Cline 2002). ‘Reveille’ was released by North Carolina in 1990. These berries are harvested from late May to late June and have chilling requirements around 700 to 800 hours. The fruit is considered to be medium

sized with light blue coloring. This cultivar is more commonly mechanically harvested for use in the fresh market due to its fruit size (Krewer and NeSmith 2006).

Flavor Chemistry and Development

As a fruit ripens, anabolic reactions slow and catabolic reactions speed up in fruit flavor development. Volatile compounds form when amino acids, fatty acids, and a number of carbohydrates, that were previously used for cell metabolism, are no longer useful and then are broken down (Reineccius and Heath 2006). According to a study conducted by Robert Saftner *et al.* (2008), flavor was ranked as a more important quality characteristic for blueberries than textural and visual attributes. All blueberries contain numerous flavor volatiles, which also differ slightly among cultivars (Du *et al.* 2011). Aldehyde compounds are found in most blueberry cultivars. Specific volatiles that have been found in highbush blueberries include: (E)-2-hexenal, (E)-2-hexenol, hexanal, and (Z)-3-hexenol and terpene alcohols such as linalool, citronellol, nerol, α-terpineol, and geraniol. The aldehyde and alcohol compounds are considered "green" or "grassy" aromas and the terpenoid compounds are considered to have floral-like aromas (Parliment and Kolor 1975; Hirvi and Honkanen 1983; Du *et al*. 2011). Du *et al*. (2011) identified 42 volatile compounds, 12 of which were reported for the first time. They found that the majority of the cultivars and advanced selections investigated were primarily aldehyde volatiles, but specific genotypes like 'FL 02-40' and 'Snowchaser' contained high amounts of terpenoids. Also, they determined in their study that location and harvest date only affected the production volatiles in the cultivar 'Primadonna' but not significantly in the other cultivars investigated.

Baked Goods

Baked goods include products such as bread, cakes, pastries, pies and food made from dough of flour or meal and that are usually cooked in an oven (Dictionary.com 2013). The baking industry has a major impact on the U.S. economy, accounting for around $311 billion in total economic output, or about 2.1% of the GDP (Dunham 2011).

Pies

Pies have been popular among many cultures for many centuries. The Romans enjoyed elaborate concoctions, with sometimes having live birds inside, while the English indulged in meat and fruit filled pies. The English settlers brought the idea of pie to America and adapted the formulation using pumpkin and cranberries. Pies can be defined by the Columbia Electronic Encyclopedia as "meat, fish, fowl, fruit, or vegetables baked with a crust of pastry, or pastry shells filled with custard or pudding" (Columbia 2011). Pies, including blueberry pies, remain a popular dessert in America and it is important to know what the optimal ingredients are to make an acceptable pie. Sensory acceptability testing was performed on four different Rabbiteye blueberry cultivars incorporated into pie fillings and preserves, and then compared to nationally distributed commercial products. The results showed that the four cultivars tested provided at least equal acceptable ratings to those pie fillings currently sold on the market (Knapp 1971). A follow up study was conducted three years later to determine whether the results from the first study could provide enough market potential to begin commercial production for processed blueberries in Florida. They determined that the quality of Florida grown blueberries was of at least equal acceptability for processing compared to similar commercial products (Knapp and Sherman 1974).

Fruit Fillings

Fruits are used for many food applications, one of them being fruit fillings in baked goods and pies. Cherries and berries are the most common choices for fruit fillings in sweet products (Sinha 2012). A benefit to using blueberries and cranberries in pies is their ability to withstand heat and processing because their color is nearly unaffected. Depending on the application, fruit fillings can have many different characteristics. Some are made so that they don't migrate into the dough when baked and others are produced so that the filling contains more whole pieces of fruit. Various starches and gums can be used to achieve a desired gel in a filling. Evaporated apple powders and apples in combination with other berries are often times employed in a commercial production of fruit fillings because the apple acts as a humectant, increases shelf life and stability, lowers water activity, and improves texture and mouth-feel. Katz and Durst (1974) patented a fruit filling that was adapted to heat treatment and baking in combination with bread or biscuit dough or other bakery products. This filling resists flow and has a homogenous external phase consisting of water and coagulated caseinate and has a pH between 3.2 and 5.4. The inner phase is encapsulated by the outer layer and contains tiny fat globules. This filling can be used for cheese, fruit, or other flavorings during baking. William Graham, the vice president of Florasynth indicated that "several factors should be considered when choosing a fruit filling, including the application's desired mouth-feel, pumpability, fruit suspension, starchiness, freeze-thaw stability, boil-out, toughness, final moisture, non-bake application, flow character, final water activity and baking conditions" (Anonymous 1998).

