FIRMNESS AND STORAGE CHARACTERISTICS
OF
CRISP-TEXTURED BLUEBERRIES

By

LES PADLEY JR.

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
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This document is dedicated to my wife and both of my families who have been there for me since the beginning, encouraging me and helping me along the way.

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During the 1980s and 1990s several cultivars with a firm texture were released from blueberry breeding programs, exemplified by ‘Reveille’ from North Carolina and ‘Bluecrisp’ from Florida. University of Florida blueberry breeders, along with local growers, considered ‘Bluecrisp’ to have a unique crisp texture that had not been encountered up to that date. Since the discovery of ‘Bluecrisp’, several new clones with crisp-texture were found in the test plots of the University of Florida’s breeding program. This research was designed to compare the “crisp” clones, ‘Bluecrisp’, FL 97-136, FL 98-325, FL 00-59, FL 00-180 and FL 00-270, for crisp-texture and storage life to standard “non-crisp” clones ‘Emerald’, ‘Millennia’, ‘Star’, and ‘Windsor’.

Firmness testing was first conducted on 99 blueberry clones, including the “crisp” clones ‘Bluecrisp’ FL97-136, and FL 98-325, using an Instron 8600 with a 10N load cell. The firmness test, deformation to 2 mm, revealed that the “crisp” characteristic could not be determined using Instron firmness testing. A test studying the firmness changes

during fruit development did not show differences between the “crisp” and “non-crisp” clones using Instron measurements of berries at the white, pink and blue stages of maturity. Berries of all varieties became much softer during the transition from white to blue. However, shear cell testing, simulating chewing, conducted in 2004 on the two groups of clones showed that ‘Bluecrisp’, FL 97-136, FL 00-59 and FL 00-180 were distinctively different from all of the other clones in maximum force required for the blades to slice the berries. A consumer sensory panel study in 2004 showed that the “crisp” clones ‘Bluecrisp’ and FL 00-59 could be distinguished as “crisp” in comparison with the “non-crisp” clones ‘Star’ and ‘Windsor’. The average consumer, though, did not have a preference for the crisp-textured blueberries when compared with the standard “non-crisp” blueberries. Postharvest storage tests in 2004 showed that, when held in air storage, the clones ‘Bluecrisp’, FL 00-59, and FL 00-180 had superior storage life compared with the other “crisp” and “non-crisp” clones. The shear cell test in 2004 also separated these three “crisp” clones from the other clones tested. A correlation that separates “crisp” and “non-crisp” clones using shear cell values and postharvest storage life might exist. When the same “crisp” and “non-crisp” clones were stored in a controlled atmosphere of 2% O_2 plus 15% CO_2, the distinction between ‘Bluecrisp’, FL00-59 and FL 00180 and the other clones was lost.

CHAPTER 1
INTRODUCTION

History of Blueberries in Florida

The commercial blueberry industry is profitable and fast growing. In 2002 North America produced 390 million pounds of blueberries with a total wholesale value of about $310 million. Cultivated blueberries represented $210 million of the total and wild blueberries $100 million. Of the 2002 national total, Florida contributed $18.5 million from approximately 809 hectares of cultivated blueberries (10, 50). Florida has the potential to greatly increase blueberry acreage and production without flooding the market (2). Florida, with its early April to early May market window (20), has the capability of playing a major role in the expansion of this industry.

Cultivated blueberries (*Vaccinium* section Cyanococcus) are native to eastern North America and were first commercialized there. At first, production was mainly located in the northern United States and was based on the northern highbush blueberry (*Vaccinium corymbosum)*. These highbush blueberry cultivars produced high yields and large fruit when planted on soils with high organic matter and low pH in areas that provided high chilling hours (50). Florida began blueberry production in the early 1900s using the native Florida blueberry species *V. ashei*, commonly called rabbiteye blueberry. The plants were transplanted from the wild into cultivated fields. By 1930, over 2000 acres of commercial blueberries were in production in North Florida (30, 41). This production did not last long due to poor fruit quality and marketing problems (9, 50). Over the next several decades the blueberry industry in Florida went into serious decline (30). Northern highbush blueberries were tried in Florida during this time, but the plants did not fare well. Lack of chill hours, low soil organic matter and subtropical diseases made it hard for the northern plants to survive so far south (25).

In 1984, the blueberry market for the United States was expanding rapidly but there were no blueberries available until late May, when harvest began in eastern North Carolina (28, 42). Florida Agricultural Experiment Station horticulturalist Ralph Sharpe believed that Florida could produce blueberries as early as late April (42). What was needed to create this industry was high yielding, large fruited, early ripening blueberry varieties. To breed these varieties, Sharpe propagated several Florida evergreen lowbush wild blueberry bushes (*V. darrowi)* that he found growing around a lake near Winter Haven, Florida. These bushes produced unusually large berries with a powdery blue color. He crossed these plants with northern highbush cultivars. This was the first step in breeding a type of low-chill, heat-tolerant highbush called southern highbush (25, 28). Southern highbush revitalized Florida's blueberry industry by allowing Florida blueberry growers to harvest during the early market window of March 20 to May 20 (42). The new industry took decades to develop, but by 1985 there was 1058 acres of blueberries in Florida, and by 1989 the blueberry acreage in Florida had nearly doubled to 2106 acres (8, 9). In 2003, Florida ranked as the 7th largest state in cultivated blueberry acreage for the U.S. with around 1900 acres (48).

Blueberry Breeding

Blueberry breeding started in the United States around 1910, and at the University of Florida (U. F.) about 1950 (42). Florida's breeding program mainly concentrated on the development of low-chill, early ripening, tetraploid, southern highbush cultivars. These southern highbush cultivars were obtained by hybridization of Florida native blueberries (mainly *Vaccinium darrowi*) and highbush cultivars (*V. corymbosum*) from Michigan, New Jersey and North Carolina. The original crosses were followed by a program of recurrent selection.

Ralph Sharpe and Wayne Sherman continued this program of recurrent selection untill Sharpe's retirement in 1976. The program was continued Sherman, who was joined by Paul Lyrene in 1977. Sherman retirement in 2003, and the program is now under the direction of Lyrene.

As currently practiced in the U. F. blueberry breeding program, by Dr. Paul Lyrene, each cycle of selection is begun by crossing 200 plants to obtain 12,000 seedlings. Pollination is done by emasculating the flowers before anthesis, and pollen is transferred by thumbnail as described by Edwards, Sherman and Sharpe (13). The seedlings from these crosses are grown and evaluated for numerous characteristics that are important in a cultivar. Desired characteristics included a vigorous, upright plant, high yield potential, resistance to various insects and diseases, adaptation to Florida soils and climates, and large, sweet, firm berries that are easy to harvest and have a long shelf life (17). From the original 12,000 plants, 200 are selected and used as parents to begin the next cycle of selection. As this process continues, each generation of selection brings better seedling populations. The seedlings are also the source of new varieties, which are propagated asexually.

In evaluating genotypes for the U. F. breeding program, seedlings are first fruited in a high density nursery (Stage 1). The plants are examined for fruit size, color, picking scar size, firmness, flavor, time of ripening and freedom from major visible defects of bush or berry (27). From the 12,000 seedlings, 500 are selected and the rest are discarded. The selected plants are grown for 2 more years (Stage 2 test). During the first of the 2 years, the bushes and berries are evaluated for the same characteristics that were evaluated in stage 1, and 100 to 150 plants are selected for propagation. In the second year the plants are reexamined to find plants showing the desirable qualities that did not appear in the first year, and an additional 20 to 50 plants are selected. For each plant selected in Stage 2, 40 softwood cuttings are taken. Based on the rooting ability of the cuttings and growth characteristics of the ramets, 120 to 150 clones per year are planted into a commercial field in plots of 20 plants per clone (Stage 3). Here they received the care and maintenance recommended for commercial blueberries in Florida (27). The plants are left in the field for 2 to 10 years, depending on the performance of each clone. Each year, the clones are examined for plant vigor and survival, leafing and flowering characteristics, and berry yield and quality (27). Approximately 12 clones are selected from each stage 3 test, and ramets are propagated from each clone. The selected clones are planted in 100-plant plots in a commercial field. These plots are examined for 3 to 6 years, and the best one to two selections become cultivars (27).

The characteristics that make a successful blueberry cultivar have been studied for decades by people such as Sharpe (13, 42), Sherman (13, 42), Ballinger (4, 5), Ballington (6), Lyrene (27, 28) and Finn (17). The heritability of certain characteristics has also been studied. Edwards, Sherman and Sharpe (13) determined that there was a high heritability estimate for fruit size, a moderate heritability for fruit color, a low heritability for fruit firmness and picking scar size and an even lower heritability for plant vigor. They also determined that additive gene action was high for fruit size, color, and firmness, and plant vigor, and plants should transmit these traits to their progeny. Finn, and Luby (17) confirmed this additive gene action in blueberries as it pertains to fruit color. They also concluded that highbush x highbush segregation patterns indicated predominately additive gene action. These studies, along with others, have helped blueberry breeders improve their breeding programs.

Growth and Fruit Development of Blueberries

Growing blueberries in Florida is a challenging business. Blueberries are a deciduous, perennial, long lived woody shrub with a fibrous root system that requires high organic matter and acidic soils to thrive. Selecting the proper site is a key to growing commercial blueberries. A site must have well drained soil at least 40 cm deep, a pH between 3.5 and 5.5 and 2 to 3% organic matter. The area must also have enough cool weather during the winter to satisfy the chilling requirement of the variety, but the frequency of late winter and early spring freezes should be low(49). Once a site is chosen, southern highbush blueberries are planted 1 m apart in rows 3 m apart. Two or more cultivars are inter-planted for cross-pollination.

Blueberry plants require at least 100 cm of water yearly to be productive (49). Overhead irrigation is the most common and practical way of applying water to the plants in Florida. Overhead irrigation is also used to protect flower buds from February, March and April freezes (28). Fertilizer (12-4-8-2) is applied frequently beginning about mid-April and ending in August or September. Bushes are pruned during the summer after final harvest. Pruning of southern highbush plants is needed to keep the desirable size and shape of the plant, to increase plant vigor and to promote good fruit development in next year’s crop (49).

Blueberries require several hundred hours of chilling (between 0°C and 7°C) in the winter to stimulate the sprouting of floral and vegetative buds in the spring. The amount of chilling required varies from one cultivar to another. Chilling hours begin in the fall after the plants go dormant. Previous to the chilling season, some axillary (vegetative) buds are inverted into flower buds. This transformation is complete by January and the swollen flower buds can be distinguished from the vegetative buds on the bush. Plants must have a proper balance between vegetative and flower buds to produce maximum yields and quality (49). In north Florida, flower buds open during February (Lyrene, personal communication).

Blueberry flowers consist of a corolla tube (white or pink colored), a pistil and anthers. The corolla tube is the most visible part of the flower and is made up of five fused petals. The pistil extends to the end of the corolla tube, but the anthers are situated in such a way that sonication by an insect, primarily bees, is needed to efficiently remove pollen from the flower. Sonication occurs when a bee places its head into the corolla tube and moves its wing muscles at high frequencies causing the pollen to fall out of the flower. Pollen lands on the bee's head, and some of it is taken to other flowers, where it may be left on the stigfmas. For optimum fruit set and berry size, it cross-pollination (pollen from one variety being placed on the stigma of another) is desirable (49).

After pollination, the flower takes 45 to 120 days to develop into a ripened blueberry (Lyrene, personal communication). Blueberry fruit development follows a double-sigmoid curve that consists of three stages (12). In stage I fruit size increases through cell division. Stage II is characterized by a rapid increase in embryo and endosperm growth with little or no increase in berry size. In Stage III cells enlarge without cell division until maturity (12). In the final days of development the blueberry undergoes a ripening process in which acid decreases while pH, sugar and berry weight increase (3). As berry color changes from green to white to pink to blue (Figure 1.1) the berries increase dramatically in size (final swell) (3, Lyrene, personal communication). It takes about 5 days for the berries to undergo this ripening process for a climacteric fruit, physical maturity is reached at mature green stage (i.e., when it can ripen on or off the plant). to become fully ripened, physiologically mature blueberries (Lyrene, personal communication).

Figure 1.1. Blueberries at white, pink and blue stages after the start of final swell (stage 3).

Harvest and Postharvest of Blueberries

Florida blueberries are harvested, packed and shipped to many parts of the world from March 20 to May 20 (46). Worldwide shipment of fresh berries requires good cultivars, and a first-rate packing and storage system. The process of producing blueberries that pack and store well begins in the field before the berries are picked. Blueberries must be ripe, firm and have a small, dry picking scar to survive the trip to the market. A picking scar that is small and dry is especially important, because a wet picking scar, caused by the skin of the berry tearing as it is removed from the stem, is a primary locus of fungus infection (7, 19, 29, 46). In the field, the berries are picked into buckets and poured into field lugs, which are kept shaded. Great care must be taken during the harvesting and handling process to avoid dropping or bruising the berries, which would lead to decay. In the packing house, the berries are placed on a conveyer belt, and unripe, overripe or damaged berries are removed, along with leaves and twigs. Berries must be firm to avoid bruising or juice leakage during this process. The sorted berries are placed in plastic clamshells, 125 to 400 g per clamshell. These are typically packed in 12-unit cartons for shipping.

After packing, the berries are placed into a storage unit at 0° to 5°C with relative humidity of 95% (5, 15, 23, 24, 35). Under these conditions, blueberries can be stored for 2 weeks without decay (5, 31, 36, 38, 46). Blueberries have been stored using modified atmosphere (MA) since 1919. Research on storage conditions has primarily focused on the quality of the blueberries. Quality parameters have included weight loss, number of defective berries, firmness, color, and decay (23, 29). As expected, weight loss, number of defective berries and decay increase over time, whereas firmness decreases and color becomes darker. Further research has shown that many of the changes that occur on the outside of the blueberry are due to internal changes in the berry. As fruit develop and mature, total titratable acidity (TTA) decreases while weight, pH, soluble solids content (SSC), sugar, and SSC/TTA ratio increase (3, 20, 26). Blueberries with low pHs of 3.5 or less tend to have slower rates of decay (3, 19, 38). These changes in acid, weight, pH, TTA, SSC, sugar and SSC/TTA occur naturally as a blueberry matures, ripens and senesces. Controlled atmospheres (CA) are used in blueberry storage to reduce the rate of senescence in the berries. CA storage consists of altering the concentrations of CO_2, O_2 and N in the storage units containing the blueberries.

