CONSUMER ACCEPTABILITY AND QUALITY CHARACTERISTICS OF SWEET ONIONS AND NOVEL HIGHBUSH BLUEBERRY CULTIVARS

by

BENJAMIN KYLE ADDINGTON

(Under the Direction of Robert L. Shewfelt)

ABSTRACT

Southern highbush blueberries and sweet onions were evaluated by both descriptive and affective sensory panels to assess their quality characteristics and how they relate to acceptability by consumers. Two types of blueberries were evaluated—crisp flesh and non-crisp flesh berries. The novel crisp flesh berry genotypes were found to be acceptable to consumers and firmer, crisper, and sweeter than the non-crisp berries by the descriptive panel. The sweet onions were evaluated mainly for their sweetness and pungency by the descriptive panel. Mathematical models developed revealed that sweetness drives superior sweet onion eating quality, while increases in pungency resulted in onions with less acceptable eating quality. The experienced panel responses correlated moderately well with analytical measures of pungent onion volatiles.

INDEX WORDS: Sensory evaluation; consumer acceptability; quality; southern highbush blueberries; crisp-flesh; sweet onions; pungency

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BSA, The University of Georgia, 2010

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

MASTER OF SCIENCE

ATHENS, GEORGIA

2012

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May 2012

ACKNOWLEDGEMENTS

First, I would like to thank Dr. Robert Shewfelt for giving me the opportunity to work for him, his encouragement along the way, and his guidance. I could not have completed this degree without him. I would also like to thank my committee members Dr. Daniel MacLean and Dr. Hong Zuang for their participation and help with completing this degree. Big thanks to Katherine Robbins and Anne Morrison for their assistance and advice—I could not have done this without you both. To all the people who helped me with data collection and who participated in sensory panels: thank you so much, y'all are awesome. Last, but certainly not least, thank you to all my family and friends for their love and encouragement in this process.

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CHAPTER 1

REVIEW OF THE LITERATURE

Fresh Fruits and Vegetables

Systems Approach

The production and distribution chain for produce is a series of operations that may largely go unseen for the average consumer. Once harvested, commercial produce is usually packed either in the field or in a packing house, and transported either to a storage facility or the market for retail sale (Shewfelt and Prussia 2009). Storage of produce can range from hours to months depending on the season, market price, and suitability for storage of a commodity. The ultimate quality and shelf life of fresh fruits and vegetables is impacted strongly by not only their postharvest handling practices, but also by the factors that exist in the field up until harvest. These factors include genetics, soil chemistry, climate, fertilization, and water supply. Cultivars should have high yields, but also have uniform harvest maturity so that a single harvest can be employed (Shewfelt and Prussia 2009). Harvest date is dictated by several factors including maturity, yield, market prices, and labor prices. Processing of fruits and vegetables does not improve their quality, so the quality of the item as a raw material is the maximum quality possible in the final product. Therefore, agricultural products destined for both fresh market consumption and processing should be of the highest quality possible.

Vegetable Flavor Chemistry

Vegetable flavor and aroma compounds are commonly formed via enzymatic reactions that are the result of cellular damage. Like fruit flavor development, vegetable aroma and flavor precursors are compounds like fatty acids, carbohydrates and amino acids that once served the purpose of cell growth and proliferation. Once vegetable cells are disrupted, enzymes and precursors that previously were compartmentalized mix to create volatile compounds that we perceive as flavors and aromas. Thioglucosinolates and cysteine sulfoxides are the main vegetable flavor precursors, while lipid compounds play a secondary role through the lipoxygenase pathway. The classic example of cysteine sulfoxides as flavor and aroma precursors is the flavor development of onions, which is described in detail in the following section. Cruciferous vegetables including most leafy greens, broccoli, cauliflower, and radishes derive their flavor from glucosinolates (Reineccius and Heath 2006).

Climacteric Fruit Flavor Chemistry

Fruits differ from vegetables in their flavor development in that the former undergoes a ripening phase during which volatile flavor and aroma compounds are formed, while the latter does not. There are two main classes of fruit ripening: climacteric and non-climacteric. Climacteric fruits like bananas, tomatoes, blueberries, apples and pears are characterized as having an elevated respiration rate during ripening and a simultaneous release of ethylene gas (Pech and others 2008; Lelievre and others 1997). These fruits are those that possess the ability to continue the ripening process post-harvest. Ethylene is a phytohormone and once released it exhibits positive feedback, thus signaling the release of more ethylene. During the ripening period, climacteric fruits undergo drastic changes due to ethylene synthesis including the breakdown of cell walls by polygalaturonase, and, in some fruits, color changes from the breakdown of chlorophyll (Lelievre et al. 1997). Non-climacteric fruits only ripen while still affixed to the plant and do not continue flavor development post-harvest. Other than their ability to ripen on or off the plant, climacteric and non-climacteric fruits undergo similar flavor development from flavor precursor compounds that were previously used for growth.

Sweet Onions

Onion Flavor Chemistry

Onion flavor is derived mainly from the hydrolysis of S-alk(en)yl cysteine sulfoxides (ACSOs) that are the result of sulfur nutrition from the soil. The reaction is catalyzed by an enzyme innate to the *Allium* genus: alliinase. These ACSOs are what will determine the flavor and pungency of an onion (Randle and others 1995). ACSO synthesis begins in the onion plant when sulfate (SO_4^{-2}) is absorbed from the soil, reduced to sulfide (S^{-2}), and is used to form cysteine (Lancaster and Shaw 1989; Randle et al. 1995). This cysteine is then used in the glutathione cycle to form γ-glutamyl peptides which are the intermediate compounds that will become the ACSOs (Lancaster and Shaw 1989). An abundance of sulfur in the soil will result in an onion that develops more of these compounds, thus one that has a stronger flavor profile, while the opposite is also true.