Consumer Testing, Behavior, and Acceptability

Acceptability is defined as "the level of continued purchase and consumption by a specific population" (Land 1988). Consumer acceptability testing and results provide external validity, meaning that the results are related to the consumer market behavior (Shewfelt 1999). The objective of a consumer study is to determine what consumers prefer and like to buy on a regular basis and therefore the success of a product, with the use of consumer input during product development, depends on this type of testing (Sijtsema *et al.* 2004). A 9-point Hedonic scale is used most frequently, but this scale contains limitations because consumers tend to not use either end of the scale, making for unequal intervals between values (Peryam and Giraridot 1952; O'Mahoney 1991; Faller and Faller 2000; Dubost *et al*. 2003). An alternative and more fitting scale for acceptability is the 3-point scale (Dubost *et al*. 2003).

Consumer behavior is defined as "the study of the processes involved when individuals or groups select, purchase, use or dispose of products, services, ideas, or experiences to satisfy needs and desires". Many factors come in to play when a consumer makes a purchase. For example, the appearance of a product, the environment in which that product is purchased, price, personal bias as well as influence from others all come into play (Solomon 1996).

Donahue *et al.* (2000) determined that a 9-point scale was not effective in differentiating blueberry quality. Another study attempted to link quality characteristics to the acceptability of blueberries. They determined that color had a big influence and that blueberries that were bright blue colored were rated as more acceptable than other

(Saftner *et al*. 2008). Chiabrando and Giacalone (2009) found that crispness and firmness in blueberries were rated as acceptable to consumers.

Sensory

Sensory testing has not always been a common practice in the food industry (Sidel and Stone 1995). Oddly enough, the military's desire to have more acceptable food options, brought about the use of sensory evaluation half a century ago (Peryam *et al*. 1954, 1960). Sensory evaluation plays two roles within a company: one being that it is a key component in the marketing, research and development, and manufacturing departments; and two, by providing a method in the development and refinement of the company's procedures and products. The methods by which the testing is run can be divided up into categories: discriminative, descriptive, and consumer (Sidel and Stone 1993, 1995). Sensory testing provides internal validity, meaning the results generated are relevant to the product itself and not necessarily to consumers or the marketplace (Shewfelt 1999)

Human subjects are the "instruments" used to test for sensory attributes and these humans must be "calibrated" by the panel leader on the descriptors of the product in order to produce valid results. Humans perceive sensory attributes in order of appearance, aroma, texture or consistency, and flavor profile (includes aromatic tastes and chemical feeling factors). There are limitations to sensory testing, however. Panelists tend to be variable among themselves as well as over time and also tend to be subject to bias. (Meilgaard *et al.* 2007). Also, the sensitivity among panelists varies by a factor of 2 to 10 or more, meaning they should not be replaced during the life of a project (Meilgaard and Reid 1999; Pangborn 1981). In order to avoid problems and minimize these variability

factors, it is important that the panel leader trains all the panelists with standard references and definition to each descriptor (Elortonso *et al*. 2007). Each product that is evaluated by a sensory panel has different descriptors associated with it. In past studies, blueberries have been evaluated for flavor (sweet, sour, bitter, astringent, blueberry-like flavor), firmness, crispness, juiciness, and color (Saftner *et al*. 2008; Padley 2005; Smith 2009; Addington 2012).

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CHAPTER 2

SENSORY QUALITY AND CONSUMER ACCEPTABILITY OF SOUTHERN HIGHBUSH BLUEBERRY CULTIVARS

Introduction

Production acreage has expanded by 50,000 acres and a per capita increase in consumption of 0.73 pounds more per year was observed in the past decade (Council 2012a, USDA 2011). Blueberries have been praised in the public media for many health benefits such as being high in antioxidants, vitamins and fiber, making them an even more popular fresh fruit choice (Council 2012b). There are differences among cultivars due to various environment and handling conditions that affect flavor and texture profiles (Smith 2010). Blueberries can be harvested more efficiently with mechanical methods, however this method can be damaging to the softer flesh cultivars (Takeda *et al.* 2008). Crisp-flesh berries appear to be less susceptible to secondary decay following mechanical damage, and therefore could lead to superior consumer acceptability (Silva *et al.* 2005). Maturity at harvest, postharvest handling techniques, the way in which the fruit is distributed, and durability of the fruit or vegetable all contribute to consumer acceptability (Pecher and Von Oppen 2000).