Using CA for blueberries began in the early 1980s when it was discovered that high CO_2 and low O_2 levels helped prevent the decay of the fruit (7, 46). Much research has been done since then. Optimum levels for these gases have been found to be 2 to 5% O_2, 15 to 20% CO_2 and nitrogen as a filler gas to make the atmosphere 100% (7, 24, 46). At these levels, blueberries harvested at the blue maturity stage can be stored for over a month at 1°C with little decay or damage to the outside of the berries. At least one study, though, has shown that high levels of CO_2 in the CA may cause internal changes in blueberries that produce an ‘off flavor’ (7). The reasons for the development of this flavor are yet unknown.

Of the variables that have been studied in the postharvest storage of blueberries, firmness has been found to be a key indicator of berry quality change during storage (25). Early methods of determining blueberry firmness included squeezing the berry between the fingers and judging the resistance, or judging firmness by masticating the berry (4, 29, 45). These methods gave variable results from one person to another (45). In 1973, Ballinger and associates (4) modified an Instron Universal Testing machine (resistance to compression) to measure the firmness of blueberry fruit. The Instron Universal Testing machine had been previously used in determining the firmness of other fruit (4, 37). Instron tests determined that blueberry firmness can vary from one harvest to another and from one year to another. It was also determined that the greatest decrease in firmness during berry development came as the berry went from the green to the pink stage (4).

Since the initial tests in 1973 many more studies have confirmed that the Instron is a reliable indicator of blueberry firmness (14, 15, 16, 23, 32). Variations in berry firmness among harvests and among years as well as dramatic decreases in firmness from the green to pink stage of development were also confirmed through other studies (14, 33, 34, 46). Although many studies have used an Instron to determine firmness, a set of standard guidelines for measuring berry firmness have still not been developed, except concerning where the berries should be compressed. It has been determined that compressing the berry along its lateral axis gives smoother, more consistent force deformation curves than compressing the fruit in the axial direction (4, 14, 15, 16). Studies have determined that blueberry firmness decreases over time in storage and that this decrease can be slowed but not stopped by lower temperature (8, 14, 16, 38). A study done from 1998 to 2000 surveyed berry firmness in 87 highbush culivars and species-introgressed highbush blueberry cultivars (14). This study determined that 1.34 N/mm deflection force was average for these cultivars, and that values above 1.57 N/mm were considered superior.

Crisp-texture has been studied in other berries such as the grape (41). The crisp-texture in grapes can be traced back to the native North American grapes that were added to the European grape gene pool. The hybrid grapes, call V. *labrusca*, can be distinguished as crisp-textured by means of puncture testing. In the puncture testing the deformation at first breakdown (DFP) and the maximum peak of force (MF) separate the "crisp" from the soft cultivars. A grape that has a small DFP and a large MF is considered "crisp", whereas berries with large DFP and small MF are considered soft

(41). No known research has been done on the DFP or the MF of blueberries as it relates to "crisp" or soft texture.

Crisp-Textured Blueberries

During the 1980s and 1990s, several blueberry cultivars with very firm texture were released from breeding programs, exemplified by 'Reveille' from North Carolina and 'Bluecrisp' from Florida. 'Bluecrisp' was considered by U.F.'s blueberry breeder, as well as local growers, to have a unique crisp-texture. This texture can best be described as biting into an apple. In recent years, several other clones with crisp-textured berries have been found in test plots in Florida. What makes this characteristic even more unique is that there is no common ancestry between any of these crisp-textured clones.

To determine how these new clones compare in crisp-texture and storage life with various commercial cultivars, several experiments were conducted. In this study, which describes these experiments, clones 'Bluecrisp', FL 97-136, FL 98-325, FL 00-59, FL 00-180 and FL 00-270 will be referred to as "crisp" clones, and the commercial clones 'Emerald', 'Millennia', 'Star', and 'Windsor' will be referred to as "non-crisp" clones. These designations were based on the perception of the breeder at the start of these experiments, and as will be seen, were not always supported by the objective tests that were made in the course of these experiments.

CHAPTER 2
QUALITY DETERMINATIONS OF FRESH BLUEBERRY CLONES

Relative Berry Firmness of 99 Clones

In the first set of experiments, various characteristics of blueberry clones that had been selected for crisp-texture were compared with the same characteristics in standard commercial varieties.

For this test, 99 blueberry clones were used, of which three clones, ‘Bluecrisp’, FL 97-136, and FL 98-325, had previously been classified as crisp based on informal observations in the field. The purpose of this test was to determine if the berries from these clones were firmer then these of standard commercial cultivars.

Materials and Methods

On May 2, 2003, berries from 99 clones of southern highbush blueberries were harvested from a variety test planted in a commercial blueberry planting at Straughn Farms Inc. in Windsor, Florida (Alachua County). The clones were advanced selections from the U. F. breeding program. During earlier stages of selection, clones had been eliminated if the berries were small, dark, had wet picking scars, or were soft. The plants were growing in 15-plant clonal plots and were about two meters tall. Approximately 20 ripe berries were gathered from each clone and placed in paper bags. Two separate samples were taken for the firm cultivar ‘Bluecrisp’. The bags were placed in a cooler and transported to a 2° C storage unit. Firmness was measured the next day by removing the berries from 10 clones at a time from the cooler and placing them on a grading table for 90 minutes to allow the berries to reach room temperature (about 22°C). Once at room temperature, the berries were inspected for leaking, collapse, decay or other damage. Damaged berries were discarded, after which 10 berries were randomly selected from each clone for firmness testing. An Instron 8600 with a 10 N load cell was used to test firmness. Each berry was placed onto a washer with an outer diameter of 2.2 cm and an inner diameter of 1 cm to keep it stable. The berries were placed on their sides with the calyx end to the left and the stem end to the right. An 8 mm probe attached to the Instron was then lowered from above until it pressed onto the equator of the berry, using an initial contact force not exceeding .03N (Fig. 2.1). Using a crosshead speed of 50 mm/min, each berry was deformed and the 3 mm deformation at 1 mm, 2 mm, and 3 mm depth were recorded (10 berries/clone).

Figure 2.1. Instron machine with 8 mm probe.

Results

When berry firmness was plotted as a histogram (Fig. 2.2) the 99 clones appeared to give a normal distribution, except that the sample for FL 98-325 was separated from the others at the high end of the distribution. Firmness of FL 97-136, FL 98-325 and FL 00-270 fell within the top 10% of the array in firmness measured by the Instron (Table 2.1). One ‘Bluecrisp’ sample also was in the top 10% in firmness, but the other ‘Bluecrisp’ sample was less firm with a ranking of 71 out of 100 samples. FL 98-325, a crisp-textured clone, was firmest and appeared to separate out from the rest of the clones in the histogram on page 31. A Tukey test was preformed on the top 10% of the histogram to confirm these observations. The test showed all clones to be similar to each other, except FL 98-325, at the five percent level. The unusual firmness of FL 98-325 in this test was not confirmed in subsequent tests (Table 2.2 and 2.3). It is not known why the firmness of FL 98-325 was so high in this test.

Discussion

Firmness is an important quality factor in blueberry. Several studies (4, 13, 16, 33, 34, 45) have been done on blueberry firmness, and methods of measuring firmness have varied. These studies have confirmed that blueberry firmness changes from harvest to harvest and from year to year. In our study, berry firmness of 99 southern highbush blueberry clones showed a bell-shaped distribution. For the 99 clones, the means force required to deform the berries 2 mm in an Instron instrument was 3.17 N (Table 2.1).

Ehlenfeldt and Martin studied berry firmness in 87 highbush blueberry clones and hybrids using a FirmTech 1 firmness tester. They found an average firmness of 1.34 N/mm deflection and values above 1.57 N/mm were considered superior (14). Our 99 clone test used an Instron 8600 to determine firmness, and got an average of 1.59 N/mm.

Table 2.1. Mean[z] force (N) required to deform berries by 2mm for 99 blueberry clones ranked from lowest to highest sampled in 2003.

Clone[y]	Mean (N)	Standard deviation (N)	Clone	Mean (N)	Standard deviation (N)	Clone	Mean (N)	Standard deviation (N)
FL 98-352	1.79	0.56	FL 98-375	3.04	0.43	FL 98-370	3.84	0.50
FL 98-17	2.06	0.44	FL 98-25	3.05	0.31	FL 98-370	3.90	0.43
FL 98-357	2.09	0.34	FL 95-209B	3.06	0.30	FL 98-385	3.92	0.50
FL 99-54	2.15	0.22	FL 96-96	3.12	0.45	FL 95-174	3.93	0.55
FL 96-90	2.20	0.31	FL 99-60	3.12	0.34	Bluecrisp2*	4.01	0.42
FL 99-74	2.25	0.25	FL 99-69	3.13	0.45	FL 98-384	4.04	0.39
FL 98-337	2.34	0.41	FL 99-51	3.13	0.29	Misty	4.08	0.38
FL 91-16	2.34	0.22	FL 98-369	3.13	0.65	FL 97-136*	4.17	0.48
FL 98-339	2.36	0.48	FL 95-50	3.14	0.38	FL 99-55	4.18	0.19
FL 98-338	2.38	1.03	Emerald	3.14	0.46	FL 98-363	4.22	0.48
FL 99-66	2.44	0.19	FL 98-402	3.16	0.52	Magnolia	4.35	0.58
FL 98-341	2.46	0.15	FL 95-174	3.19	0.66	FL 99-37	4.35	0.44
FL 98-351	2.47	0.28	FL 98-438	3.20	0.62	FL 98-436	4.50	1.39
FL Jewel	2.51	0.51	FL 98-433	3.22	0.17	FL 98-325*	5.49	0.62
FL 98-365	2.56	0.82	FL 98-388	3.25	0.66			
Sapphire	2.59	0.20	FL 98-411	3.26	0.25			
FL 98-437	2.60	0.30	FL 98-342	3.27	0.27	Overall		
FL 99-48	2.63	0.22	FL 98-29	3.30	0.51	Average	3.17	0.45
FL 99-59	2.66	0.39	FL 98-303	3.30	0.28			
FL 99-56	2.66	0.40	FL 90-91	3.31	0.34			
FL 99-65	2.67	0.30	FL 96-24	3.32	0.29			
FL 98-423	2.67	0.51	FL 98-427	3.33	0.30			
FL 98-401	2.67	0.32	FL 86-19	3.33	0.27			
FL 98-27	2.67	0.37	FL 92-166-N	3.39	0.40			
FL 97-118	2.68	0.54	FL 98-18	3.44	0.44			
FL 98-414	2.69	0.32	FL 98-371	3.49	0.57			
FL 98-415	2.71	0.30	FL 98-430	3.51	0.34			
FL 98-372	2.72	0.27	Bluecrisp1*[x]	3.54	0.39			
FL 98-421	2.72	0.30	FL 00-270	3.55	1.07			
FL 98-428	2.74	0.36	FL 97-63	3.57	0.27			
FL 98-431	2.78	1.07	Southern Bell	3.57	0.53			
FL 96-43	2.82	0.57	FL 98-358	3.59	0.65			
FL 99-45	2.83	0.63	FL 98-381	3.62	0.20			
Legacy	2.84	0.48	FL 98-297	3.62	0.32			
FL 98-125	2.87	0.37	Star	3.62	0.27			
FL 95-197	2.90	0.40	FL 99-50	3.64	0.25			
FL 98-416	2.90	0.28	FL 98-356	3.64	0.60			
FL 98-439	2.98	0.26	FL 95-173	3.72	0.40			
FL 93-171	3.00	0.33	Millennia	3.74	0.69			
Sebring	3.00	0.26	FL 98-420	3.77	0.46			
Sharpblue	3.02	0.34	FL 93-221	3.78	0.31			
FL 98-383	3.03	0.49	FL 97-79	3.80	0.58			
Windsor	3.03	0.41	FL 99-71	3.82	0.33			

[z] Mean of 10 berries individually sampled.

[y] The symbol * following the clone name indicates that it had been considered a crisp-textured clone previous to this experiment.

[x] Bluecrisp 1 and 2 were from 2 different fields.

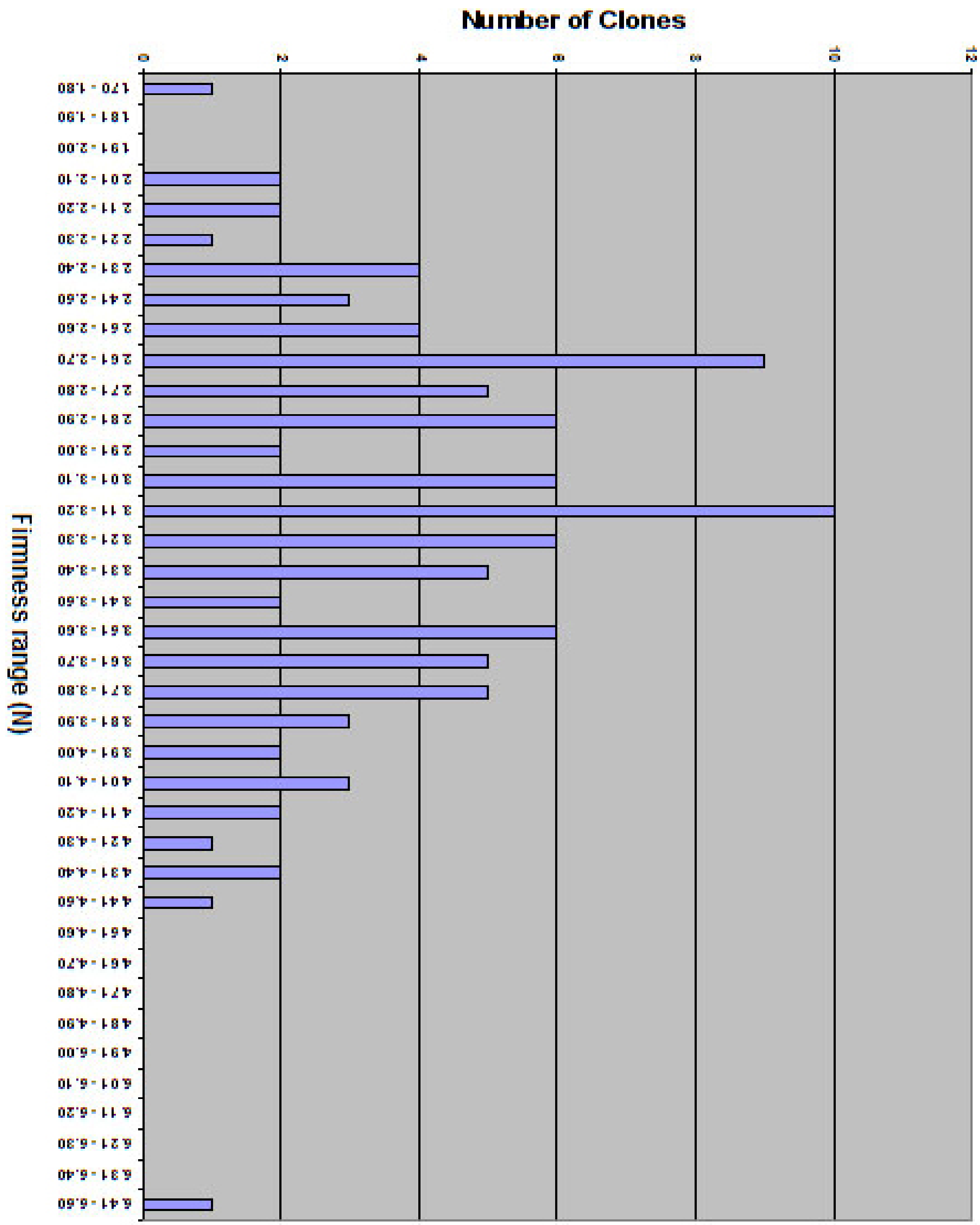

Figure 2.2 Histogram of mean firmness of 99 test blueberry clones. Class Interval 0.10 N. The value for each clone was the average of 10 berries individually tested.