Prior to cell rupture, the ACSO compounds are stored in the cytoplasm while alliinase is stored in the vacuole (Lancaster and Shaw 1989). There are three main ACSO compounds found in onions: methyl cysteine sulfoxide (MCSO), propyl cysteine sulfoxide (PCSO), and 1-propenyl cysteine sulfoxide (1-PRENCSO). Once the cells are damaged the ACSOs are hydrolyzed by alliinase to create sulfenic acids, mainly 1-propenesulfenic acid which will be converted to the lachrymatory factor (LF) propanethial S-oxide, and thiosulfinates (Block and others 1992; Schmidt and others 1996). The various thiosulfinates formed are responsible for the flavor and aromas commonly associated with onions. Propyl-type thiosulfinates give onions their raw onion flavors while the methyl-type can contribute a cabbage-like flavor (Randle 1997).

Pungency

The factors affecting an onion's pungency can be put into two categories: environmental and genetic. These environmental factors include irrigation, temperature, and soil nutrition/composition (Platenius and Knott 1941; Yoo and others 2006; Hamilton and others 1997). While these environmental factors play a large role in final onion pungency, genetics have been found to play an even bigger role (Yoo et al. 2006; Platenius and Knott 1941). The explanation of cultivar factors having such an impact is based on the belief that certain cultivars may more readily uptake sulfur than others and that some cultivars may produce varying ratios of ACSOs (Randle 1997). It should also be noted that even though genetics play a large role, identical cultivars grown under different conditions, during different years and in different locations can have different flavor profiles. Sulfur content in the soil and its effect on onion flavor and pungency has been well-researched due to sulfur's role in onion flavor compounds.

Even within an onion, flavor intensities can vary depending on where in the onion samples are taken. Freeman (1975) found that flavors were the most intense towards the center and the roots of the bulb, while the least intense flavors were found towards the stalk and the outer leaves.

The LF compound has been determined to be responsible for burning of the mouth and eyes as well as the main compound responsible for the perceived sensation of pungency (Randle 1997; Yoo et al. 2006; Schmidt et al. 1996). With increasing interest in plant breeding methods of quantifying and modifying onion flavor have been developed. In addition to volatile flavor and aroma compounds being formed by the reaction by alliinase, both ammonia and pyruvate are also formed. This enzymatically produced pyruvate (EPY) became the gold-standard for estimating onion pungency when Schwimmer and Weston developed the method for its measurement in 1961. Their method involved pureeing onions, purification, and separating the juice from the solid matter before being analyzed spectrophotometrically (Schwimmer and Weston 1961). Randle and Bussard (1993b) improved upon the method of Schwimmer and Weston by utilizing a crusher to simply juice the onion which reduced the time necessary to obtain results. Research has classified the concentration of pyruvate to certain degrees of pungency. Generally, 0 to 4 µmol pyruvate per gram are classified as mild or sweet and >8 µmol pyruvate per gram as pungent (Schwimmer and Weston 1961; Lee and others 2009; Dhumal and others 2007).

Acceptability

Onions are vegetables consumed world-wide for its characteristic flavor-enhancing properties. When eating onions, especially raw or minimally processed, consumers prefer an onion with a sweeter, milder, less pungent flavor profile (Centner and others 1989; Smittle and others 1979). According to Smittle and others (1979), sweet onions are those that satisfy these flavor requirements and consumers are willing to pay a higher price for these attributes. The demand and preference for these sweet onions has resulted in some types being protected under trademark including Vidalia and Walla Walla sweet onions.

Blueberries

Crisp vs. Non-Crisp Flesh

Texture, along with appearance and flavor, is one of the important indicators of quality and freshness in fresh fruits (Chiabrando and others 2009). In some fruits like peaches and melons, a less firm or mushy texture is preferred while the opposite can be true for others, like apples. New cultivars of southern highbush blueberries are being developed that possess texture profiles that are more firm. These blueberries are being referred to as “crisp flesh” berries. As their name implies, they have a flesh that is crisp and a texture that is firmer than a traditional southern highbush blueberry (Li and others 2011). The texture of these berries might best be likened to that of grapes—they have a tight skin with a bursting-like effect when chewed. There has been some difficulty in the literature for delineating this crisp characteristic, but it has been determined that consumers could differentiate this texture (Padley and Lyrene 2006). Their traditional southern highbush counterparts have been termed “non-crisp flesh” berries and this nomenclature will be used interchangeably for the remainder of this work. Similar terminology, melting-flesh (MF) and nonmelting-flesh (NMF), has been used to describe the texture of peaches with the latter indicating peaches with a more firm texture (Brovelli and others 1998a).

Harvesting Methods

There are two methods used for harvesting blueberries: hand-picking and mechanical harvesting. Highbush blueberries, which are almost always destined for fresh market consumption, are typically hand-picked to preserve quality (Takeda and others 2008; Ehlenfeldt 2005; Yu and others 2011). Yields for hand-picked berries are significantly higher than those for mechanical harvesting, but this is most likely due to losses to the ground and picking under ripe fruit by the mechanized harvesters (Van Dalfsen and Gaye 1999). A problem facing the highbush blueberry industry is the expense associated with this harvesting method with the rising costs of manual labor. Mechanical harvesting costs less than half as much as it does to hand-pick Rabbiteye blueberries (Takeda et al. 2008). While the choice seems as easy as switching to mechanical harvesting for highbush berries to lower costs there is a trade-off in quality of the harvested fruit. The problem with mechanical harvesting blueberries for the fresh market is the incidental bruising that results in undesirable appearance, accelerated decay and shriveling (Ehlenfeldt 2005; Yu et al. 2011; Ballinger and others 1973). Brown and others (1996) found that 77% of the hand-harvested traditional highbush berries in their experiment had either no damage or slight bruising, while 22% of those that were harvested with a conventional mechanical harvester had no damage or slight bruising. Rabbiteye blueberries that were hand-picked were found to be 29-37% more firm than those harvested by machine (Austin and Williamson 1977). The crisp flesh blueberries have been developed with the purpose of having a more firm flesh that could stand up to the rigors of mechanical harvesting, but also may have a pleasing texture for consumers. Similar attempts have been made to breed peaches that have firmer, nonmelting-flesh to mitigate damage from mechanical harvesting methods (Brovelli et al. 1998a).