Research on the sensory characteristics of Southern highbush blueberries has explored how differences between cultivar and growing location affect quality. Rosenfeld *et al*. (1999) observed that sensory scores for texture and blueberry flavor were affected by temperature and packaging film. Silva *et al*. (2005) evaluated fresh highbush and

rabbiteye blueberries and panelists found no significant differences in color, flavor, and skin toughness among the cultivars evaluated.

There has been even less research conducted to determine sensory differences between the "crisp" and "non-crisp" flesh blueberry cultivars. A descriptive sensory panel can be used to determine sensory quality. Also, a consumer panel using a three-point acceptability scale can be used to describe exceeding, meeting and failing to meet expectations when describing blueberry quality (Deming 2000; Van Trijp and Schifferstein 1995). This method is more realistic compared to a traditional nine-point Hedonic scale (Dubost *et al.* 2003). Padley (2005) conducted research on the firmness characteristics of crisp blueberry selections and results from the sensory panel show that panelists could detect a difference between the "crisp" and "non-crisp" selections but did not always prefer the one over the other. Smith (2010) found that crisp varieties are significantly crispier than the non-crisp selections observed and that consumer acceptability of "crisp" blueberries is determined primarily by texture. Addington (2012) developed mathematical models for determining acceptability of blueberry characteristics and found that blueberry-like flavor, crispness, and firmness were all critical characteristics in determining superior quality of fresh blueberries. Sourness was found to be a differentiating factor between superior and acceptable fruit.

The objective of this study was to determine consumer acceptability and sensory quality characteristics of crisp and non-crisp flesh Southern highbush blueberries. In addition, to validate mathematical models for predicting acceptability developed by Addington (2012).

Materials and Methods

Sensory Panel Training

An experienced sensory panel of nine participants was trained during three, one hour sessions to familiarize themselves with the nine descriptors: sour, sweet, bitter, astringent, juiciness, crispness, firmness, blueberry-like flavor, and color. These descriptors were chosen based on previous similar studies (Smith 2010, Addington 2012) using standards developed by Meilgaard (2006).

The final standards were as follows: sweet (sucrose 5% solution), sour (citric acid .08% solution), bitter (caffeine .08% solution), and astringent (alum .05% solution) represented tastes typically found in blueberries; juiciness (cucumber) represented the juicy and succulent characteristics of blueberries; crispness (club cracker) was associated with the crisp variety blueberries; and firmness had two standards (hard boiled egg whites and olives) to represent the texture of blueberries. A color scale was distributed during this session as a standard for blueberry color that contained different blue hue levels at various intensities.

Consumer Evaluation

Southern Highbush blueberries were harvested from three different states; Florida (April, 2012 – 'Jewel', 'Star', 'Sweetcrisp' and advanced selection, 98-235 – provided by the Horticulture Department at The University of Florida), Georgia (mid-May, 2012 – 'Emerald', 'Rebel' and 'Bluecrisp' provided by Cooperative Extension in Bacon County), and North Carolina (late-May, 2012)—'O'Neal'and 'Reveille' provided by North Carolina State University from their Castle Hayne plots.

After blueberries were retrieved from their locations, they were stored in plastic clam shells in a cooler set at 1.67°C for no longer than two weeks. The experienced panel evaluated the fruit in a controlled setting at the Food Processing Laboratory and Research Center of the Department of Food Science and Technology in Athens. Samples were identified with three digit numbered codes.

A consumer panel consisting of about one hundred panelists was conducted for each of the blueberry collections from each state for a total of three different panels. There were no replications for each of the cultivars. Sample cups were identified with randomized three digit numbered codes. Consumers were given three samples at a time in random order and asked to rate them as "Superior", "Acceptable" or "Not Acceptable" for overall blueberry quality.