A direct comparison between the two experiments can not be made because different testers were used, but the average firmness, measured as N/mm deflection, for our 99 clone test was larger then the value Ehlenfeldt and Martin of the 87 highbush blueberry test considered to be superior in their tests. Further southern highbush testing using an Instron machine is needed to confirm the results from this test.

Firmness Changes During Fruit Development

Blueberry fruit change dramatically during final swell as the color changes from green to blue. Weight and SSC increase and TTA (26) and firmness decrease. Firmness decreases most between the white and pink stages and less significantly thereafter. It had been hypothesized by Dr. Paul Lyrene that the crisp-textured clones soften more slowly then standard commercial clones. The purpose of this test was to determine if this hypothesis was right.

For this experiment, normal and crisp textured blueberries were harvested during several of the final stages of ripening and for several days afterward. Berries from four crisp-textured clones were used: ‘Bluecrisp’, FL 97-136, FL 98-325, and FL 00-59, and four commercial cultivars were used: ‘Emerald’, ‘Millennia’, ‘Star’ and ‘Windsor’.

2003 Materials and Methods

Five to eight bushes of the clones ‘Bluecrisp’, FL 97-136, FL 98-325, FL 00-59, ‘Emerald’, ‘Millennia’, ‘Star’ and ‘Windsor’ were netted (to exclude birds and berry harvesters) in a variety test attached to a commercial field. Once the berries had reached the white stage of development, 20 berries from each clone were harvested, placed into clamshells and transported in a cooler of ice back to the lab. At the lab the berries were warmed up to room temperature and their firmness was tested. The white stage was after final swell had begun and 1 to 2 days before the berries turned pink then purple. Blueberries were also harvested at the pink and blue stages of development (Fig. 1.1). The skins of some blueberries were marked with the date they first became blue using a paint marker (uniPAINT fine line PX21). Twenty berries were harvested from each clone at each of six sampling times: 3, 5, 7, 9, 12, and 15 days after they first turned blue.

Berry firmness was tested using an Instron 8600 as described previously. All twenty berries harvested for each clone at each maturity level were tested for firmness.

2003 Results

The firmness testing during fruit development for 2003 was interrupted by pickers and some data were lost (Table 2.2). From the remaining data shown in Table 2.2 it can be seen that a dramatic decrease in firmness occurred from the white to pink stages of berry development. Changes in firmness after the pink stage of berry development were small. Both “crisp” and “non-crisp” clones softened significantly during the transition from white to pink. The data failed to show a major difference between the “crisp” and “non-crisp” clones in the softening that occurred as the berries went from white to blue. It had been hypothesized earlier that the high firmness of the “crisp” berries when fully ripe might be the result of less loss of firmness during the final stages of ripening, but this seems not to have been the case. ‘Bluecrisp’ and FL 98-325 were less firm at the pink stage (Table 2.2) than in the fully ripened blue stage Table 2.1. This indicates that one or more non-genetic factors have a large effect on Instron firmness.

2004 Materials and Methods

In 2004, FL 00-180 and FL 00-270 were added to the test as possible crisp-textured clones. Five to eight bushes of the clones ‘Bluecrisp’, FL 98-325, FL 00-59, FL 00-180, FL 00-270, ‘Emerald’, ‘Millennia’, ‘Star’ and ‘Windsor’ were netted in a

Table 2.2. Mean[z] deformation force (2mm deformation) of fruit for eight blueberry clones sampled at 9 stages of maturity in 2003.

	2mm Deformation Force (N) at Maturity Stage							
Clone[y]	White	Pink	Blue	Day 3[x]	Day 7	Day 9	Day 12	Day 15
Bluecrisp*	7.77 ab	2.83 a	2.14	2.17 a	2.30			
FL 97-136*	10.24 a			2.51 a		2.41	1.70	
FL 98-325*	10.57 a	2.56 ab			2.82	2.97		
FL 00-59*	9.03 ab[w]	2.85 a		2.71 a				
Emerald	5.85 b							1.70
Millennia	8.34 ab		2.67					
Star	9.88 a	1.73 b						0.84
Windsor	8.98 ab	1.77 b		2.12 a				
P > F	0.013	0.001		0.045				

[z] Mean of 20 berries individually sampled.

[y] Clones followed by a * had been considered crisp textured

[x] Days after berry first turned blue

[w] Within columns means followed by the same letter are not significantly different ($P<0.05$) by ANOVA and Tukey's test.

commercial field and allowed to ripen. Once the berries had reached the white stage of development, 20 berries from each clone were harvested, and their firmness was tested as previously described. Blueberries were also harvested at the pink and blue stages of development. To test the firmness of the berries an Instron 8600 testing machine with a 10 N load cell was used. The procedure was the same as previously described.

2004 Results

All clones softened significantly between the white and pink stages (Table 2.3). The six "crisp" clones did not differ conspicuously in the pattern of firmness loss from the four "non-crisp" cultivars. Analysis of variance (Table 2.4) showed that clones, stages of ripening, and clone x stage interaction all contributed significantly to variances in the firmness of the samples.

Table 2.3. Mean[z] deformation force of fruit for nine blueberry clones sampled at three stages of maturity in 2004.

	2mm Deformation force(N) at maturity stage		
Clone[y]	White	Pink	Blue
Bluecrisp*	7.52 ab	3.20 abc	2.81 ab
FL 98-325*	5.51 ab	3.76 a	2.80 ab
FL 00-59*	7.79 ab[x]	3.69 a	3.30 a
FL 00-180*	7.32 ab	2.64 bc	2.39 bc
FL 00-270*	7.27 ab	3.39 abc	1.87 c
Emerald	4.78 b	2.45 c	1.97 c
Millennia	9.24 a	3.49 ab	1.86 c
Star	9.08 ab	2.84 abc	2.44 bc
Windsor	5.06 ab	2.64 bc	2.14 bc
Stage means	7.06	3.12	2.40
P > F	0.009	0.000	0.000

[z]Means of 10 berries individually sampled.
[y]Clones followed by a * are crisp textured
[x] Within columns means followed by the same letter are not significantly different ($P<0.05$) by ANOVA and Tukey's test.

Table 2.4. ANOVA for mean deformation force of fruit for 9 blueberry clones sampled at three stages of maturity in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	26	53.32	15.70	<0.0001
Clones	8	13.41	3.95	0.0002
Stages	2	566.95	166.93	<.0001
Stages x Clones	16	9.08	2.67	0.0007
Error	243	3.40		

Discussion

When "crisp" blueberries were originally observed by Dr. Lyrene theorized that the crisp texture in these new blueberries could be caused by a lack of polygalacturonase (PG) in the final stages of fruit development (Lyrene, personal communication). PG is an enzyme that helps breaks down pectin, causing the cell walls to soften (39). Production of PG in other fruits has been inhibited through genetic engineering, or by breeding creating such fruit as the non-melting flesh peach and the Flavor-Savor tomato (18, 43).

Several studies (4, 46, 39) have shown that during the final days of ripening blueberries soften as they change color from white to blue. The greatest decrease in firmness occurs from the pink to the blue stage and is caused by the synthesis of PG in the berry (39). The tests done in 2003 and 2004 showed a decrease in firmness of all clones as they ripened from white to blue, confirming previous studies. The fact that the "crisp" berries lost firmness rapidly ass they matured from green to blue suggests that PG levels are not related to the crisp texture in "crisp" blueberries. Further studies examining changes in PG levels as "crisp" and "non-crisp" clones mature should be conducted to confirm these results.

Shear-Cell Testing

In an effort to detect a difference between berries of "crisp" and "non-crisp" clones, berries were tested using a Kramer shear-cell attached to the Instron. The Kramer shear-cell is a multi-bladed fixture designed to produce shear stress in a specimen that relates to firmness (22). The specimen is placed into a metal box (82.5 mm x 98 mm) with a lid. The top and the bottom of the box have slits designed to allow ten, 3-mm blades to pass through them. The blades penetrate the top of the box and then push through to the bottom. As the blades are moved through the box, the specimen is first compressed, then extruded, and finally sheared as the blades penetrate the bottom slots (22). The forces needed for the blades to move through the box relate to berry texture (22). The purpose of this experiment was to determine the maximum force needed to shear blueberries and to determine if this force is different for crisp textured selections and some standard cultivars.

Materials and Methods

In 2004, three clamshells of ripe berries (approximately 125 g of berries in each) were collected from April 30 through May 6 for each of the following clones: ‘Bluecrisp’ FL 97-136, FL 98-325, FL 00-59, FL 00-180, FL 00-270, ‘Emerald’, ‘Star’, ‘Windsor’ and ‘Millennia’. The clamshells were placed in a cooler and brought to the lab where each clamshell was inspected to eliminate damaged or leaking berries. Approximately 70 g of sound berries were randomly selected and placed into a shear-cell box to make approximately two layers of berries. The shear-cell box, the lid and the blades to the box were set in place on an Instron 8600 (Fig. 2.3). At a crosshead speed of 50 mm/min the blades were passed through the box of berries until they penetrated through to the other side of the box. The maximum force needed for the blades to pass through the box of berries was recorded. This procedure was repeated for the other two clamshells of berries for a total of three repetitions per clone.

On May 18 and May 19 of the same year the shear-cell procedure was repeated using the same clones and technique to obtain a second set of data for each clone. The berries were harvested from the same bushes. The bushes had been harvested periodically before the samples were taken to insure that only newly ripened berries were included in the second samples. Means were obtained from these repetitions and compared to the earlier shear-cell test results.

Results

There was good agreement between the shear-cell tests run April 30 to May 6 and those run May 18 and 19 (Table 2.5, Fig. 2.4). ‘Bluecrisp’, FL 97-136 FL 00-59 and FL 00-180 had high shear-cell readings and FL 00-270, ‘Millennia’, ‘Star’ and ‘Windsor’ had lower readings (Table 2.5). The shear-cell testing was done on six putative crisp-textured blueberry clones and four standard commercial clones. In the early harvest, the firmest four clones in descending order were FL 97-136, 'Bluecrisp', FL 00-59 and FL 00-180 (Fig. 2.4). At the 5% level 'Bluecrisp', FL 97-136, and FL 00-59 were different from all other clones except FL 00-180. FL 00-59 was not significantly

Figure 2.3. Instron 8600 with shear-cell attached.

different from FL 00-180 but was significantly different from the rest of the clones. The rest of the clones merge together and are not easily distinguished as seen from Tukey testing in Table 2.5. In the late season harvest there were not enough berries to do shear-cell testing on FL 97-136, but all other clones were tested. In the late-season shear-cell tests, ‘Bluecrisp’, FL 00-180 and FL 00-59 were the top three clones and differed from the other clones at the 5% level of a Tukey test.

There was a close relationship between the shear-cell force on the 1st and 2nd sample dates for the 9 clones that were sampled twice (Fig. 2.4). Clones FL 98-325 and FL 00-270, which had been thought to be crisp, had relatively low shear force, but the other four “crisp” clones were very high in shear-cell force. Although the second samples were harvested approximately 2 weeks later in the season, shear-cell force did not dramatically change between the two sample dates (Table 2.5). Tukey testing done on the mean sample times confirmed ‘Bluecrisp’, FL 00-59 and FL 180 as the top three clones through out shear cell testing (Table 2.5).

Table 2.5. Shear-cell means[z] for 10 clones sampled at two different times during the 2004 growing season.

	Max force (N)		
Clone[y]	First sample time[x]	Second sample time[w]	Mean sample times
Bluecrisp*	458.0 a[v]	433.7 a	445.84 a
FL 00-59*	418.9 ab	393.7 a	406.34 ab
FL 97-136*	477.5 a		
FL 98-325*	308.6 cdef	325.8 b	317.20 c
FL 00-180*	360.4 bc	401.6 a	381.01 b
FL 00-270*	270.1 def	293.5 bcd	281.79 cd
Emerald	317.0 cd	313.2 bc	315.09 c
Millennia	246.8 ef	288.0 bcd	267.38 d
Star	219.9 f	252.5 d	236.21 d
Windsor	269.1 def	257.8 cd	263.44 d
P > F[u]	0.0001	0.0001	0.0001

[z]Mean of 3 shear-cell tests.

[y] Clones followed by a * had been considered crisp textured.

[x]Time period was April 30 to May 6.

[w]Time period was May 18 to May 19.

[v]Means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey’s test.

[u]Probability that the clones did not differ in shear force.