Flavor Development

Flavor development in fruits occurs during the ripening period when metabolic reactions cease and catabolic reactions being to take place (Reineccius and Heath 2006). Aroma compounds in fruits are typically volatile compounds with very low aromatic thresholds. Even small quantities of precursor compounds can result in aroma compounds that are quite evident. The major aromatic volatile categories that are typically found in highbush blueberries include are aldehydes, terpenoids, alcohols and esters (Du and others 2011; Parliment and Kolor 1975). Of these, aldehyde compounds comprised the largest portion of total volatiles in four select highbush cultivars, ranging from 54-77% of the total volatiles (Du et al. 2011). These compounds are formed from the degradation of amino acids, fatty acids and various carbohydrates in the fruit once ripening begins (Reineccius and Heath 2006). Previously used for cell metabolism, but no longer needed for growth, amino acids and carbohydrates are acted on by enzymes when cells begin to break down—volatile aromatic compounds are the result. Compounds like α-terpineol, geraniol, and linalool were found to be the predominant terpenoid compounds in highbush blueberries (Du et al. 2011; Parliment and Kolor 1975). In the fragrance and flavor industries, linalool is sometimes used as a blueberry aroma impact compound (Arctander 1969). Like aldehydes, the precursor compounds for terpenoids are typically carbohydrates (Reineccius and Heath 2006). Aldehyde volatiles are responsible for "green" or grassy-like aromas, while terpenoid volatiles are responsible for floral or rose-like aromas (Du et al. 2011). The last major constituents of blueberry volatiles belong to the alcohol group. Alcohols like 1-heptanol, 2-heptanol, hexanol, and trans-2-hexenol were found in the highest concentrations of the alcohols and are typically responsible for grassy aromas (Parliment and Kolor 1975; Du et al. 2011).

Acceptability

Acceptability of a food by consumers is an extremely complex combination of numerous factors including not only the characteristics of the product itself, but also the price and health benefits/disadvantages that the product confers (Shewfelt 2000). Popularity of blueberries has increased greatly due to research into their potential health benefits. Saftner and others (2008) sought to link quality characteristics to blueberry acceptability and determined that berries with a bright blue color were rated as more acceptable. Berry size correlated positively with acceptability as did extract pH, thus larger berries and berries with higher pH values were given higher acceptability ratings (Saftner et al. 2008). Chiabrando and Giacalone (2008) found the opposite effect for berry pH and acceptability, but found positive correlations between crispness and firmness with overall appreciation.

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CHAPTER 2

SWEET ONION PUNGENCY AND ACCEPTABILITY

Abstract

It is not clear whether sweetness of sweet onions is due to the presence of sugars, the absence of pungency or a combination of the two. Six cultivars of sweet onions from Georgia were evaluated by an experienced panel for sweetness, bitterness, and pungency and compared with responses of a consumer panel for acceptability. In a separate experiment evaluations of the experienced panel were compared with instrumental measures of pungency and relevant volatile components. Significant differences among the cultivars were observed for sweetness and pungency but not for bitterness. Mathematical models relating consumer acceptability to sensory quality suggest that sweetness is related to superior quality of sweet onions and that increased pungency decreases acceptability. Chemical determination of pungency showed a significant positive correlation with sensory pungency and lachrymatory factor.

Introduction

Onion flavor chemistry involves a complex combination of reactions that result from damage to cell membranes. Once onion cells are damaged, sulfur-containing compounds react with an enzyme innate to members of the *Allium* genus, alliinase, to produce pungent and volatile flavor compounds (Schmidt et al. 1996; Yoo et al. 2006). During mastication S-alkenyl cysteine sulfoxide compounds are released and react with alliinase to form volatile flavor compounds, mainly propanethial S-oxide (lachrymatory factor; LF) and other thiosulfinates as well as pyruvic acid (Randle and Bussard 1993a; Yoo et al. 2006; Schmidt et al. 1996; Wall and Corgan 1992). Schmidt and others (1996) and Yoo and others (2006) report that the most important of these compounds in reference to the perception of pungency is LF. The concentration of sulfur-containing compounds in the sweet onion and its pungency is influenced by several factors including: cultivar/genetics, soil type/composition, growing temperature, and irrigation (Randle and Bussard 1993a; Platenius and Knott 1941). Of these, genetic factors and soil type have the most significant effect on pungency (Platenius and Knott 1941).

The most common instrumental method to measure onion pungency, pyruvic acid determination (PDA), was developed by Schwimmer and Weston (1961), but the method can be costly and inconvenient. The standard method measures the amount of enzymatically produced pyruvate spectrophotometrically. Several modifications to of this method have been made in the years since, but the most notable was that of Randle and Bussard (1993b). Instead of the time-consuming maceration and filtration steps developed by Schwimmer and Weston, Randle and Bussard employed a pneumatic piston to press an onion through a screen to obtain the juice.

Sensory measures have been used to evaluate onions for pungency, but with some variability (Vagen and Slimestad 2008; Randle and Bussard 1993b).