Statistical Analysis

Statistical Analysis Software (SAS 9.3), located at SAS Institute Inc. in Cary, North Carolina was used to analyze data by Analysis of Variance (ANOVA) with Duncan mean separation determined cultivar, state, and by variety. Data was also compared to the Addington (2012) model and quantified using Chi-Square Goodness of Fit test.

Results

Sensory Panel

The sensory panel found no significant differences among all the blueberry cultivars in bitterness, astringency, juiciness, blueberry-like flavor, and color. Significant differences were observed in sweetness, sourness, firmness, crispness, and blueberry-like flavor ($p\text{-value} \leq 0.05$). 'Rebel' was observed by the panel to have significantly less

blueberry-like flavor than all the other cultivars. On average ‘Sweetcrisp’ and ‘Bluecrisp’ were given the highest sweetness ratings. When rating sourness, Reveille was found to be significantly more sour than ‘Star’ and ‘Jewel’. The ‘Bluecrisp’ cultivar, designated as a crisp flesh berry, was given the highest firmness rating by the panel, while Jewel, a non-crisp cultivar was given the lowest firmness rating. In a similar trend, the panel gave ‘Sweetcrisp’ the highest crispness rating and Star the lowest (Table 2.1).

The sensory panel found no significant differences between crisp and non-crisp varieties in sweetness, sourness, bitterness, astringency, flavor, juiciness, and color. Panelists rated the crisp cultivars to be significantly more firm and crisp compared to the non-crisp cultivars (p-value > .05) (Table 2.2).

The sensory panel found no significant differences among different states when describing sweetness, bitterness, astringency, juiciness, firmness, crispness, or color. Florida and Georgia berries were considered slightly less sour (p-value >.10) and blueberry-like flavor was nearly significantly different between Florida and North Carolina (p-value > .10) (Table 2.3)

Consumer Panel

More crisp blueberries were rated as “superior” (46.8%) compared to the non-crisp berries at (19.9%). Also, more crisp berries were rated as at least acceptable, if not superior (93.3%) than non-crisp (74.8%) (Table 2.4)

Discussion

The panel found no significant differences among all the blueberry cultivars in bitterness, astringency, juiciness, blueberry-like flavor, and color. They were, however able to detect differences in sweetness, sourness, blueberry-like flavor, and color.

Firmness and Crispness had the most significant ratings between cultivars. This observation coincides with data separated by crisp and non-crisp cultivars. The panel could only detect differences between berries when rating crispness and firmness. The crisp cultivars were clearly separated by firmness (4.69 vs. 2.47) and crispiness (3.65 vs. 1.80) compared to the non-crisp cultivars. These results are similar to the observations in previous studies (Smith 2010 and Addington 2012). Other studies show that consumers prefer blueberries with a firmer texture (Sousa *et al.* 2006, Almenar *et al.* 2010). Blueberry researchers have had trouble classifying crisp flesh cultivars and measuring their textural properties (Li et al. 2011). "Crispness", related to blueberries and fresh produce, is more typically characterized as an auditory characteristic, therefore making this description hard to characterize (Addington 2012). When looking at the consumer panels, the crisp flesh blueberries had a higher superior rating (46.8%) compared to the non-crisp flesh (19.6%). In addition, the crisp flesh berries had a higher rating when describing their quality as at least acceptable, if not superior (93.3%) compared to non-crisp at (74.8%). Addington (2012) found similar results. Using the three-point scale of acceptability will provide more data related to external validity compared to the nine-point Hedonic scale (Van Trijp and Schifferstein 1995).

When the panel data was separated by state (Table 2.4), there were no significant differences at a p-value > .05. However, blueberries from Florida were characterized by the panel as having nearly significantly more "blueberry-like flavor" than fruit from the other two states. Xiafen *et al.* (2011) demonstrated differences in volatile composition as effected by location. They found that there were no significant differences due to

environmental factors and those differences found in sensory characteristics were mainly due to varying composition among cultivars (Xiaofen *et al*. 2011).

A mathematical model that predicts percent superior blueberries and percent of blueberries that are acceptable was created by Addington (2012):

% Superior Berries=15.19+.64xBlueberry Flavor+2.04xFirmness+3.53xCrispness

%Superior+%Acceptable=71.46+0.66xSourness+0.72xBlueberryFlavor+1.39xFirmness+ 1.41xCrispness

These models show that blueberry-like flavor, firmness, and crispness are the key quality characteristics for predicting consumer acceptability of blueberries.