Discussion

The Kramer shear cell was built to study the texture of materials through a process of compression, extrusion and shearing of the material. It has been used to assess the texture of many fruits and vegetables (1, 21, 22, 47), but extensive work with the shear cell has not been done with blueberries. A study published in 2005 examined shear stress in rabbiteye and highbush blueberries and determined that rabbiteye blueberries (482 N) require more force then highbush berries (290 N) (44). A combination of certain

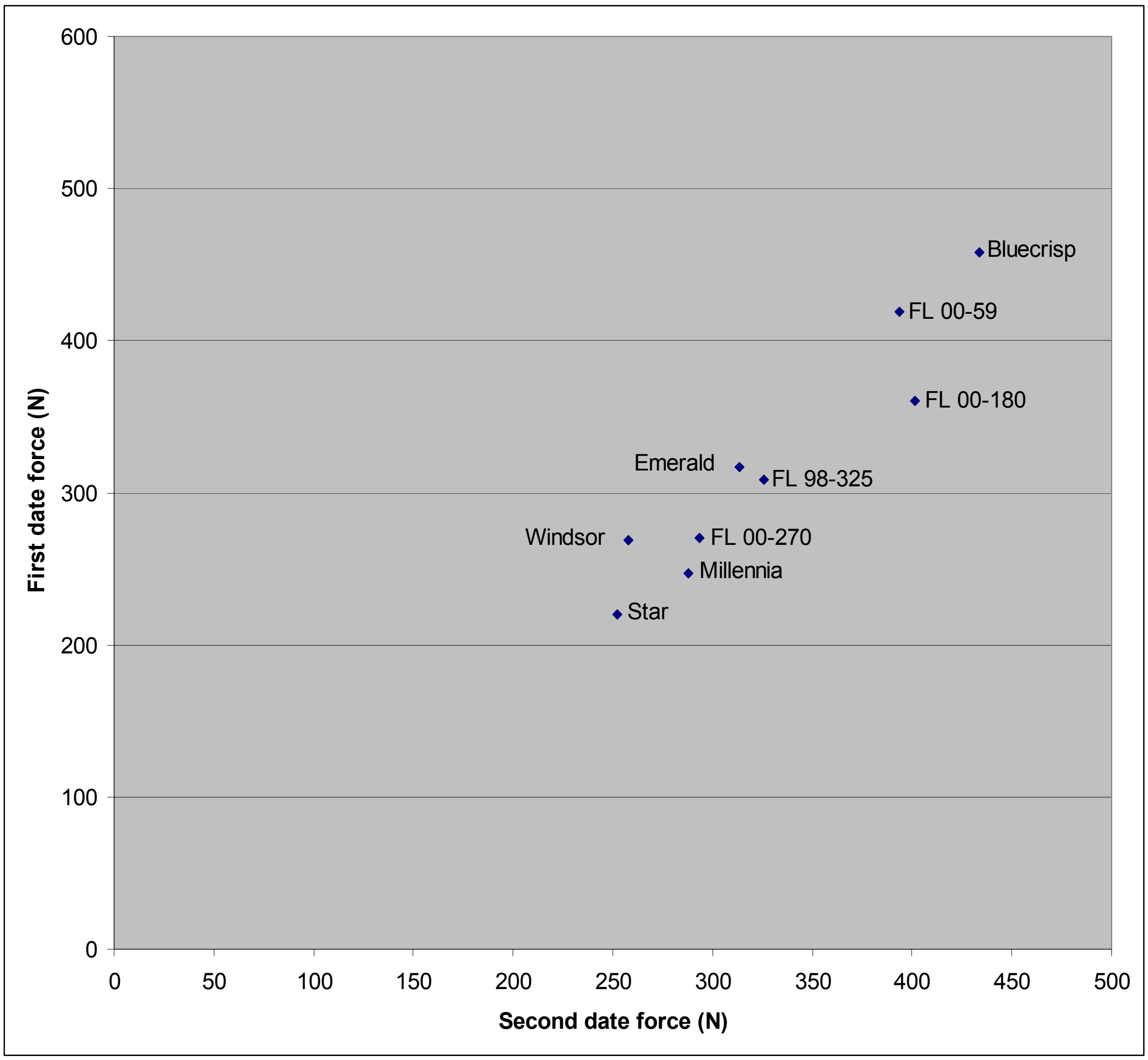

Figure 2.4. Relationship between shear-cell forces of nine selected blueberry cultivars and clones harvested at the blue stage in the first and second sampling dates of 2004.

rabbiteye genes in the southern highbbush may be creating the crisp texture. Further shear cell testing on southern and northern highbush, rabbiteye and lowbush blueberries should be conducted to determine if this is true.

Standard deviations (SD) among berries within samples averaged 6% of the means, for shear-cell testing compared to eleven percent of the means for firmness testing. Furthermore, shear cell means fluctuated less from harvest to harvest than Instron firmness means (Table 2.1, 3.1) (4). Shear cell testing may be a more consistent way of comparing blueberries than firmness testing.

Consumer Sensory Panel Study

The crisp-textured clones had been selected based on the subjective opinions of growers and the blueberries breeders at the University of Florida. To determine if the untrained public could distinguish the difference between the crisp-textured berries and standard commercial blueberries a consumer sensory panel study was conducted. ‘Bluecrisp’ and FL 00-59 represented crisp textured blueberries, and ‘Emerald’ and ‘Star’ represented standard commercial blueberries.

2003 Materials and Methods

In a commercial field, 500 blueberries were gathered from each of the following clones: ‘Bluecrisp’, FL 00-59, ‘Emerald’ and ‘Star’. The berries from each clone were placed into 4-liter zip lock bags and placed on ice in a cooler for transport to a 2° C storage chamber where they were kept overnight. The next day, the berries were taken out of storage and allowed to reach room temperature (22° C). Each berry was inspected to eliminate immature and overripe berries and berries with cuts and leaks. The remaining berries were placed in zip lock bags and taken to the sensory panel facility operated by the University of Florida, Department of Food Science and Human Nutrition.

Each clone was assigned a random four-digit number. The four-digit numbers were then randomly assigned to either the top left, top right, bottom left or bottom right of a tray that was presented to the evaluators. For each clone, four berries were randomly selected and placed into a cup. The four cups were randomly placed on the tray. Saltine crackers and a glass of water were also placed on the tray to cleanse the panelist's palate between samples. When a panelist entered the sensory panel chamber, he/she was seated at a booth that had a computer and a small sliding window. The window was opened and a worker presented a tray with the cups of berries. The panelist then sampled the berries and answered the questions (listed in Table 2.6) about each group of berries using the computer.

Table 2.6. Questions asked for the 2003 taste panel study.

Question number	Berry attribute evaluated	Evaluation scale
1	Appearance	Ranked 1 (extremely disliked) to 9 (extremely liked) by number
2	Texture/firmness	Ranked 1 (extremely disliked) to 9 (extremely liked) by number
3	Sweetness	Ranked 1 (extremely disliked) to 9 (extremely liked) by number
4	Flavor	Ranked 1 (extremely disliked) to 9 (extremely liked) by number
5	Overall acceptability	Ranked 1 (extremely disliked) to 9 (extremely liked) by number

2003 Results

The panelists preferred some clones over others with respect to fruit appearance, texture/firmness, and sweetness, but showed no clonal preferences regarding flavor (Tables 2.7-2.11). In 2003, the panelists tended to prefer the texture of the "crisp" clones over that of 'Emerald' and 'Star' (Table 2.8). The questions presented with the 2003 samples were ambiguous in that they did not reveal whether the panelists could detect differences among the clones or whether they could detect differences but did not prefer one texture over another.

Table 2.7. Overall appearance of panelists of four blueberry clones on a scale from 1 (dislike extremely) to 9 (like extremely) (n=90; 2003 study).

Clone	Rating 1	2	3	4	5	6	7	8	9	Mean	Standard Deviation	Tukey Test
Bluecrisp			1[z]	7	10	18	24	24	6	6.70	1.41	b
FL 00-59			1	3	11	7	22	31	15	7.21	1.43	a
Emerald			2	6	9	14	18	34	7	6.89	1.49	ab
Star		2	8	8	15	12	19	18	8	6.18	1.87	c

[z] The number of panelist who rated the clone.

Table 2.8. Overall texture/firmness of panelists of four blueberry clones on a scale from 1 (dislike extremely) to 9 (like extremely) (n=90; 2003 study).

Clone	Rating 1	2	3	4	5	6	7	8	9	Mean	Standard Deviation	Tukey Test
Bluecrisp		1[z]	3	8	7	17	31	15	8	6.54	1.57	ab
FL 00-59		2		6	8	10	25	24	15	7.00	1.61	a
Emerald	1	3	1	11	6	22	24	16	6	6.29	1.73	bc
Star	2	2	3	9	10	27	22	10	5	6.02	1.72	c

[z] The number of panelist who rated the clone.

Table 2.9. Overall sweetness of panelists of four blueberry clones on a scale from 1 (dislike extremely) to 9 (like extremely) (n=90; 2003 study).

Clone	Rating 1	2	3	4	5	6	7	8	9	Mean	Standard Deviation	Tukey Test
Bluecrisp	1[z]	1	4	12	13	8	26	16	9	6.30	1.84	Ab
FL 00-59	1	1	4	7	7	10	13	29	18	6.92	1.92	A
Emerald	1	3	7	7	10	19	21	18	4	6.08	1.84	B
Star		5	7	11	10	22	15	18	2	5.82	1.83	B

[z] The number of panelist who rated the clone.

Table 2.10. Overall flavor of panelists of four blueberry clones on a scale from 1 (dislike extremely) to 9 (like extremely) (n=90; 2003 study).

Clone	Rating 1	2	3	4	5	6	7	8	9	Mean	Standard Deviation	Tukey Test
Bluecrisp		5[z]	4	10	11	17	17	18	8	6.16	1.91	A
FL 00-59	1	4	4	7	6	15	19	15	19	6.59	2.06	A
Emerald	3	4	5	3	17	17	18	15	8	6.03	2.02	A
Star	1	3	6	8	14	18	16	16	8	6.08	1.91	A

[z] The number of panelist who rated the clone.

Table 2.11. Overall acceptability of panelists of four blueberry clones on a scale from 1 (dislike extremely) to 9 (like extremely) (n=90; 2003 study).

Clone	Rating 1	2	3	4	5	6	7	8	9	Mean	Standard Deviation	Tukey Test
Bluecrisp		1[z]	4	9	13	16	24	16	7	6.33	1.65	Ab
FL 00-59		2	5	4	8	12	24	20	15	6.78	1.79	A
Emerald	1	1	4	6	15	21	19	19	4	6.23	1.65	Ab
Star	1	3	2	10	14	24	23	10	3	5.94	1.62	B

[z] The number of panelist who rated the clone.

2004 Materials and Methods

To resolve this ambiguity of the 2003 sensory panel, the 2004 questionnaire was changed to directly ask each panelist if they could distinguish between the "crisp" and commercial berries. The 2004 panel was conducted using the crisp-textured clones 'Bluecrisp' and FL 00-59, and the standard clones 'Star' and 'Windsor'. Each clone was placed through the same harvesting and taste panel procedure that was used in 2003 except the questions were different (Table 2.12).

Table 2.12. Questions asked for the 2004 taste panel study.

Question number	Question topic	Evaluation scale
1	How often do you eat blueberries	1 (never), 2 (1-2 times a year), 3 (3-10 times a year), 4 (> 10 times a year)
2	Place in order solely based on firmness each group of berries	1 (softest) to 4 (crunchiest) by number
3	Rank each group of berries on texture/firmness.	1 (extremely disliked) to 9 (extremely liked) by number
4	Rank overall quality of each group of berries	1 (extremely disliked) to 9 (extremely liked) by number

2004 Results

Forty four percent of the panelists who participated in the 2004 panel ate blueberries 1 to 2 times a year, 32% ate blueberries 3 to 10 times a year and the rest either never ate blueberries or ate them more then ten times a year (Table 2.13). From these data it could be said that most of these test subjects were not regular blueberry eaters. The second question asked the panelist to rank the groups from softest to crunchiest. This question separated 'Bluecrisp' and FL 00-59 as being the crunchiest and 'Emerald' and 'Star' as being softer (Table 2.14). Based on a sample of four berries per clone about 78% of the panelists chose one of the two "crisp" clones as being crunchiest and only 22% chose one of the other two clones (Table 2.14). The third question (Table 2.15) asked panelists to indicate how well they liked the firmness of the groups of berries on a scale from one (extremely disliked) to nine (extremely disliked). Here the texture of the two crisp clones received the highest preference ratings (Table 2.15), although the preference for 'Bluecrisp' texture was not significantly higher than for 'Star'. The forth and final question (Table 2.16) asked each panelist to rank the overall desirability of each

group of blueberries. This question did not reveal any major differenced among the groups, although FL 00-59 was ranked significantly higher than 'Star'. The difference between "crisp" and "non-crisp" clones was more consistent in firmness ranking than for firmness desirability (Table 2.14 versus Table 2.15). This implies that some panelist who could recognize crisp texture did not prefer it. Table 2.17 showed that how often a panelist ate blueberries was not correlated with the recognition of "crisp" berries. Overall, from these results it could be said that "crisp" berries can be distinguishable from regular commercial berries, and are often but not always considered more desirable than "non-crisp" berries.

Table 2.13. Previous blueberry eating experience of the 95 panelists whom were part of the evaluation panel in 2004.

Number of panelist who had eaten blueberries			
never	1-2 times/year	3-10 times/year	>10 times/year
6	42	31	16

Table 2.14. Firmness ranking of 4 blueberry clones by 95 panelists from 1 (softest sample) to 4 (crunchiest sample).

	Rank				Rank	Tukey
Clone	1	2	3	4	total	test
Bluecrisp	10[z]	15	33	37	287	a[y]
FL 00-59	9	16	32	38	289	a
Star	30	39	17	9	195	b
Windsor	46	25	13	11	179	b

[z] Number of people who ranked the clone at that position.

[y] Totals followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

Table 2.15. Desirability of the berry firmness of 4 blueberry clones evaluated on a scale from 1 (dislike extremely) to 9 (like extremely) by 95 panelists.

	Desirability										Standard	Tukey
Clone	1[z]	2	3	4	5	6	7	8	9	Mean	deviation	test
Bluecrisp	2[y]	3	4	10	9	13	23	21	10	6.34	1.982	ab[x]
FL 00-59	1	1	3	2	9	21	22	21	15	6.82	1.669	a
Star	3	3	12	9	14	9	18	18	9	5.85	2.188	bc
Windsor	2	6	8	16	11	16	15	12	9	5.63	2.124	c

[z] Scale from 1(dislike extremely) to 9(like extremely)

[y] Number of people who ranked the clone at that position.

[x] Means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

Table 2.16. Overall desirability of the berry quality of 4 blueberry clones evaluated by 95 panelists.

	Desirability										Standard	Tukey
Clone	1[z]	2	3	4	5	6	7	8	9	Mean	deviation	test
Bluecrisp	5[x]	3	2	8	14	17	22	14	10	6.07	2.074	ab[y]
FL 00-59		3	2	6	9	21	18	20	16	6.71	1.768	a
Star	1	1	7	12	9	23	15	17	10	6.17	1.877	ab
Windsor	1	9	2	13	11	17	15	12	15	6.00	2.183	b

[z] Scale from 1(dislike extremely) to 9(like extremely)

[y] Means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

[x] Number of people who ranked the clone at that position.

Table 2.17. Desirability of berry firmness and overall desirability of berries of 4 blueberry clones as judged by panelists with differing blueberry consumption histories.