When eating onions, especially raw, consumers prefer ones with a milder, less pungent flavor and are willing to pay a premium price (Smittle et al. 1979; Centner et al. 1989). With so many factors affecting pungency year-to-year inconsistencies exist so effective methods to measure onion pungency are necessary to ensure a product that consumers will accept (Vavrina and Smittle 1993). The specific contributions of sweet and pungent compounds to consumer acceptability of sweet onions are not clear. Crowther and others (2005) suggest that the absence of pungent compounds is directly related to acceptability.

The objectives of this study were to determine what quality characteristics drive consumer acceptability of sweet onions, to develop mathematical models to predict consumer acceptability of sweet onions, and to determine the relationship between sensory and instrumental measures of onion pungency.

Materials and Methods

<u>Sweet Onions:</u>

Six sweet onion cultivars were provided by The University of Georgia's Vidalia Onion & Vegetable Research Center in Lyons, Georgia: 'Nunhems 1006', 'Nunhems 1008', 'Savannah Sweet', 'Sweet Vidalia', 'Granex Yellow PRR', and 'Sapelo Sweet'. The cured onions were transported back to the Athens campus in onion sacks by van and stored in sacks in a 40°F refrigerator until use. The onions were harvested in late April and were assessed by panels during the first weeks of August.

Instrumental Analysis:

Onions were divided in halves with one half of each onion shipped overnight to Georgia Southern University for instrumental analysis and the other half retained for sensory analysis. Instrumental measurement was conducted using the methods outlined in Schmidt and others (1996). Pungency was determined using a modified version of the Schwimmer and Weston (1961) method of the pyruvic acid determination described by Randle and Bussard (1993b). Degrees Brix were measured using a 0-18° Brix Fisher Refractometer (Model #13-946-20; Fisher Scientific, Pittsburgh, PA).

Experienced Sensory Panels:

A ten member experienced panel evaluated the onion samples for three sensory descriptors: sweetness, bitterness, and pungency. The onions were evaluated once a week for four weeks. Approximately 1-2 hours before the panels, the onions were sliced into wedges in an attempt to get all onion leaves in each sample. The onion wedges were then put into coded cups with lids and refrigerated until evaluation. The panelists rated each descriptor on a 4-point scale: 1=not sweet/bitter/pungent, 2=slightly sweet/bitter/pungent, 3=sweet/bitter/pungent and 4=very sweet/bitter/pungent. Panelists were instructed to first chew the onion sample with a closed mouth to evaluate for sweetness and bitterness. Then, once sweetness had been assessed, the panelists were instructed to open their mouths to evaluate for pungency as the burning or stinging of the mouth and/or nose. Before and after each sample the panelists were instructed to cleanse their palates with water and unsalted crackers that were provided. Three samples were tested at each session.

Consumer Testing:

Consumer testing was conducted on two separate days at two different locations on the University of Georgia campus. A total of 199 consumers tasted three onion samples in a balanced order so that each onion sample was presented in each position: first, second, or third. The samples were prepared exactly as for the experienced panels, and given randomly generated codes different than those used in the experienced panel. Consumers evaluated three onion samples on a 3–point acceptability scale as described by Dubost and others (2003) ballot: 1=unacceptable, 2=acceptable or 3=superior onion flavor. After tasting the onion samples the participants were then asked to complete a brief questionnaire on sweet onion purchasing habits/trends.

Statistical Analysis:

The statistical analyses conducted were ANOVA with post-hoc Duncan's Multiple Range Test and multiple regression with backwards elimination using SAS 9.2 statistical software (SAS Institute Inc., Cary, North Carolina). Statistical models were developed by equating consumer test responses to experienced panel responses and analyzing their significance with a backward variable elimination. Correlation analysis was conducted using a Pearson product-moment correlation of the instrumental analyses with the experienced panel using SAS 9.2 statistical software (SAS Institute Inc., Cary, NC).

Results

<u>Experienced Panel:</u>

Significant differences were observed for sweetness and pungency but not bitterness among the six cultivars evaluated by the experienced panel (Table 2.1). ‘Sapelo Sweet’ was rated as the most pungent but also as the least sweet. ‘Sweet Vidalia’ was given the highest sweetness rating, while ‘Nunhems 1006’ was given the lowest pungency score.

<u>Consumer Evaluation:</u>

‘Sweet Vidalia’ onions were the rated as having the highest percentage of “superior” ratings, while ‘Savannah Sweet’ received the highest percentage of “unacceptable” ratings. ‘Sapelo Sweet’ received the lowest percentage of “unacceptable” ratings, meaning that it received the highest number of ratings “acceptable” or better (Table 2.2).

The consumers who participated were asked to complete a short questionnaire concerning their onion purchasing habits and expectations. Their responses were compiled and are displayed in Table 2.3. The results revealed that most consumers (86.9%) purchase their sweet onions at a supermarket and that the onions that consumer purchase most were sweet onions (70.9%) and yellow onions (43.7%). When asked where onions were stored in the home after purchase, 49.8% of the participants responded “in the refrigerator” and most, 51.8%, expected a shelf life of 2-4 weeks. The most important purchasing characteristic to consumers was appearance (59.3%), while the most important consumption characteristic was taste (65.3%).

When asked if they were willing to accept onions that had been scanned using X-rays to detect internal defects 77.9% of the consumers responded “yes,” 14.6% responded “no,” and 7.0% were unsure. Finally, 82.9% of the consumers were generally satisfied with the onions available in the supermarket currently while 1.5% were not. Those that were not satisfied cited short shelf life and some quality defects as the reason for their dissatisfaction.