To validate the model, Chi-square goodness of fit test was used. To test the null hypothesis of the predictive model and determine whether it is a good fit for data obtained in this research. After using the Chi-square goodness of fit test, the null hypothesis was accepted for the superior + acceptable model because the test produced a very low test statistic (χ^2=14.79). The null hypothesis was also accepted for the predictive model for superiority (χ^2=10.50), after the removal of cultivar 'Rebel'. In order to fit the model, it was necessary discard data from this cultivar because the unacceptability ratings were so high. We were able to accept the null hypothesis for all the other cultivars however. 'Rebel' overall had very low ratings by the panel. Panelists stated that 'Rebel' had a mealy, mushy, and contained a tasteless flavor in the comments section on the experienced ballot. Krewer and NeSmith (2006) reported that berries of this cultivar are known to be bland.

Conclusions

The results from this study show that consumers found the crisp-flesh blueberries to be superior to the non-crisp flesh cultivars. Sensory and consumer testing show that consumers will be accepting of the firmer flesh blueberries. Also, the mathematical quality predictive model developed by Addington has been validated with current data and shows promise in its effectiveness to predict liking related to quality characteristics of fresh blueberries.

Table 2.1: Average panel responses for blueberry quality characteristics (n=9)

Cultivar	Sweet	Sour	Bitter	Astringent	Juiciness
FL98-325[1]	4.39[a]	3.28[ab]	2.11[a]	2.00[a]	6.22[a]
Star	4.94[a]	2.11[b]	1.39[a]	2.06[a]	6.00[a]
Jewel	4.89[a]	2.00[b]	1.33[a]	1.44[a]	7.33[a]
Sweetcrisp[1]	5.06[a]	3.61[ab]	2.11[a]	2.17[a]	5.50[a]
Bluecrisp[1]	5.06[a]	2.61[ab]	1.72[a]	2.06[a]	7.28[a]
Emerald	4.89[a]	2.89[ab]	2.00[a]	2.56[a]	7.11[a]
Rebel	2.33[b]	3.00[ab]	1.61[a]	1.50[a]	6.56[a]
Reveille[1]	3.83[ab]	4.67[a]	2.00[a]	2.50[a]	6.89[a]
O'Neal	4.11[ab]	3.56[ab]	2.22[a]	2.06[a]	7.50[a]

[1]Designates the crisp flesh cultivars

[2] Means in the same column with the same superscript are not significantly different ($p<0.05$) as determined by Duncan test

Table 2.1 (continued)

Cultivar	Firmness	Crispness	Flavor	Color
FL98-325[1]	4.61[a]	3.61[ab]	7.44[a]	10.39[a]
Star	1.78[d]	1.11[c]	8.11[a]	9.56[a]
Jewel	1.56[d]	1.39[c]	8.39[a]	11.01[a]
Sweetcrisp[1]	4.50[ab]	3.61[ab]	9.17[a]	11.00[a]
Bluecrisp[1]	5.22[a]	3.83[a]	7.78[a]	9.17[a]
Emerald	2.44[cd]	1.67[c]	7.56[a]	11.00[a]
Rebel	3.81[abc]	2.67[abc]	4.56[b]	10.28[a]
Reveille[1]	4.44[ab]	3.56[ab]	7.89[a]	9.67[a]
O'Neal	2.78[bcd]	2.17[bc]	7.28[a]	9.56[a]

[1]Designates the crisp flesh cultivars
[2] Means in the same column with the same superscript are not significantly different ($p<0.05$) as determined by Duncan test

Table 2.2: Average panel responses for blueberry quality characteristics grouped by crisp and non-crisp varieties (n=9)

Variety	Sweetness	Sourness	Bitterness	Astringency	Flavor
Crisp	4.58[a]	3.54[a]	1.99[a]	2.18[a]	8.07[a]
Non-crisp	4.23[a]	2.71[a]	1.71[a]	1.92[a]	7.18[a]

[1]Means in the same column with the same superscript are not significantly different ($p<0.05$) as determined by Duncan test

Table 2.2 (continued)

Variety	Firmness	Crispness	Juiciness	Color
Crisp	4.69[a]	3.65[a]	6.90[a]	10.29[a]
Non-crisp	2.47[b]	1.80[b]	6.47[a]	10.06[a]