Clone	Panelists[z]	Firmness rank Mean	Firmness rank Standard dev.	Firmness rank Tukey test	Desirability of firmness Mean	Desirability of firmness Standard dev.	Desirability of firmness Tukey test	Overall desirability Mean	Overall desirability Standard dev.	Overall desirability Tukey test
FL 00-59	Never	2.67	1.37	a	6.00	1.26	a	6.00	2.28	a
FL 00-59	1-2 times	3.00	0.96	a	6.67	1.95	a	6.45	1.84	a
FL 00-59	3-10 times	2.97	0.91	a	7.48	1.23	a	7.39	1.45	a
FL 00-59	> 10 times	3.31	1.08	a	6.25	1.39	a	6.31	1.70	a
Bluecrisp	Never	3.00	0.89	a	5.50	2.07	a	4.33	1.51	a
Bluecrisp	1-2 times	3.12	0.99	a	6.10	1.66	a	6.07	1.67	a
Bluecrisp	3-10 times	3.23	0.96	a	6.61	2.12	a	6.16	2.22	a
Bluecrisp	> 10 times	2.50	0.89	a	6.75	2.41	a	6.56	2.68	a
Star	Never	2.33	1.03	a	4.50	1.87	a	4.00	2.10	b
Star	1-2 times	2.10	0.91	a	5.74	1.98	a	6.07	1.67	a
Star	3-10 times	1.77	0.84	a	6.10	2.27	a	6.58	1.75	a
Star	> 10 times	2.38	1.09	a	6.19	2.61	a	6.44	2.13	a
Windsor	Never	2.00	1.26	a	4.67	2.66	a	4.17	3.06	a
Windsor	1-2 times	1.79	1.02	a	5.29	2.04	a	5.81	1.95	a
Windsor	3-10 times	2.03	1.08	a	5.90	2.20	a	6.58	2.13	a
Windsor	> 10 times	1.81	0.98	a	6.38	1.86	a	6.06	2.26	a

[z]Previous blueberry eating experience in a year

Discussion

Very little work has been done on blueberry taste as it pertains to consumer sensory panels. The Dave Wilson Nursery has done a taste panel study every year since 1992. In 2002 blueberries were added to this panel, and it was determined that new cultivars ‘Southmoon’, ‘Jubilee’, ‘Misty’ and ‘Ozark Blue’ (scores ranging from 5.5 to 6.3 on their 10 point scale) tasted better than the older standard cultivars ‘O’Neal’, ‘Georgia Gem’ and ‘Bluecrop’ (scores ranging from 4.8 to 5.4) (11).

In the 2003 sensory panel study the “crisp” clones could not be distinguished from the “non-crisp” clones in any of the questions. This was probably because panelists did not prefer the “crisp” clones over the “non-crisp” clones. Panelists were not asked whether they could distinguish between “crisp” and “non-crisp” clones. The 2004 sensory panel study directly asked the panelists if they could detect a difference between the “crisp” and “non-crisp” clones, and if they preferred one type over another. We were able to determine that panelists could tell a difference but did not always prefer the crisp-textured clones over the standard cultivars.

The blueberries in our study were harvested the day before each consumer sensory panel was conducted and kept in an ideal storage condition until they were used. Most fresh blueberries eaten by consumers are shipped across the country, kept on the grocery shelf for several days and possibly stored in the home refrigerator for several more days before they are eaten. If the crisp-textured clones retain their “just-picked” characteristics longer than standard commercial varieties, sensory panel evaluations done on berries that had been subjected to commercial packing, transport, and sales might have separated the “crisp” and normal berries better than our test with just-picked berries. Further research should be conducted to determine if this is the case.

CHAPTER 3
POSTHARVEST STORAGE TEST

It was hypothesized that the “crisp” blueberries might store longer then standard commercial blueberries. Standard commercial blueberries can be stored at 2°C in air for up to 2 weeks without serious degradation. To determine if “crisp” blueberries store longer then standard commercial berries, selected quality parameters of four “crisp” clones and four “non-crisp” clones determined during air and CA cold storage for 8 weeks in 2003 and 2004.

2003 Study

Materials and Methods

Five to eight blueberry plants of the “crisp” clones ‘Bluecrisp’, FL 00-59, FL 97-136, FL 98-325 and the “non-crisp” clones ‘Emerald’, ‘Millennia’, ‘Star’ and ‘Windsor’ were netted in a commercial field at the beginning of the harvest season in April 2003. As the berries from each clone matured, they were harvested at the blue stage and placed in 125 g plastic clamshells donated by Straughn farms Inc. For each harvest a minimum of three clamshells per clone were taken. A total of 15 clamshells were needed for each clone. The name of the clone, date of harvest and a storage time of 0, 2, 4, 6 or 8 weeks was written on each clamshell. The berries were then placed in a cooler with ice for transport to a 2° C storage unit where they were separated based on storage time. Berries harvested for 0 week storage were evaluated for initial quality factors. Berries harvested for evaluations after 2, 4, 6 and 8 weeks storage were placed in the 2° C storage room for their designated length of time.

At the end of the designated storage periods each blueberry was taken out of the clamshell and checked for mold, incident of shrivel, severity of shrivel, leaking/collapse, weight loss and firmness. To check for decay, each blueberry was visually inspected, and the total number of berries with decay was recorded. For incident of shrivel, each berry was examined for signs of shrivel starting at the scar end and going around the berry. The severity of shrivel was rated for each berry using a 9 point scale, from 1 (no signs of shriveling) to 9 (severely shriveled). To examine leaking/collapse, the blueberries were checked for fluid leakage and cellular collapse not caused by decay. To check for weight loss, each clamshell was weighed before being placed into storage. When removed from storage the clamshells were reweighed and weight loss was obtained. To examine the firmness, ten blueberries were randomly taken from each clamshell and force deformation measurements with an Instron 8600 testing machine, as previously described, were taken. This process was repeated on all 10 berries for each group of berries that came out of cold storage. Once examined, the berries were poured into zip lock freezer bags and placed in a freezer at -30° C. The pH, SSC and TTA were later determined. All percentage data was converted to arcsin for analysis.

To determine pH, SSC and TTA, the blueberries were taken out of -30° C storage, eight bags at a time. The frozen berries from each bag were placed in a glass jar. The jars were sealed and placed in a large plastic container with approximately 2 inches of tap water to thaw the berries. The berries were left in the containers for 1.5 hours to reach room temperature. Once at room temperature, the berries were blended for 10 s until reaching a paste-like consistence. Fifty grams was then placed into a tube and centrifuged at 34.02 gn for 20 minutes. The supernatant was then poured through cheese cloth into a small vial. From this supernatant, the pH, SSC and TTA were determined.

Results

Firmness of newly harvested blueberries differed among clones (Table 3.1). FL 98-325 was distinctively firmer than all other clones (Table 3.1). Of the four “crisp” clones, only ‘Bluecrisp’ had a firmness mean similar to the four “non-crisp” clones.

Firmness declined for all clones during storage (Table 3.1). The mean rate of softening ranged from 0.11 to 0.21 N per week for the eight clones. The “crisp” clones appeared to lose firmness as fast as the “non-crisp” clones. Overall there was a significant week x clone interaction, but, the “crisp” clones did not maintain firmness better than the “non-crisp”. This is shown both by the slopes in Table 3.1 and by the Tukey test for firmness at week 8.

All clones except ‘Star’ had some decayed berries after 2 weeks storage at 2° C. Decay incidence increased in all clones over time during the storage test (Table 3.3). The rate of increase in decay incidence ranged from 0.08% to 2.86% per week (Table 3.3). Even though the week x clone interaction was significant the “crisp” clones did not show any consistent differences in the rate of decay development compared to the “non-crisp” clones. This is shown in the slopes and Tukey testing in Table 3.3. Clones FL 00-59 (“crisp”), ‘Emerald’ and ‘Millennia’ (“non-crisp”) had less decay over time than the other clones (Tables 3.3 and 3.4).

The number of leaking berries increased with each clone over time during the storage test (Table 3.5). The Tukey test on week 8 and the slopes reveled that the “crisp” clones did not develop leaking berries significantly slower then the “non-crisp” clones

Table 3.1. Mean deformation force[z] at 2mm depth for 8 blueberry clones stored in air for 8 weeks at 2°C in 2003.

	2mm Deformation Force (N)						
Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	2.37 d[x]	2.21 cd	1.95 b	1.36 c	1.17 c	-0.16 bc[w]	0.0001
FL 97-136	3.02 bc	2.80 b	2.47 b	1.96 bc	1.79 b	-0.17 b	0.0001
FL 98-325	4.18 a	4.55 a	4.18 a	3.72 a	2.74 a	-0.19 cd	0.0017
FL 00-59	3.07 b	2.55 bc	2.35 b	2.11 b	1.74 b	-0.15 bc	0.0001
Emerald	2.31 d	2.08 d	2.01 b	1.63 bc	1.26 bc	-0.12 a	0.0001
Millennia	2.67 bcd	2.83 b	2.05 b	1.63 bc	1.26 bc	-0.20 d	0.0001
Star	2.59 cd	2.65 b	1.89 b	1.52 bc	1.05 c	-0.21 d	0.0001
Windsor	2.27 d	2.12 d	2.24 b	1.79 bc	1.36 bc	-0.11 a	0.0014
P > F	<.0001	<.0001	<.0001	<.0001	0.0001		

[z]Mean of 30 berries individually sampled, 10 from each of three clamshells.
[y]m is the estimated change in force(N) per week based on linear regression analysis.
[x]Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests

Table 3.2. ANOVA for mean deformation force needed at 2mm for 8 blueberry clones stored for 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	2.00	37.84	<.0001
Clones	7	6.87	129.76	<.0001
Weeks	4	6.68	126.11	<.0001
Weeks x Clones	28	0.119	2.25	0.0026
Error	80	0.053		

R-Square	0.95

(Table 3.5). The week x clone interaction was not significant (Table 3.5). Overall there was an increase in leaking berries over time, but not significant interaction with the clones over time.

All of the clones lost weight over time (Table 3.7). The week x clone interaction was significant showing that there were differences amongst the clones over time (Table 3.8). From the Tukey test and the slopes, there were no differences in the rate of weight loss between the “crisp” clones and the “non-crisp” clones (Table 3.7). FL 00-59, ‘Emerald’ and ‘Millennia’ showed less weight loss than the other clones.

Table 3.3. Incidence of decay (%) for eight blueberry clones stored for 8 weeks at 2°C in 2003.

	Decay (%)						
Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m^z	Prob m = 0
Bluecrisp	0.00^y	0.38 c^x	4.08 ab	7.35 a	18.6 ab	2.22 ab^w	<.0001
FL 97-136	0.00	0.81 c	5.20 ab	6.26 a	12.81 bc	1.55 c	<.0001
FL 98-325	0.00	0.81 c	7.62 ab	9.46 a	24.31 ab	2.86 a	<.0001
FL 00-59	0.00	7.80 ab	3.27 b	4.01 a	2.74 d	0.08 e	0.2928
Emerald	0.00	2.61 ab	7.44 ab	3.11 a	5.96 cd	0.62 de	0.0201
Millennia	0.00	14.24 a	8.56 ab	11.71 a	10.25 bcd	0.90 d	0.0167
Star	0.00	0.00 c	13.42 a	9.49 a	10.64 bcd	1.53 bc	0.0006
Windsor	0.00	14.24 a	4.57 ab	11.39 a	29.35 a	2.79 abc	0.0005
P > F		<.0001	0.0951	0.1692	0.0004		

^{z}m is the estimated change in the percent of decaying berries per week based on linear regression analysis.
^{y}Mean of 30 berries individually sampled, 10 from each of three clamshells.
^{x}Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey’s test.
^{w}Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests

Table 3.4. ANOVA for incidence of decay (%) of eight blueberry clones stored for 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	252.03	13.84	<.0001
Clones	7	149.10	8.19	<.0001
Weeks	4	1500.86	82.40	<.0001
Weeks x Clones	28	99.36	5.46	<.0001
Error	80	18.21		

R-Square	0.87

The number of shriveled berries increased dramatically over time during the storage test (Table 3.9). The week x clone interaction was significant showing that there were differences amongst the clones over time (Table 3.10). However, in examining the Tukey test results and the slopes, these differences did not distinguish the “crisp” clones from the “non-crisp” clones (Table 3.9). Overall, the amount of shriveling increased over time, but the “crisp” clones were not significantly different from the “non-crisp” clones.

The severity of shrivel for each clone increased over time during this storage test (Table 3.11). At week 2, “crisp” clones ‘Bluecrisp’, FL 97-136 and FL 98-325 showed less severity of shriveling then the other clones. This distinction did not continue as storage time lengthened (Table 3.11). The week x clone interaction for shriveling severity was significant. The “crisp” clones did not develop less shriveling than the “non-crisp” clones.

Table 3.5. Incidence of leaking (%) for eight blueberry clones stored for 8 weeks at 2°C in 2003.

	Leaking (%)						
Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[z]	Prob m = 0
Bluecrisp	0.00[y]	0.00 a[x]	1.41 a	3.92 a	8.80 ab	1.08 c[w]	<.0001
FL 97-136	0.00	0.00 a	0.74 a	2.52 a	10.61 ab	1.19 bd	0.0002
FL 98-325	0.00	0.00 a	3.86 a	5.54 a	18.26 ab	2.10 a	<.0001
FL 00-59	0.00	0.00 a	0.65 a	5.97 a	6.24 b	0.92 d	<.0001
Emerald	0.00	0.00 a	2.30 a	3.14 a	10.16 ab	1.17 bd	0.0008
Millennia	0.00	1.32 a	6.29 a	7.86 a	18.28 ab	2.15 a	<.0001
Star	0.00	0.00 a	4.00 a	8.08 a	14.14 ab	1.82 ab	<.0001
Windsor	0.00	1.32 a	3.94 a	9.58 a	25.65 a	2.98 a	<.0001
P > F		0.0196	0.4777	0.3069	0.0337		

[z]m is the estimated change in the percent of leaking berries per week based on linear regression analysis.
[y]Mean of 30 berries individually sampled, 10 from each of three clamshells.
[x]Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey’s test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.6. ANOVA for incidence of leaking (%) for eight blueberry clones stored for 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	222.43	10.11	<.0001
Clones	7	108.01	4.91	0.0001
Weeks	4	1841.62	83.72	<.0001
Weeks x Clones	28	19.72	0.90	0.6169
Error	80	21.99		

R-Square	0.83

Table 3.7. Incidence of weight loss (%) of eight blueberry clones stored for 8 weeks at 2°C in 2003. Values for each week are the cumulative weight loss from week 0 to the week stated.