Linking Consumer Acceptability and Sensory Descriptors:

No mathematical models for consumer acceptability as a function of sensory quality were significant when incorporating all six cultivars. The most likely explanation is that the differences between the six were so small that the consumer panel was unable to differentiate them. When the three most different cultivars – ‘Nunhems 1006’ (lowest pungency and medium sweetness), ‘Sweet Vidalia’ (highest sweetness and lower pungency), and ‘Sapelo Sweet’ (lowest sweetness and highest pungency) – were analyzed the significant models shown below were developed:

$$\%\ \text{Superior Responses} = 36.54 + (0.81 \times \text{Sweetness}) \quad R^2 = 0.16;\ \text{p-value} = 0.03$$

$$\%\ \text{Superior} + \text{Acceptable Responses} = 86.71 + (0.27 \times \text{Pungency}) \quad R^2 = 0.21;\ \text{p-value} = 0.01$$

These models demonstrate that superior sweet onion flavor is related to its sweetness. The model for superior and acceptable responses suggests that increased pungency is the factor that differentiates superior from acceptable sweet onions. Additional studies would need to be completed to confirm this observation.

Comparison of instrumental and sensory measures of pungency:

Statistical analysis revealed that a panel assessment and instrumental measures of pungency were positively correlated (r=0.56, p=0.01) (Table 2.4). The lachrymatory factor (LF) also had a moderately positive correlation (r=0.52, p=0.02) with analytical pungency.

Discussion

A possible explanation for the small differences observed in the six cultivars could be that a moderation of pungency in the three months of storage after harvest. Kopsell and Randle (1997) reported both increases and decreases in pungency of short-day onions as storage time increased. Results from this experiment confirmed that consumers desire sweeter, mild onions especially when consumed raw and that pungency can reduce consumer acceptability of a sweet onion (Centner et al. 1989; Smittle et al. 1979). It is still not clear whether acceptability is related strictly to the absence of pungency or increased levels of sugars when pungency is low. Research by Wall and Corgan (1992) compared enzymatically produced pyruvate values for pungency with sensory scores for pungency over several years and found that the scores correlated very strongly (r>0.79). Crowther and others (2005) also found a strong relationship (r=0.90) between pyruvate measurements and a composite sensory score for pungency they named "strength."

It is clear that results from an experienced panel and instruments for sweet onion pungency can be related with moderate success. A moderate and significant correlation between pungency values and LF confirms that LF and enzymatically produced pyruvate are fair predictors of each other.

Table 2.1: Sensory quality of six cultivars of sweet onions (n=10)

Cultivar	Bitterness	Sweetness	Pungency
Savannah Sweet (A)	2.1^{a}	2.8^{a}	2.3^{ab}
Nunhems 1006 (B)	1.4^{a}	2.3^{ab}	1.7^{b}
Nunhems 1008 (C)	1.3^{a}	2.6^{ab}	2.1^{ab}
Sweet Vidalia (D)	1.7^{a}	2.9^{a}	2.1^{ab}
Granex Yellow PRR (E)	2.0^{a}	2.9^{a}	2.7^{a}
Sapelo Sweet (F)	2.0^{a}	1.9^{b}	2.7^{a}

[1]Means in the same column with the same superscript are not significantly different ($p<0.05$) as determined by Duncan's Multiple Range Test.

Table 2.2: Sweet onion consumer panel results by cultivar.

Rating	Savannah Sweet (A)	Nunhems 1006 (B)	Nunhems 1008 (C)	Sweet Vidalia (D)	Granex Yellow PRR (E)	Sapelo Sweet (F)
Unacceptable	18	13	14	13	15	12
Acceptable	53	49	55	46	51	52
Superior	29	38	31	41	34	36
Superior + Acceptable	82	87	86	87	85	88

[1] Reported as percentages of total responses per cultivar.

Table 2.3: Results from consumer test questionnaire

Question	Responses	% of Total Consumers
Gender		
Male	94	47.2
Female	105	52.8
Age		
18-29	146	73.4
30-39	15	7.5
40-49	18	9.1
50+	20	10.1
Where do you purchase sweet onions?		
Supermarket	173	86.9
Farmers Market	20	10.1
Roadside Stand	9	4.5
Other	9	4.5
What types of onions do you purchase?		
Sweet	141	70.9
Yellow	87	43.7
Red	73	36.7
Green	28	14.1
White	36	18.1

Table 2.3 (continued)

Important purchasing characteristics		
Label	12	6.0
Aroma	13	6.5
Appearance	118	59.3
Size	57	28.6
Other	22	11.1
Important consumption characteristics		
Taste	130	65.3
Aroma	19	9.6
Firmness	62	31.2
Other	22	11.1
Where do you store onions in your home?		
Refrigerator	99	49.8
On counter	56	28.1
Under counter	14	7.0
Stocking	5	2.5
Other	31	15.6
Expected onion shelf life		
<2 weeks	59	29.7
2-4 weeks	103	51.8
5-8 weeks	17	8.5
9-12 weeks	4	2.0
>12 weeks	1	0.5

Table 2.3 (continued)

Would you accept onions that have been scanned with X-rays?		
Yes	155	77.9
No	29	14.6
Depends	14	7.0
Generally satisfied with onions currently available at supermarket?		
Yes	165	82.9
No	3	1.5
Depends	9	4.5

[1]For some questions consumers could select more than one answer

Table 2.4: Pearson Correlation coefficients (r) for instrumental and sensory measures of onion pungency

	°Brix	Pungency	LF	Mean Panel Score
°Brix	1.0	0.07	-0.15	0.19
Pungency	-	1.0	**0.52**	**0.56**
LF	-	-	1.0	0.26
Mean Panel Score	-	-	-	1.0

[1]Bold values indicate those that were significant ($p<0.05$)