[1]Means in the same column with the same superscript are not significantly different ($p<0.05$) as determined by Duncan test

Table 2.3: Average panel results of blueberries separated by state

State	Sweet	Sour	Bitter	Astringent	Juiciness
Florida	4.82[a]	2.75[b]	1.74[a]	1.91[a]	6.26[a]
Georgia	4.09[a]	2.83[b]	1.78[a]	2.04[a]	6.98[a]
North Carolina	3.97[a]	4.11[a]	2.11[a]	2.28[a]	7.19[a]

[1]Means in the same column with the same superscript are not significantly different ($p<0.05$) as determined by Duncan test

Table 2.3 (continued)

State	Firmness	Crispness	Flavor	Color
Florida	3.11[a]	2.43[a]	8.28[a]	10.50[a]
Georgia	3.82[a]	2.72[a]	7.58[ab]	10.15[a]
North Carolina	3.61[a]	2.86[a]	6.63[b]	9.61[a]

[1]Means in the same column with the same superscript are not significantly different ($p<0.05$) as determined by Duncan test

Table 2.4: Consumer acceptability of crisp vs. non-crisp cultivars (n=786)

Rating	Non-Crisp (%)	Crisp (%)
Unacceptable	25.2	6.70
Acceptable	55.2	46.5
Superior	19.6	46.8
Acceptable +Superior	74.8	93.3

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CHAPTER 3

CRISP AND NON-CRISP SOUTHERN HIGHBUSH BLUEBERRIES AND THEIR FUNCTIONALITY IN A PIE APPLICATION

Introduction

Fruit pies are a popular dessert in the United States and can be filled with many types of berries, including blueberries. There are certain characteristics that consumers desire when eating a fruit pie. It is typically acceptable to have“medium flake” pastry dough, where the crust is evenly browned, flaky, and tender. The filling should be firm, smooth, and cooked consistently all the way through and not seep into the pie crust too much (Purdue University 2002). Blueberries contain pectin and starch, which play a major role in making blueberries a good gelling ingredient for pie. They contain 0.3 g of pectin per 73g of fresh blueberries (Marlett 1997). Crisp cultivars are more likely to withstand heat processing compared to non-crisp cultivars and do not tend to breakdown in certain baking applications (Council 2012). Results from an unpublished study investigating the application of radio frequency and precooking treatments in order to soften or ‘burst’ the crisp flesh berries show that sensory panelists prefer the pie slices with berries that had been subjected to this type of treatment. The researchers hypothesize that this was due to the fact that the berries became softer and juicier and thus provided a more favorable pie filling (McKenzie 2010).

There are some problems that consumers and processors confront when formulating a blueberry pie. The blueberry filling can break down and become “soggy or

flimsy". This defect can be due to yeast called *Candida tropicales* that grows on the surface of blueberries typically after harvesting. This yeast produces an α-amylase enzyme that builds up over time and breaks down the starches in the berry, therefore reducing the firm integrity of the skin. It is suggested to keep berries in a sanitary, cold, and dry environment to reduce yeast growth after harvest (Council 2012).

Difference tests are commonly used when there is an ingredient change to a formulation (Meilgaard 2007). They are often useful in baking and determining if a product is of acceptable sensory quality. Rasco *et al.* (1989) used difference testing when substituting dried grains from distilling production for soft winter wheat flour in baguettes, cinnamon rolls, and chocolate chip cookies. They found that panelists were unable to differentiate between the control and experimental cinnamon rolls and chocolate chip cookies (Rasco *et al.* 1989).

It is beneficial for blueberry growers to know that there is a consumer demand for the crisp or non-crisp varieties of blueberries. Also, knowing that there is versatility in their use, whether it is in baked goods or for eating them fresh, is important (Knapp 1971; Knapp and Sherman 1974).

It is not clear whether crisp and non-crisp blueberry cultivars can be used interchangeably in pies due to the crisp berries' firm texture. The objective of this study was to determine whether consumers could tell a difference between the southern highbush crisp and non-crisp blueberries and if they were acceptable for use in baking applications, more specifically blueberry pies.