Clone	Week 0[z]	Week 2[z]	Week 4[z]	Week 6[z]	Week 8[z]	M[y]	Prob m = 0
Bluecrisp	0.0[x]	2.0 d[w]	3.4 c	5.2 c	7.5 cd	0.91 c[v]	<0.0001
FL 97-136	0.0	4.3 ab	5.6 a	7.7 a	9.3 bcd	1.09 b	<0.0001
FL 98-325	0.0	4.4 ab	5.2 a	6.5abc	9.7 bc	1.08 b	<0.0001
FL 00-59	0.0	3.7bc	5.6 a	5.7 bc	7.7 cd	0.87 d	<0.0001
Emerald	0.0	3.4 bc	3.9 bc	5.3 bc	6.7 d	0.77 d	<0.0001
Star	0.0	2.8 cd	5.9 a	7.7 a	10.5 ab	1.30 a	<0.0001
Windsor	0.0	5.4 a	4.9 ab	7.3 a	12.7 a	1.37 a	<0.0001
Millennia	0.0	5.4 a	5.2 a	6.6 ab	8.2 bcd	0.88 d	<0.0001
P > F		<.0001	<.0001	<.0001	0.0001		

[z]Loss from original weight at week 0.
[y]m is the estimated change in weight(g) per week based on linear regression analysis.
[x]Mean of 30 berries individually sampled, 10 from each of three clamshells.
[w]Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[v]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.8. ANOVA for incidence of weight loss (%) of eight blueberry clones stored for 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	31.264	104.01	<.0001
Clones	7	10.341	34.40	<.0001
Weeks	4	267.89	891.23	<.0001
Weeks x Clones	28	2.691	8.95	<.0001
Error	80	0.301		

R-Square	0.98

Table 3.9. Incidence of shriveling (%) for eight blueberry clones stored for 8 weeks at 2°C in 2003.

	Number of berries per 100						
Clone	Week 0	Week 2	Week 4	Week 6	Week 8	M[z]	Prob m = 0
Bluecrisp	0.00[y]	20.25 b[x]	88.95 bc	93.07 bc	99.58 ab	13.60 ab[w]	<.0001
FL 97-136	0.00	11.17 bc	75.30 bcd	84.32 c	96.45 bc	13.30 a	<.0001
FL 98-325	0.00	2.08 c	58.57 d	42.91 d	90.07 c	11.05 bc	<.0001
FL 00-59	0.00	12.93 bc	77.82 bc	94.00 abc	98.64 ab	13.92 bc	<.0001
Emerald	0.00	26.33 b	73.71 cd	87.17 c	98.16 ab	12.86 c	<.0001
Millennia	0.00	66.30 a	99.44 a	99.42 a	100.00 a	11.66 ab	<.0001
Star	0.00	16.10 bc	90.39 b	98.97 ab	99.44 ab	14.09 ab	<.0001
Windsor	0.00	66.30 a	79.23 bc	94.89 abc	100.00 a	11.43 abc	<.0001
P > F		<.0001	<.0001	<.0001	0.0001		

[z]m is the estimated change in number of shriveled berries per week based on linear regression analysis.
[y]Mean of 30 berries individually sampled, 10 from each of three clamshells.
[x]Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.10. ANOVA for incidence of shriveling (%) of eight blueberry clones stored for 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	3345.82	193.57	<.0001
Clones	7	1174.40	67.94	<.0001
Weeks	4	29112.66	1684.31	<.0001
Weeks x Clones	28	207.70	12.02	<.0001
Error	80	17.29		

R-Square	0.99

Table 3.11. Incidence of shrivel severity[z] of eight blueberry clones stored for 8 weeks at 2°C in 2003.

	Index values						
Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	1.00[x]	1.51 c[w]	3.05 abc	3.60 bc	5.10 ab	0.62 a[v]	0.0001
FL 97-136	1.00	1.23 c	2.74 bc	3.07 c	4.41 b	0.53 b	0.0001
FL 98-325	1.00	1.04 c	2.19 c	2.11 d	4.50 b	0.50 cd	0.0001
FL 00-59	1.00	3.95 a	2.85 bc	3.63 bc	4.34 b	0.42 d	0.0012
Emerald	1.00	3.93 a	2.96 bc	3.48 bc	4.85 ab	0.46 cd	0.0005
Millennia	1.00	4.23 a	4.03 a	4.49 a	5.60 a	0.57 abcd	0.0001
Star	1.00	3.11 b	3.55 ab	4.26 ab	5.13 ab	0.57 abc	0.0001
Windsor	1.00	4.24 a	2.99 bc	4.63 a	5.65 a	0.59 abc	0.0001
P > F		<.0001	0.0008	<.0001	0.0011		

[z]Each berry was rated on a scale from 1 (no shriveling) to 9 (extreme shriveling).

[y]m is the estimated change in shrivel severity per week based on linear regression analysis.
[x]Mean of 30 berries individually sampled, 10 from each of three clamshells.
[w]Week 8 means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[v]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.12. ANOVA for Incidence of shrivel severity of eight blueberry clones stored for 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	6.781	83.17	<.0001
Clones	7	5.103	62.59	<.0001
Weeks	4	49.080	601.94	<.0001
Weeks x Clones	28	1.157	14.20	<.0001
Error	80	0.0815		

R-Square	0.98

The pH, SSC and TTA for each clone at each week were tested. No significant differences were found between the "crisp" and "non-crisp" clones. For the pH, all clones increased slightly except 'Windsor', which decreased, but had a high probability of having a slope of zero (Table 3.13). All clones started with similar pHs and after 8 weeks differences among the clones could be seen, but the "crisp" and "non-crisp" clones did not stand out from each other (Table 3.13, 3.14).

SSC of the freshly-picked berries ranged from 7.47 to 12.83 among the clones (Table 3.15). SSC did not separate the "crisp" from the "non-crisp" clones (Table 3.15). There were no significant interactions among the storage times and clones with respect to SSC (Table 3.16). All but three of the slopes showed a decrease in SSC with slopes not significantly different from zero, except for FL 97-136 and FL 98-325, which had a tendency to increase with time (Table 3.15). The initial TTA values ranged from 0.22 to 1.45 for the clones (Table 3.17). There was no distinction between the "crisp" and "non-crisp" clones. Only four clones showed significant changes in TTA over time (Table 3.17). The TTA decreased over time for these four. There were differences over storage time and clones and a significant variance for clones x weeks of storage (Table 3.18).

Table 3.13. Mean[z] pH of eight blueberry clones stored at 2°C over 8 weeks in 2003.

Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	3.84 a[x]	3.84 a	4.06 a	3.96 a	n/a	0.029 d[w]	0.0336
FL 97-136	3.45 bc	3.68 ab	3.73 bc	3.72 bc	3.83 b	0.043 cd	0.0047
FL 98-325	3.65 ab	3.85 a	3.92 ab	3.94 ab	4.06 a	0.047 cd	0.0124
FL 00-59	3.37 c	3.44 c	3.45 de	3.50 cd	3.63 cd	0.021 cd	0.0231
Emerald	3.11 d	3.20 d	3.22 e	3.24 e	3.23 e	0.019 b	0.0236
Millennia	3.47 bc	3.14 d	3.42 de	3.50 cd	3.54 cd	0.018 bc	0.4239
Star	3.38 c	3.51 bc	3.64 cd	3.60 cd	3.67 bc	0.039 cd	0.0066
Windsor	3.46 bc	3.68 ab	3.46 de	3.50 de	3.48 d	-0.010 a	0.5135
P > F	<.0001	<.0001	<.0001	<.0001	<.0001		

[z]Mean of 3 clamshells individually sampled.
[y]m is the estimated change in pH per week based on linear regression analysis.
[x]Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.14. ANOVA for mean pH of eight blueberry clones stored at 2°C over 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	0.176	31.39	<.0001
Clones	8	0.724	129.13	<.0001
Weeks	4	0.155	27.55	<.0001
Weeks x Clones	27	0.026	4.65	<.0001
Error	76	0.006		

R-Square	0.94

Table 3.15. Mean[z] SSC of eight blueberry clones stored at 2°C over 8 weeks in 2003.

Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	12.83 a[x]	14.27 a	14.37 a	12.67 a	n/a	-0.020 abc[w]	0.9531
FL 97-136	9.00 abc	9.40 b	11.00 a	11.77 a	9.80 ab	0.495 bc	0.0092
FL 98-325	8.47 bc	12.77 ab	12.47 a	12.07 a	13.05 a	0.525 c	0.0232
FL 00-59	11.83 ab	11.30 ab	11.30 a	11.20 a	12.30 a	-0.095 bd	0.6377
Emerald	7.47 c	8.43 b	9.80 a	8.93 a	7.60 b	0.288 b	0.2774
Millennia	12.13 ab	10.73 ab	11.30 a	10.47 a	9.10 ab	-0.222 a	0.0928
Star	8.93 bc	10.70 ab	12.47 a	10.60 a	10.40 ab	0.338 bc	0.1705
Windsor	9.60 abc	11.33 ab	10.67 a	10.65 a	8.77 ab	0.022 ad	0.9254
P > F	0.0012	0.0176	0.1736	0.3142	0.0143		

[z]Mean of 3 clamshells individually sampled.

[y]m is the estimated change in SSC per week based on linear regression analysis.

[x]Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.16. ANOVA for mean SSC of eight blueberry clones stored at 2°C over 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	8.47	3.00	<.0001
Clones	8	25.04	8.87	<.0001
Weeks	4	9.08	3.21	0.0171
Weeks x Clones	27	3.19	1.13	0.3323
Error	76	2.82		

R-Square	0.61

Table 3.17. Mean[z] TTA of eight blueberry clones stored at 2°C over 8 weeks in 2003.

Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	0.22 d[x]	0.28 d	0.21 d	0.25 c	n/a	0.003 a[w]	0.6538
FL 97-136	0.52 bcd	0.37 cd	0.47 c	0.45 c	0.46 bc	-0.005 ab	0.6493
FL 98-325	0.42 cd	0.36 cd	0.31 cd	0.30 c	0.28 c	-0.020 de	0.0074
FL 00-59	0.58 bc[x]	0.51 c	0.48 c	0.43 c	0.47 bc	-0.025 c	0.0010
Emerald	1.45 a	0.71 b	0.76 ab	0.81 a	0.95 a	-0.093 e	0.0288
Millennia	0.61 bc	1.16 a	0.85 a	0.76 ab	0.80 ab	0.007 abcd	0.8389
Star	0.75 b	0.50 c	0.47 c	0.51 bc	0.48 bc	-0.038 e	0.0299
Windsor	0.48 bcd	0.41 cd	0.52 bc	0.40 c	0.38 c	-0.007 bcd	0.4907
P > F	<.0001	<.0001	<.0001	<.0001	0.0013		

[z]Mean of 3 clamshells individually sampled.
[y]m is the estimated change in TTA per week based on linear regression analysis.
[x]Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.18. ANOVA for mean TTA of eight blueberry clones stored at 2°C over an 8 weeks in 2003.

Source	DF	Mean Square	F value	Pr > F
Model	39	0.198	17.69	<.0001
Clones	8	0.723	64.72	<.0001
Weeks	4	0.079	7.06	<.0001
Weeks x Clones	27	0.060	5.41	<.0001
Error	77	0.011		

R-Square	0.90

In 2004, to better determine if crisp-textured blueberries are different from commercial blueberries, two atmospheres were used – one being normal air and the other a low O2 / high CO2 CA. Two new clones were also added that were believed to have crisp texture: FL 00-180 and FL 00-270.

2004 Study

Materials and Methods

Five to eight blueberry plants of each of the clones 'Bluecrisp', FL 97-136, FL 98-325, FL 00-59, FL 00-180, FL 00-270, 'Emerald', 'Millennia', 'Star' and 'Windsor' were netted in a commercial field at Windsor, Florida at the beginning of the harvest season. As the berries from each clone matured they were harvested at the blue stage and placed in 125 g clamshells. For each harvest a minimum of three clamshells per clone were taken. A total of 15 clamshells per clone were needed for the CA storage test, and 15 clamshells were needed for the air storage test. The name of the clone, date of harvest, storage environment and the storage time were written on each clamshell. The clamshells were placed in a cooler of ice for transport to a 2° C storage unit, where they were separated based on storage environment and storage time. Storage time for air was 2, 4, 5, and 6 weeks and CA storage was for 2, 4, 6, and 8 weeks. All the berries for a particular storage environment and storage time were placed into a sealed 5 gallon (79.49 L) bucket, which had one intake and one outlet hose attached to it. The buckets for the same atmosphere were then hooked together and a minimum flow rate of 81ml/min was established through the buckets using pressurized gasses and needle value flow meters to prevent CO2 buildup. For the CA, a mixture of 15% CO2, 2% O2 and 83% N with a relative humidity of 90–95% was delivered to the buckets. For the air atmosphere, a pure flow of air with a relative humidity of 90–95% was delivered to the buckets. The outlet tubes from the end of the bucket lines were checked each day for flow rate, CO2 and O2 concentrations. As each storage time ended, the lids of the buckets were taken off and the clamshells were removed for post-storage examination. Berries harvested for week 0 storage were examined without storage.

For evaluation, 10 blueberries were randomly taken from each clamshell and checked for decay, number of berries that were shriveled, severity of shriveling, leaking/collapse and firmness. To check for decay, each blueberry was visually inspected. Of the 10 berries examined, the number with mold was recorded. The same berries were examined for signs of shriveling, starting at the scar end and going around the berry. Berries were recorded as shriveled or not shriveled. The severity of shriveling was recorded for each berry using a 9 point scale, from 1 (no signs of shriveling) to 9 (severely shriveled). Ten random berries per clamshell were visually examined for leaking fluids or cellular collapse not caused by disease. For firmness testing, a set of 10 different blueberries were placed through the same Instron testing procedure that was done in 2003. The pH, SSC and TTA for berries in each clamshell were determined using the same procedures as in 2003.

Results

Before storage, FL 00-59 was the firmest clone (Table 3.19). As a group, the “crisp” clones were not exceptionally firm at the beginning of the storage test. By week 2 “crisp” clones ‘Bluecrisp’, FL 98-325 and FL 00-59 had a higher firmness then the other clones. At week 6, Tukey’s test showed three (‘Bluecrisp’, FL 00-59 and FL 00-180) of the four “crisp” clones sampled at that time to be significantly firmer than the “non-crisp” clones (Table 3.19). As indicated by the slopes (Table 3.19), some clones became firmer during storage, others less firm. ‘Bluecrisp’ gained the most in firmness and ‘Millennia’ lost the most.

Decay incidence in the air atmosphere storage increased over time for all clones except FL 00-59, which still had no decay after 6 weeks (Table 3.21). The week x clone interaction showed significance, but the week 6 Tukey’s test and the slopes showed that the “crisp” clones did not fare better the “non-crisp” clones (Tables 3.21 and 3.22). Among the slopes FL 00-59 was the only clone that differed significantly from the others (Table 3.21).