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CHAPTER 3

NOVEL BLUEBERRY CULTIVAR QUALITY CHARACTERISTICS AND ACCEPTABILITY

Abstract

Ten genotypes of southern highbush blueberries (four “crisp flesh” and six “non-crisp flesh”) from northern Florida, southern Georgia, and eastern North Carolina were evaluated by 288 consumers and 10 experienced sensory panelists. The objectives of this experiment were to determine both the acceptability of crisp-flesh genotypes and the quality characteristics drive consumer acceptability of blueberries. Consumers were asked to rate the acceptability of the berries as superior, acceptable, or unacceptable. More of the crisp flesh berries (45.5%) were rated as superior when compared with the non-crisp (26.4%) demonstrating that consumers are likely to accept the crisp fleshed berries. The experienced panel evaluated the same treatments and with the crisp-flesh genotypes scored as firmer, crisper, sweeter and less sour. Mathematical models revealed that blueberry-like flavor, crispness, and firmness were the critical characteristics in determining superior quality of fresh berries with sourness as the differentiating factor between superior and acceptable fruit.

Introduction

With increasing research and interest in the area of functional foods and functional food ingredients over the past several decades, both blueberry production and consumption have more than quintupled from 1980 to 2009 (USDA Economic Research Service, 2010). The quality of fruits and vegetables destined for the fresh market must be optimized within the postharvest handling system. The quality of these perishable items decreases rapidly over time. Maturity at harvest, handling and distribution practices, and durability of the fruit or vegetable all contribute to consumer acceptability (Shewfelt 2000).

The increased consumption of blueberries has led to the development of cultivars of that are able to withstand the rigors of harvesting and postharvest handling better to ensure optimal quality at the point of purchase (Saftner et al. 2008; Silva and others 2005). Some of these new cultivars are being referred to as "crisp flesh" blueberries by researchers and their acceptability to consumers has not yet been investigated extensively. By having firmer berries fewer defects, such as decay from mechanical harvesting damage, could result in the consumer obtaining a superior quality fruit that results in repeat purchase (Silva and others 2005). Maintenance of firmness at harvest and through distribution to the consumer has had a mixed history in relation to consumer acceptability. Cling (non-melting flesh) peaches have superior shipping and storage stability by maintaining firmness during distribution (Ben-Arie and others 1970) with superior appearance at a sacrifice of flavor (Bruhn 1995; Brovelli and others 1998b). Likewise harvest of mature-green tomatoes favors shippability, appearance and maintenance of firmness at the cost of fresh-tomato flavor (Bruhn and others 1991; Shewfelt and others 1987; Causse and others

2003). Crisp-flesh grapes do not appear to sacrifice flavor (Rolle and others 2011), but there are no definitive consumer studies on these selections.

The objectives of this study were to determine consumer acceptability of crisp-flesh blueberries relative to their non-crisp counterparts and the quality characteristics that drive consumer acceptability for fresh blueberries. Mathematical models to predict acceptability were developed linking descriptive notes and consumer acceptability scores.

Materials and Methods

<u>Blueberries:</u>

A total of ten different blueberry genotypes were evaluated, four crispy flesh (‘Sweetcrisp’, ‘Bluecrisp’, ‘Reveille’, ‘Farthing’) and six non-crispy (‘Star’, ‘Scintilla’, ‘Biloxi’, ‘Legacy’, ‘Emerald’, and ‘B1’). The cultivars and advanced selection were provided by research stations in Florida, Georgia, and North Carolina. Berries were harvested by hand at peak freshness and transported back in coolers packed with ice by van to the University of Georgia campus in Athens, GA where they were stored at 40°F until use. No longer than 2 weeks elapsed between receipt of berries and sensory testing.

<u>Experienced Panel:</u>

A ten-member experienced panel was familiarized with the definitions of nine quality characteristics: sweetness, sourness, bitterness, astringency, blueberry-like flavor, color, crispness, juiciness, and firmness. Descriptor definitions and appropriate scales were developed using standards outlined by Meilgaard and others (2007) and are displayed in Table 3.1. A 15 cm unstructured line scale was used for each descriptor and panelists indicated the intensity for each characteristic. Sample cups were coded with randomly generated 3-digit numbers.

Consumer Panel:

A total of 288 consumers evaluated three blueberry cultivars on three separate dates, one for the crop from each state. At least one of the genotypes tested by each consumer was crispy and at least one of them was non-crispy, with a balanced presentation order so that each sample was sampled in each position. Participants were not aware of the study's goal and were asked to rate the blueberry samples as superior, acceptable, and unacceptable without comparing the samples to each other as described by Dubost et al., 2003. After completing the test ballot, the consumers were asked to complete a short questionnaire about blueberry purchasing habits/trends. Consumer tests were conducted within 2 days of the sensory tests for the comparison of the data sets.

Statistical Analysis:

The statistical analyses conducted were ANOVA ($p<0.05$) and Tukey-Kramer mean separation test using SAS 9.2 statistical software (SAS Institute Inc., Cary, North Carolina). Statistical models were developed by equating consumer test responses to experienced panel responses and analyzing their significance with a backward variable elimination.

Results

Experienced Panel:

The analysis of variance revealed that there were significant differences ($p<0.05$) in sweetness, sourness, firmness, and crispness between the cultivars (Table 3.2). As expected, the crisp-flesh genotypes were rated as firmer than those that were not crisp. Likewise the crispness descriptor all of the crisp genotypes were rated higher with the exception of 'Biloxi' which was rated as more crisp than 'Farthing' generally considered as crisp flesh. 'Sweetcrisp' from both Florida and Georgia were rated as having the most blueberry-like flavor and firmness by the panel. Florida-grown 'Sweetcrisp' also was rated highest in sweetness and crispness. 'B1' (from Georgia) had the lowest ratings for sweetness, blueberry-like flavor, firmness, crispness, and color while also being rated as the most bitter. The genotypes did not significantly differ from each other in bitterness, astringency, blueberry-like flavor, juiciness, or color.