Materials and Methods

Blueberry Pie Preparation

Blueberries obtained from Florida, Georgia, and North Carolina were used to formulate blueberry pies. Blueberries were stored in a cooler at 2°C for no longer than two weeks before being used. A blueberry pie formulation was retrieved from AllRecipies.com. Ingredients and amounts included: 177 g white sugar, 59 g cornstarch, 3.7 g salt, 74 g ground cinnamon, 591 g fresh blueberries, 1 frozen double crust pie, 15 g butter. The ingredients were tripled in order to make 3 pies at one time, which replicated three times for a total of nine pies for each trial. Nine cultivars were tested. Pies were made by combining the sugar, cornstarch, salt, cinnamon and then adding blueberries. Pies were baked in a convection oven at 210°C for 55 min, cooled for 30 min, wrapped with single layers of plastic wrap and aluminum foil and refrigerated at 2°C.

Figure 3.1. A photo of the crisp flesh pies after baking that was presented to panelists.

Sensory Evaluation

A triangle test was used for evaluation of crisp and non-crisp varieties in pies. A total of nine pies were baked for each consumer panel; 6 non-crisp pies and 3 crisp pies. For example, in the Florida evaluations, ‘Jewel’ and ‘Star’ were the genotypes in non-

crisp pies and ‘Sweetcrisp’ and ‘FL98-325’ in crisp pies. Thirty consumers participated in each difference test for a total of ninty participants. Brita-filtered water and unsalted-top Saltine crackers were provided to cleanse the palate between samples. A food reward was provided upon completion of the test.

Statistical Analysis

Data were analyzed using a Chi-Square test to determine significant differences.

Results and Discussion

The minimum number of correct responses required for significance at $\alpha=0.05$ is 15 and at $\alpha=0.10$ is 14 when there are thirty panelists. These results show that panelists were unable to tell a difference between the pies baked with crisp berries and the pies baked with non-crisp berries in this study (Table 3.1).

These results are similar to the results that Knapp (1971) found when he used rabbiteye blueberry cultivars and incorporated them into pie fillings. He compared them to common commercial pie fillings using a sensory panel that reflected preferences based on flavor and berry texture. Final results showed that these rabbiteye cultivars made in to pie fillings were of equal acceptability compared to those pie fillings currently on the market. Our results differ from those of McKenzie (2010) which showed a more marked difference between the pies from crisp and non-crisp berries. The inconsistency of crisp berries makes it difficult to draw firm conclusions.

Pie slices from those made with crisp berries were visually different from those made from non-crisp fruit. During the baking process the crisp fruit failed to burst and form the gel typically associated with non-crisp fruit. While panelists in this study were unable to differentiate the pies from the two types of fruit, we expect that experienced

bakers would be able to tell the difference upon slicing the pies. Thus, we believe that the crisp berries would have limited application in home baking, but would be acceptable for commercial pies.

Conclusions

Blueberries have become a very popular fruit choice, whether they are being used for fresh eating, freezing, or processing over the last couple of decades. It is helpful to investigate the versatility of various cultivars so that their functionality in cooking or baking applications is understood and used properly. The results from this study show that consumers are unable to detect differences in pie formulations between crisp and non-crisp cultivars of southern highbush blueberries. This study shows that there is potential for expansion into the processing market place for crisp southern highbush blueberries to be used not only for fresh consumption, but also for baking applications.

Table

Table 3.1. Difference test results for blueberry pies by state (n=30/state)

State	Incorrect	Correct
Florida	17	13
Georgia	19	11
North Carolina	20	10

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CHAPTER 4

SUMMARY AND CONCLUSIONS

Nine Southern highbush blueberry cultivars, four crisp and five non-crisp flesh, were evaluated for sensory and consumer acceptability. The significant differences in sensory quality between the two types of berries were in crispness and firmness. The differences in flavor and color quality of the selections were not significant. Consumers found the crisp-flesh blueberries to be superior to the non-crisp flesh cultivars. The quality model developed by Addington (2012) to predict consumer acceptability as a function of sensory descriptors was validated when one non-crisp cultivar was removed from the analysis.

In addition, crisp and non-crisp selections of Southern highbush blueberries were incorporated into pie formulations to identify whether consumers were able to detect the difference. Results showed that consumers were unable to detect differences in pie formulations.

Major conclusions from the study are:

- crisp flesh blueberries are more acceptable when consumed fresh than non-crisp cultivars,
- the Addington model predicts acceptability of Southern highbush blueberries as a function of critical sensory descriptors, and
- consumers were unable to detect a difference in pies baked with crisp berries from those with non-crisp flesh fruit.