The percent of leaking berries increased in all clones over time, except for FL 00-59, which had only one leaking berry in all the samples (Table 3.23). The week x clone interaction was significant for number of leaking berries, but the week 6 Tukey's test and the slopes showed no consistent differences between the "crisp" and "non-crisp" clones (Tables 3.23 and 3.24). Among the slopes the only clone to stand out as being significantly different from the rest was FL 00-59.

The incidence of shriveling in the air atmosphere increased with storage time in all clones (Table 3.25). The week x clone interaction was significant, but the week 6 Tukey's test and the slopes showed no consistent differences amongst the "crisp" and "non-crisp" clones (Tables 3.25 and 3.26). 'Bluecrisp', FL00-59 and FL00-180 had the lowest rates of shriveling when compared to slopes of the other clones (Tables 3.25). The same trend could be seen in the severity of shrivel over time as was seen in the frequency of shriveled berries over time (Tables 3.27 and 3.28).

The pH, SSC and TTA for the blueberries stored in the air atmosphere did not differ significantly for the "crisp" and "non-crisp" clones (Table 3.29). Slopes indicated that there were only small and inconsistent pH changes during the weeks of storage (Table 3.29). The 'weeks' component of the ANOVA analysis for pH was nonsignificant (Table 3.30).

There were significant differences in SSC among the clones at week 0 (Table 3.31), and these differences were maintained throughout. SSC was not a factor that distinguished the "crisp" from the standard clones. All slopes for the clones had high probabilities of being zero and there was not a significant clone x week interaction (Tables 3.31 and 3.32).

Clones varied widely in TA at the beginning of the storage test (Table 3.33). As a group, the six crisp clones had lower TA than the four standard clones. Overall there were only minor changes in TA during storage.

Table 3.19. Mean deformation force[z] at 2mm depth for 10 blueberry clones stored in air for 8 weeks at 2°C in 2004.

	2mm Deformation Force (N)						
Clone	Week 0	Week 2	Week 4	Week 5	Week 6	m[y]	Prob m = 0
Bluecrisp	2.50 bcd[x]	3.49 a	3.66 a	3.53 a	3.13 a	0.20 a[w]	0.0022
FL 97-136	2.26 cde	2.58 b	2.04 d	2.39 bcd	M*	0.02 b	0.5897
FL 98-325	2.88 b	3.51 a	3.33 ab	2.57 bc	M	-0.04 d	0.6251
FL 00-59	3.42 a	3.49 a	3.06 bc	2.96 ab	3.51 a	-0.11 cd	0.0009
FL 00-180	2.35 cde	2.64 b	2.52 cd	2.46 bc	3.19 a	0.02 b	0.5337
FL 00-270	1.89 f	1.78 c	1.65 e	1.85 de	1.75 b	-0.02 d	0.4183
Emerald	2.01 ef	2.18 bc	2.05 de	2.17 cd	1.93 b	0.02 e	0.5131
Millennia	2.09 def	2.40 b	1.82 e	1.36 e	2.07 b	-0.15 e	0.0206
Star	2.54 bc	2.66 b	2.52 cd	2.31 cd	2.06 b	-0.04 f	0.3348
Windsor	2.19 def	2.66 b	2.05 de	2.55 bc	1.72 b	0.02 bc	0.7014
P > F	<.0001	<.0001	<.0001	<.0001	0.0001		

[z]Mean of 30 berries individually sampled, 10 from each of 3 clamshells.

[y]m is the estimated change in force(N) per week based on linear regression analysis.

[x]Week means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests

*Data missing

Table 3.20. ANOVA for mean force needed to deform the berries by 2mm for 10 blueberry clones stored for 6 weeks in 2004. (air atmosphere).

Source	DF	Mean Square	F value	Pr > F
Model	47	1.051	18.61	<.0001
Clones	9	4.253	75.28	<.0001
Weeks	4	0.538	9.53	<.0001
Weeks x Clones	34	0.259	4.59	<.0001
Error	96	0.056		

R-Square	.90

Table 3.21. Incidence of decay (%) for 10 blueberry clones stored for 6 weeks in air storage at 2°C in 2004.

Clone	Week 0	Week 2	Week 4	Week 5	Week 6	m[z]	Prob m = 0
Bluecrisp	0.00 [y]	0.00 a[x]	13.33 a	13.33 cd	10.00 cde	2.39 e[w]	0.0176
FL 97-136	0.00	6.67 a	13.33 a	60.00 a	63.33 ab	11.18 ab	0.0002
FL 98-325	0.00	6.67 a	10.00 a	40.00 ab	83.33 a	11.95 a	0.0003
FL 00-59	0.00	0.00 a	0.00 a	0.00 d	0.00 e	0.00 f	-
FL 00-180	0.00	0.00 a	0.00 a	30.00 abc	3.33 de	2.44 e	0.1510
FL 00-270	0.00	0.00 a	13.33 a	53.33 ab	36.67 abcd	8.13 bc	0.0009
Emerald	0.00	0.00 a	13.33 a	23.33 abcd	33.33 bcd	5.69 c	0.0012
Millennia	0.00	0.00 a	23.33 a	26.67 abcd	43.33 abc	7.30 bc	0.0012
Star	0.00	0.00 a	6.67 a	16.67 abcd	20.00 bcde	3.56 de	.0217
Windsor	0.00	0.00 a	0.00 a	3.33 cd	30.00 bcd	3.60 d	0.0554
P > F		.0087	0.2514	.0002	<0.0001		

[z]m is the estimated change in the percentage of decaying berries per week based on linear regression analysis.
[y]Mean of 30 berries individually sampled, 10 from each of 3 clamshells.
[x]Week 6 means followed by the same letter are not significantly different ($P<0.05$) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different ($P<0.05$) by two-sample t-tests

Table 3.22. ANOVA for incidence of decay (%) for 10 blueberry clones stored for 6 weeks in air storage in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	929.40	10.27	<.0001
Clones	9	1068.95	11.81	<.0001
Weeks	4	5949.10	65.72	<.0001
Weeks x Clones	36	336.77	3.72	<.0001
Error	100	90.52		

R-Square	0.83

Table 3.23. Incidence of leaking (%) for 10 blueberry clones stored for 6 weeks in air storage at 2°C in 2004.

Clone	Week 0	Week 2	Week 4	Week 5	Week 6	m[z]	Prob m = 0
Bluecrisp	0.00 [y]	3.33 bc[x]	6.67 b	20.00 abc	16.67 bc	3.22 d[w]	0.0040
FL 97-136	0.00	30.00 a	16.67 ab	53.33 ab	50.00 ab	7.90 bc	0.0017
FL 98-325	0.00	20.00 ab	10.00 b	63.33 a	70.00 a	11.26 a	0.0004
FL 00-59	0.00	0.00 c	3.33 b	0.00 c	0.00 c	0.00 g	0.7920
FL 00-180	0.00	0.00 c	3.33 b	20.00 abc	30.00 c	1.84 f	0.1818
FL 00-270	0.00	0.00 c	46.67 a	53.33 ab	30.00 abc	8.25 ab	0.0039
Emerald	0.00	3.33 bc	13.33 ab	30.00 abc	20.00 abc	4.45 cde	0.0017
Millennia	0.00	0.00 c	46.67 a	46.67 ab	26.67 abc	7.41 bc	0.0056
Star	0.00	3.33 bc	10.00 ab	16.67 abc	16.67 abc	3.08 ef	0.0297
Windsor	0.00	0.00 c	10.00 ab	10.00 bc	56.67 ab	7.30 bc	0.0087
P > F		<.0001	0.0016	0.0004	0.0002		

[z]m is the estimated change in the percent of leaking berries per week based on linear regression analysis.
[y]Mean of 30 berries individually sampled, 10 from each of three clamshells.
[x]Week 6 means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.24. ANOVA for incidence of leaking (%) for 10 blueberry clones stored for 6 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	952.39	10.56	<.0001
Clones	9	1322.88	14.67	<.0001
Weeks	4	5397.03	59.84	<.0001
Weeks x Clones	36	365.92	4.06	<.0001
Error	100	90.19		

R-Square	0.84

Table 3.25. Incidence of shriveling (%) for 10 blueberry clones stored for 6 weeks in air storage at 2°C in 2004.

Clone	Week 0	Week 2	Week 4	Week 5	Week 6	m^z	Prob m = 0
Bluecrisp	0.00 [y]	3.33 ab[x]	16.67 ab	33.33 bc	33.33 cd	6.26 d[w]	0.0001
FL 97-136	0.00	30.00 a	53.33 ab	86.67 a	83.33 ab	14.89 a	0.0001
FL 98-325	0.00	20.00 ab	16.67 ab	76.67 ab	86.67 a	14.22 ab	0.0001
FL 00-59	0.00	0.00 b	3.33 b	6.67 c	0.00 e	1.55 e	0.2875
FL 00-180	0.00	0.00 b	6.67 b	63.33 ab	6.67 de	5.29 d	0.0993
FL 00-270	0.00	10.00 ab	63.33 a	86.67 a	63.33 abc	14.11 ab	0.0002
Emerald	0.00	3.33 ab	26.67 ab	46.67 abc	53.33 abc	9.68 bc	0.0001
Millennia	0.00	0.00 b	70.00 a	60.00 ab	63.33 abc	13.05 abc	0.0002
Star	0.00	6.77 ab	26.67 ab	66.67 ab	40.00 bcd	9.37 c	0.0029
Windsor	0.00	6.77 ab	40.00 ab	50.00 ab	76.67 abc	12.67 b	0.0001
P > F		.0104	.0024	<.0001	<0.0001		

[z]m is the estimated change in the percent of shriveled berries per week based on linear regression analysis.
[y]Mean of 30 berries individually sampled, 10 from each of three clamshells.
[x]Week 6 means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.26. ANOVA for incidence of shriveling (%) of 10 blueberry clones stored at 2°C for 6 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	1843.39	16.37	<.0001
Clones	9	2132.30	18.94	<.0001
Weeks	4	13789.26	122.47	<.0001
Weeks x Clones	36	443.85	3.94	<.0001
Error	100	112.59		

R-Square	0.89

Table 3.27. Incidence of shrivel severity[z] of 10 blueberry clones stored for 6 weeks in air storage at 2°C in 2004.

	Index values						
Clone	Week 0	Week 2	Week 4	Week 5	Week 6	m[y]	Prob m = 0
Bluecrisp	1.00 [x]	1.13 bc[w]	1.50 abc	1.73 e	2.03 cd	0.17 d[v]	0.0021
FL 97-136	1.00	2.13 a	2.57 bc	5.70 a	4.60 ab	0.71 ab	0.0001
FL 98-325	1.00	1.87 ab	1.47 bc	4.43 abc	6.13 a	0.77 a	0.0002
FL 00-59	1.00	1.00 c	1.10 c	1.13 e	1.00 d	0.01 e	0.3732
FL 00-180	1.00	1.00 c	1.13 c	3.10 cde	1.17 d	0.17 d	0.1424
FL 00-270	1.00	1.10 bc	3.17 ab	4.90 ab	4.00 abc	0.66 b	0.0004
Emerald	1.00	1.13 bc	2.23 abc	2.70 cde	2.30 bcd	0.33 c	0.0001
Millennia	1.00	1.00 c	3.77 a	4.03 abcd	3.50 bcd	0.56 b	0.0004
Star	1.00	1.17 bc	1.63 bc	2.53 cde	2.37 bcd	0.27 c	0.0025
Windsor	1.00	1.07 c	2.00 abc	2.07 de	4.30 abc	0.48 b	0.0003
P > F		0 .0002	0.0004	<.0001	<.0001		

[z]Each berry was rated on a scale from 1 (no shriveling) to 9 (extreme shriveling).

[y]m is the estimated change in shrivel severity per week based on linear regression analysis.

[x]Mean of 30 berries individually sampled, 10 from each of three clamshells.

[w]Week 8 means followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

[v]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.28. ANOVA for incidence of shrivel severity of 10 blueberry clones stored for 6 weeks at 2°C in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	5.90	16.98	<.0001
Clones	9	0.35	23.4	<.0001
Weeks	4	8.14	94.62	<.0001
Weeks x Clones	36	32.90	6.74	<.0001
Error	100	2.34		

R-Square	0.89

Table 3.29. Mean[z] pH of 10 blueberry clones in an air atmosphere over 6 weeks in 2004.

	Week 0	Week 2	Week 4	Week 5	Week 6	m[y]	Prob m = 0
Bluecrisp	4.10 ab[x]	4.05 b	4.05 ab	3.99 a	4.09 a	-0.013 cde[w]	0.5636
FL 97-136	4.41 a	4.40 a	4.08 ab	n/a[v]	n/a	-0.073 a	0.0272
Fl 98-325	4.16 ab	4.37 a	4.26 a	n/a	n/a	0.019 def	0.6462
Fl 00-59	3.95 bc	3.86 bc	3.79 bc	3.81 ab	3.82 b	-0.041 bc	0.1162
FL 00-180	3.55 cd	3.46 gf	3.66 cd	3.54 c	3.54 c	0.029 e	0.2422
FL 00-270	3.65 cd	3.68 cde	3.63 cd	3.63 bc	3.61 bc	-0.004 cde	0.7421
Emerald	3.61 cd	3.79 cd	3.67 cd	3.60 c	3.58 bc	0.015 d	0.4940
Millennia	3.65 cd	3.30 g	3.51 cd	3.62 c	3.51 c	-0.036 cde	0.4707
Star	3.46 d	3.60 def	3.54 cd	3.61 c	3.68 bc	0.020 f	0.2797
Windsor	3.49 d	3.56 ef	3.42 d	3.27 d	3.42 c	-0.016 b	0.4805
P > F	<.0001	<.0001	<.0001	<.0001	<.0001		

[z]Mean of three clamshells individually sampled.
[y]m is the estimated change in titratable acid per week based on linear regression analysis.
[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests
[v]Berries were too decayed to obtain any data.

Table 3.30. ANOVA for mean pH of 10 blueberry clones in an air atmosphere over 6 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	45	0.248	23.12	<.0001
Clones	9	1.070	99.75	<.0001
Weeks	4	0.014	1.26	0.2931
Weeks x Clones	32	0.028	2.60	0.0002
Error	89	0.011		

R-Square	0.92

Table 3.31. Mean[z] SSC 10 blueberry clones in an air atmosphere over 6 weeks in 2004.