Consumer Panels:

More crisp-flesh blueberries were rated as "superior" (45.5%) when compared to the non-crisp genotypes (26.4%). The Georgia and Florida-grown 'Sweetcrisp' received the highest percentages of superior ratings (65.3% and 50%, respectively). 'Legacy' and 'Scintilla' received the highest acceptable ratings (68% and 63%, respectively). 'B1' received the highest number of "unacceptable" ratings (37.5%). The results are displayed in Table 3.3.

The consumers who participated were asked to complete a short questionnaire concerning their blueberry purchasing habits and expectations. Their responses were compiled and are displayed in the Table 3.4 at the end of the chapter. The results revealed that most consumers who participated purchase their fresh blueberries at a supermarket between one and three times per month. When purchasing blueberries, their appearance and size appeared to be the most important characteristics, while the important consumption characteristics were taste and berry firmness. Almost 90% of the consumers questioned responded that they store fresh blueberries in the refrigerator and most (75.7%) expect a shelf life of around 1 week. Overall, almost half of the consumers indicated that they were satisfied with the blueberries available in the supermarket. If the consumer did not purchase blueberries at a supermarket they were instructed to not put a response. The consumers who did not indicate satisfaction with supermarket blueberries cited seasonal differences, low firmness, sourness, poor flavor, and price as their reasons for their dissatisfaction.

Linking Consumer Acceptability to Experienced Panel:

By comparing the percent rated as superior for each cultivar by the consumers to the experienced panel responses significant models were created. To estimate the percent superior berries and percent of berries that are acceptable:

$$\% \text{ Superior Berries} = 15.19 + 0.64 \times \text{Blueberry Flavor} + 2.04 \times \text{Firmness} + 3.53 \times \text{Crispness}$$

$$\% \text{ Superior} + \% \text{Acceptable} = 71.46 + 0.66 \times \text{Sourness} + 0.72 \times \text{Blueberry Flavor} + 1.39 \times \text{Firmness} + 1.41 \times \text{Crispness}$$

These models show that blueberry-like flavor, firmness, and crispness are the critical quality characteristics for predicting consumer acceptability of blueberries. The model for berries that were acceptable and superior indicates that sourness differentiates acceptable from superior fruit.

Discussion

The introduction of crisp-flesh cultivars has presented challenges in classifying them and measuring textural properties (Li et al. 2011). Since the description of crispness represents more of an auditory characteristic, it is unclear how to differentiate crisp and non-crispy berries. Chiabrando and others (2006) cite blueberry firmness-to-the touch as one of the most important purchasing characteristics for consumers. A berry with a higher initial firmness could result in one that retains its firmness longer, thus prolonging the apparent shelf-life of the fruit to consumers (Ehlenfeldt 2005). Additional studies have shown that panelists tend to prefer blueberries with a firmer texture (Sousa and others 2006; Almenar and others 2010).

It is clear that consumers in the present study preferred the crisp-flesh blueberries to the non-crispy types in this study. In addition to the textural differences observed in the two types of fruit, the crisp berries were sweeter and less sour than their non-crispy counterparts. Thus, it becomes premature to conclude that the selective breeding for crisp-flesh berries represents an improvement. Factors such as harvest maturity, growing location, cultural factors and postharvest physiology can all affect blueberry quality (Du et al. 2011) and thus consumer acceptability. The tests clearly establish that consumers will accept crisp-flesh blueberries and that crispness is a positive attribute. We used the scale for consumer acceptability described by Dubost and others (2003), as it provides a more realistic assessment of how actual consumer reaction to food than Hedonic scales which attempt to infer acceptability from an expression of liking. The three-point scale is grounded in quality theory (Deming 2000) of exceeding, meeting and failing to meet expectations. Such a scale is more likely to provide external validity as described by van Trijp and Schifferstein (1995) than the more frequently used nine-point Hedonic scale.

Table 3.1: Descriptors, their definitions (some adapted) used, and reference samples used for the blueberry experienced panel (Meilgaard et al. 2007)

Descriptor	Definition/Instructions	Reference Sample and Intensity
Sweetness	Taste stimulated by sucrose and other sugars, such as fructose, glucose, etc.	Cane Sugar Intensity 5
Sourness	Taste stimulated by acids, such as citric, malic, phosphoric, etc.	Citric Acid Intensity 2
Bitterness	Taste stimulated by substances such as quinine, caffeine, and hop bitters.	Caffeine Intensity 2
Astringency	The shrinking or puckering of the tongue surface caused by substances such as tannins or alum.	Alum Intensity 2
Blueberry-Like Flavor	The flavor one would expect when eating a blueberry.	--
Firmness	The force to attain a given deformation. Use molars to determine the amount of force necessary to deform the blueberry.	Queen Size Olives with pimento removed Intensity 6
Crispness	The force and noise with which a product breaks or fractures when chewed with the molar teeth.	Club Cracker Intensity 5
Juiciness	The amount of juice/moisture perceived in the mouth. Chew sample with molar teeth for up to 5 chews.	Cucumber Intensity 8
Color	Blue color intensity from light to intense	Light=1 Medium Light=4 Medium= 7.5 Medium Intense= 11 Intense= 14

Table 3.2: Average panel responses for blueberry quality characteristics (n=10)

Cultivar	Sweetness	Sourness	Bitterness	Astringency	Blueberry-Like Flavor	Firmness	Crispness	Juiciness	Color
Sweetcrisp (FL)[2]	5.6^{a}	3.08^{abc}	0.41^{a}	1.25^{a}	8.16^{a}	4.91^{a}	3.75^{a}	6.41^{a}	9.97^{a}
Farthing (FL)[2]	4.08^{ab}	2.68^{bc}	0.60^{a}	1.19^{a}	5.48^{a}	4.45^{ab}	2.48^{ab}	5.80^{a}	8.05^{a}
Scintilla (FL)	4.30^{ab}	3.11^{abc}	0.52^{a}	1.26^{a}	6.81^{a}	2.82^{bc}	1.64^{bc}	6.50^{a}	7.83^{a}
Star (FL)	3.90^{ab}	3.82 ^{abc}	0.38^{a}	1.26^{a}	5.63^{a}	3.17^{abc}	2.16^{abc}	6.37^{a}	10.23^{a}
Sweetcrisp (GA)[2]	5.36^{ab}	2.59^{abc}	0.29^{a}	0.86^{a}	6.93^{a}	4.50^{ab}	3.43^{ab}	5.14^{a}	8.29^{a}
Bluecrisp (GA)[2]	4.50^{ab}	0.64^{c}	0.56^{a}	0.76^{a}	5.50^{a}	4.16^{ab}	3.50^{ab}	5.14^{a}	8.14^{a}
B1 (GA)	2.36^{b}	2.00^{bc}	1.14^{a}	1.40^{a}	3.36^{a}	1.29^{c}	0.57^{c}	5.79^{a}	7.07^{a}
Emerald (GA)	3.07^{ab}	3.36^{abc}	0.50^{a}	0.91^{a}	4.71^{a}	2.50^{bc}	1.50^{bc}	4.21^{a}	7.21^{a}
Reveille (NC)[2]	5.42^{ab}	2.34bc	0.52^{a}	1.08^{a}	4.79^{a}	4.42^{ab}	3.60^{a}	5.82^{a}	8.62^{a}

Table 3.2 (continued)

Biloxi (NC)	3.28^{ab}	5.80^{a}	0.53^{a}	1.64^{a}	6.49^{a}	3.77^{ab}	2.97^{ab}	7.20^{a}	8.99^{a}
Legacy (NC)	3.86^{ab}	4.81^{ab}	0.74^{a}	1.63^{a}	5.87^{a}	3.70^{ab}	1.59^{bc}	6.04^{a}	9.97^{a}

[1]Means in the same column with the same superscript are not significantly different ($p<0.05$) as determined by Tukey-Kramer test.
[2]Indicates genotypes with crisp-flesh

Table 3.3: Consumer acceptability of crisp vs. non-crisp cultivars

Consumer Rating	Crisp (%)	Non-Crisp (%)
Unacceptable	10.6	17.2
Acceptable	44.0	56.4
Superior	45.5	26.4
Acceptable + Superior	89.5	82.8

Table 3.4: Responses from blueberry consumer test questionnaire

Question	Responses	% of Total Consumers
Gender		
Male	104	36.1
Female	184	63.9
Age		
18-29	91	31.6
30-39	60	20.8
40-49	50	17.4
50+	87	30.2
Where do you purchase blueberries?		
Supermarket	242	84.0
Farmers Market	45	15.6
Roadside Stand	11	3.8
U-Pick	47	16.3
Other/Homegrown	16	5.6
How often do you purchase fresh blueberries?		
Less than once a month	94	32.6
Between one and three times a month	120	41.7
Once a week	44	15.3
More than once a week	10	3.5

Table 3.4 (continued)

Important purchasing characteristics		
Label	8	2.8
Appearance	193	67.0
Size	85	29.5
Organic	29	10.1
Other	85	29.5
Important consumption characteristics		
Taste	262	91.0
Firmness	153	53.1
Color	35	12.2
Size	26	9.0
Other	26	9.0
How do you store whole blueberries at home?		
Refrigerator	258	89.6
On counter	9	3.1
Freezer	42	14.6
Other	0	0
Expected fresh blueberry shelf life		
1 week	218	75.7
2 weeks	45	15.6
3+ weeks	14	4.9

Table 3.4 (continued)

Generally satisfied with blueberries available at supermarket?		
Yes	142	49.3
No	48	16.7
Depends	59	20.5

[1]For some questions consumers could select more than one answer or could choose to not reply

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CHAPTER 4

CONCLUSIONS

Two specialty agricultural commodities, southern highbush blueberries and sweet onions, were examined for their quality characteristics and acceptability to consumers. In the blueberry study, blueberry cultivars with two different flesh types, crisp and non-crisp flesh, were compared. It was determined through consumer sensory tests that berries with crisp-flesh are acceptable to consumers. Mathematical models to predict consumer acceptability were developed by relating consumer acceptability scores with descriptive sensory scores from an experienced panel. The models revealed that blueberry-like flavor, crispness, and firmness were the characteristics that led to superior blueberry eating quality, while increased sourness led to berries with acceptable eating quality. Overall the crisp-flesh berries evaluated were found to be firmer, crisper, and sweeter than the non-crisp, traditional highbush berries by the experienced sensory panel. Consumers indicating acceptance of these crisp-flesh berries along with an increased sensory perception of firmness provides promising reasons for further investigating the mechanical harvesting potential of these firmer berries.

In the sweet onion study similar evaluations were performed with the addition of an analytical measurement of pungency. The mathematical models to predict consumer acceptability demonstrated that onion sweetness led to superior eating quality while pungency led to decreased acceptability. Comparison of the pungent volatiles measured analytically with an experienced panel's scores for pungency revealed that a panel could discern sweet onion pungency with moderate correlation. An understanding of sweet onion pungency and its acceptability to consumers provides knowledge to breeders and growers so that produce of the highest quality to consumers can be developed and offered.