Clone	Week 0	Week 2	Week 4	Week 5	Week 6	m[y]	Prob m = 0
Bluecrisp	12.70 ab[x]	12.90 a	12.23 a	12.20 ab	11.70 ab	-0.117 bc[w]	0.6620
FL 97-136	14.50 a	12.97 a	12.10 ab	n/a[v]	n/a	-0.600 de	0.1292
FL 98-325	10.13 bc	12.13 a	9.73 abcd	n/a	n/a	-0.100 abcd	0.7843
FL 00-59	12.20 abc	12.00 a	11.50 abc	12.30 a	12.90 a	-0.175 a	0.4884
FL 00-180	8.27 c	7.00 b	8.03 d	8.03 c	7.80 d	-0.058 ab	0.7967
FL 00-270	9.87 bc	8.93 ab	9.13 cd	8.40 ac	8.83 cd	-0.183 bc	0.4450
Emerald	11.30 abc	11.77 a	9.20 bcd	9.63 abc	9.00 cd	-0.525 d	0.0705
Millennia	11.87 abc	11.50 a	10.37 abcd	12.07 ab	10.93 abc	-0.375 bc	0.0891
Star	10.33 bc	11.93 a	10.33 abcd	10.87 abc	10.60 abc	0.000 abc	1.0000
Windsor	10.27 bc	10.70 ab	9.43 abcd	9.10 bc	9.80 bcd	-0.208 ce	0.2189
P > F	0.0015	0.0009	0.0006	0.0012	<.0001		

[z]Mean of three clamshells individually sampled.

[y]m is the estimated change in SSC per week based on linear regression analysis.

[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests

[v]Berries were too decayed to obtain any data.

Table 3.32. ANOVA for mean SSC of 10 blueberry clones in an air atmosphere over 6 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	45	8.24	5.87	<.0001
Clones	9	33.12	23.61	<.0001
Weeks	4	5.30	3.77	0.0070
Weeks x Clones	32	1.38	0.98	0.5054
Error	89	1.40		

R-Square	0.75

Table 3.33. Mean[z] TTA of 10 blueberry clones in an air atmosphere over 6 weeks in 2004.

Clone	Week 0	Week 2	Week 4	Week 5	Week 6	m[y]	Prob m = 0
Bluecrisp	0.24 bcd[x]	0.23 de	0.26 def	0.31 c	0.26 b	0.003 d[w]	0.6885
FL 97-136	0.14 d	0.13 e	0.20 ef	n/a[v]	n/a	0.015 cd	0.0777
FL 98-325	0.15 d	0.13 e	0.14 f	n/a	n/a	-0.003 e	0.4974
FL 00-59	0.23 cd	0.31 cde	0.31 cdef	0.29 c	0.35 b	0.021 c	0.0701
FL 00-180	0.30 abcd	0.55 b	0.35 bcdef	0.43 bc	0.46 ab	0.013 bcde	0.6631
FL 00-270	0.29 abcd	0.4 bcd	0.44 abcd	0.13 bc	0.47 ab	0.027 b	0.0008
Emerald	0.44 ab	0.35 cd	0.41 abcde	0.48 b	0.46 ab	-0.007 cd	0.5744
Millennia	0.42 abc	0.90 a	0.54 ab	0.51 b	0.65 a	0.03 bcde	0.5852
Star	0.46 a	0.43 bc	0.49 abc	0.42 bc	0.43 ab	0.006 e	0.7353
Windsor	0.43 abc	0.40 bcd	0.56 a	0.76 a	0.36 ab	0.027 a	0.2646
P > F	<.0001	<.0001	<.0001	<.0001	0.010		

[z]Mean of three clamshells individually sampled.

[y]m is the estimated change in TTA per week based on linear regression analysis.

[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests

[v]Berries were too decayed to obtain any data.

Table 3.34. ANOVA for mean TTA of 10 blueberry clones in an air atmosphere over 6 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	0.105	13.69	<.0001
Clones	9	0.423	55.28	<.0001
Weeks	4	0.025	3.24	0.0152
Weeks x Clones	36	0.034	4.46	<.0001
Error	100	0.008		

R-Square	0.87

In the C.A., the clones over time tended to decrease (Table 3.35). Examining the clones at week 0 showed no difference between the "crisp" clones and the "non-crisp" clones, except FL 00-59 was firmer than all other clones (Table 3.35). By week 8, however, the five firmest clones were all "crisp", and of the "crisp" clones, only FL 00-270 was quite soft. Week x clone interaction was significant with respect to firmness in a C.A. (Table 3.36).

Very few berries developed decay in the C.A. (Table 3.37). The ANOVA showed significant differences in weeks and clones but no week x clone interaction (Table 3.38).

Under controlled atmosphere storage, the number of leaking berries did not increase significantly over time except in 'Emerald', 'Millennia' and 'Windsor' (Table 3.39). Clone, week and week x clone interaction were all significant, but no difference could be seen between the "crisp" and "non-crisp" clones at week 8 or in the slopes (Tables 3.39 and 3.40). The lack of decay and leaking berries after the C.A. storage indicates that the high CO2 and low O2 concentrations retarded berry degradation and mold growth (Tables 3.37, 3.38, 3.39 & 3.40).

The number of shriveled berries increased for each clone over time (Table 3.41). The clone effect and the week x clone interaction was significant, but the "crisp" clones did not stand out as being better when compared to the "non-crisp" at week 8 or in the rate of shriveling as indicated by the slopes (Tables 3.41 and 3.42). The severity of shrivel for each clone (Table 3.44) followed the same trend as the number of shriveled berries (Table 3.43).

Table 3.35. Mean deformation force[z] at 2mm depth for 10 blueberry clones stored in C.A. for 8 weeks at 2°C in 2004.

	2mm Deformation Force (N)						
Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	2.50 bcd[x]	3.15 a	3.15 a	3.22 a	2.99 a	0.05 ab[w]	0.1585
FL 97-136	2.26 cdef	2.07 bcd	2.07 b	1.75 bc	2.12 bc	-0.03 bc	0.4125
FL 98-325	2.88 b	3.11 a	2.73 a	1.93 b	2.22 bc	-0.12 cdef	0.0015
FL 00-59	3.42 a	3.16 a	n/a	3.16 a	2.70 ab	-0.07 cde	0.0124
FL 00-180	2.35 cde	2.31 b	M*	1.69 bcd	2.33 abc	-0.03 a	0.2765
FL 00-270	1.89 f	1.79 cd	M	1.23 de	1.20 de	-0.10 cde	0.0001
Emerald	2.01 ef	1.67 d	1.24 c	0.96 e	0.99 e	-0.14 cde	0.0001
Millennia	2.09 def	2.30 b	M	1.35 cde	1.08 de	-0.15 ef	0.0002
Star	2.54 bc	2.45 b	M	1.39 cde	0.90 e	-0.22 f	0.0001
Windsor	2.19 def	2.22 bc	2.00 b	1.95 b	1.74 cd	-0.06 d	0.0021
P > F	<.0001	<.0001	<.0001	<.0001	0.0001		

[z]Mean of 30 berries individually sampled, 10 from each of three clamshells.

[y]m is the estimated change in force(N) per week based on linear regression analysis.

[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

* data missing

Table 3.36. ANOVA for deformation force at 2mm for 10 blueberry clones stored for 8 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	44	1.40	22.72	<.0001
Clones	9	4.69	76.41	<.0001
Weeks	4	2.47	40.14	<.0001
Weeks x Clones	31	0.30	4.81	<.0001
Error	90	0.06		

R-Square	0.92

Table 3.37. Incidence of decay (%) for 10 blueberry clones stored for 8 weeks in C.A. storage at 2°C in 2004.

Clone	Week 0	Week 2	Week 4	Week 6	Week 8	M^z	Prob m = 0
Bluecrisp	0.00 [y]	0.00 b[x]	0.00 a	3.33 a	0.00 a	0.17 b[w]	0.5000
FL 97-136	0.00	0.00 b	6.67 a	6.67 a	0.00 a	0.33 ab	0.4455
FL 98-325	0.00	6.67 a	10.00 a	10.00 a	0.00 a	0.17 b	0.8162
FL 00-59	0.00	0.00 b	0.00 a	0.00 a	0.00 a	0.0 b	-
FL 00-180	0.00	0.00 b	3.33 a	0.00 a	0.00 a	0.0 b	1.0000
Fl 00-270	0.00	0.00 b	0.00 a	0.00 a	0.00 a	0.0 b	-
Emerald	0.00	0.00 b	0.00 a	3.33 a	0.03 a	0.50 a	0.1230
Millennia	0.00	0.00 b	3.33 a	0.00 a	0.00 a	0.17 b	0.5000
Star	0.00	0.00 b	0.00 a	0.00 a	0.00 a	0.0 b	-
Windsor	0.00	0.00 b	6.67 a	0.00 a	0.00 a	0.0 b	1.0000
P > F		0.0047	0.1444	0.1165	0.4711		

[z]m is the estimated change in the fraction of molding berries per week based on linear regression analysis.

[y]Mean of 30 berries individually sampled, 10 from each of three clamshells.

[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.

[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.38. ANOVA for incidence of decay (%) for 10 blueberry clones stored for 8 weeks in C.A. storage in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	61.30	2.21	0.0004
Clones	9	106.68	3.84	0.0003
Weeks	4	152.27	5.48	0.0005
Weeks x Clones	36	39.84	1.43	0.0834
Error	100	27.79		

R-Square	0.52

Table 3.39. Incidence of leaking (%) for 10 blueberry clones stored for 8 weeks in C.A. storage at 2°C in 2004.

Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[z]	Prob m = 0
Bluecrisp	0.00 [y]	3.33 a[x]	6.67 a	6.67 ab	6.67 a	0.83 c[w]	0.2323
FL 97-136	0.00	13.33 a	13.33 a	23.33 ab	16.67 a	2.17 bc	0.1023
FL 98-325	0.00	16.67 a	13.33 a	20.00 ab	3.33 a	0.50 ce	0.6265
FL 00-59	0.00	0.00 a	0.00 a	3.33 ab	0.00 a	0.17 de	0.5000
FL 00-180	0.00	0.00 a	10.00 a	6.67 ab	10.00 a	1.33 bcd	0.1130
FL 00-270	0.00	16.67 a	16.67 a	10.00 ab	0.00 a	-0.33 e	0.7442
Emerald	0.00	6.67 a	6.67 a	23.33 ab	13.33 a	2.17 b	0.0111
Millennia	0.00	3.33 a	10.00 a	36.67 a	16.67 a	3.33 a	0.0108
Star	0.00	10.00 a	10.00 a	3.33 ab	20.00 a	1.67 bcd	0.1280
Windsor	0.00	3.33 a	6.67 a	0.00 b	20.00 a	1.83 bc	0.0207
P > F		0.0611	0.5941	0.0105	0.233		

[z]m is the estimated change in the fraction of leaking berries per week based on linear regression analysis.

[y]Mean of 30 berries individually sampled, 10 from each of three clamshells.
[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests

Table 3.40. ANOVA for incidence of leaking (%) for 10 blueberry clones stored for 8 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	302.82	2.91	<.0001
Clones	9	365.21	3.51	0.0008
Weeks	4	1269.06	12.21	<.0001
Weeks x Clones	36	179.87	1.73	0.0175
Error	100	103.93		

R-Square	0.59

Table 3.41. Incidence of shriveling (%) for 10 blueberry clones stored for 6 weeks in air storage at 2°C in 2004.

Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[z]	Prob m = 0
Bluecrisp	0.00[y]	3.33 bc[x]	13.33 ab	10.00 c	20.00 cd	2.33 fg[w]	0.0135
FL 97-136	0.00	23.33 ab	33.33 a	70.00 a	63.33 a	8.67 a	0.0001
FL 98-325	0.00	6.67 abc	16.67 ab	26.67 abc	30.00 bcd	3.50 eg	0.0040
FL 00-59	0.00	0.00 c	0.00 b	6.67 c	13.33 d	1.67 g	0.0008
FL 00-180	0.00	0.00 c	13.33 ab	13.33 bc	20.00 cd	2.67 d	0.0002
FL 00-270	0.00	26.67 a	33.33 ab	53.33 ab	43.33 abc	5.67 bcde	0.0006
Emerald	0.00	13.33 abc	20.00 ab	36.67 abc	50.000 ab	6.17 bc	0.0001
Millennia	0.00	3.33 bc	10.00 ab	36.67 abc	20.00 cd	3.67 cdef	0.0059
Star	0.00	10.00 abc	10.00 ab	16.67 bc	33.33 abcd	3.67 def	0.0001
Windsor	0.00	6.67 abc	13.33 ab	30.00 abc	50.00 ab	6.17 b	0.0001
P > F		0.0007	0.0239	0.0002	<0.0001		

[z]m is the estimated change in the fraction of shriveled per week based on linear regression analysis.
[y]Mean of 30 berries individually sampled, 10 from each of 3 clamshells.
[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.42. ANOVA for incidence of shriveling (%) of 10 blueberry clones stored at 2°C for 8 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	784.49	12.77	<.0001
Clones	9	1089.61	17.73	<.0001
Weeks	4	5929.63	96.49	<.0001
Weeks x Clones	36	136.53	2.22	0.0010
Error	100	61.46		

R-Square	0.86

Table 3.43. Incidence of shrivel severity[z] of 10 blueberry clones stored for 8 weeks in C.A. storage at 2°C in 2004.

	Index values						
Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	1.00 [x]	1.07 a[w]	1.13 a	1.33 b	1.40 ab	0.05 e[v]	0.0326
FL 97-136	1.00	1.63 a	1.87 a	3.37 a	2.13 a	0.20 a	0.0096
FL 98-325	1.00	1.70 a	1.83 a	1.93 ab	1.47 ab	0.06 cdf	0.2302
FL 00-59	1.00	1.00 a	1.00 a	1.10 b	1.13 b	0.02 g	0.0024
FL 00-180	1.00	1.00 a	1.43 a	1.30 b	1.53 ab	0.07 cef	0.0220
FL 00-270	1.00	1.73 a	1.77 a	2.33 ab	1.77 ab	0.11 bef	0.0499
Emerald	1.00	1.27 a	1.50 a	1.10 b	1.90 ab	0.11 bd	0.0001
Millennia	1.00	1.07 a	1.20 a	2.10 ab	1.63 ab	0.12 bc	0.0005
Star	1.00	1.20 a	1.20 a	1.23 b	1.53 ab	0.06 e	0.0041
Windsor	1.00	1.27 a	1.40 a	1.50 b	2.27 a	0.14 b	0.0001
P > F		0.0069	0.0316	0.0009	0.0060		

[z]Each berry was related on a scale from 1 (no shriveling) to 9 (extreme shriveling).
[y]m is the estimated change in the shrivel index value per week based on linear regression analysis.
[x]Mean of 30 berries individually sampled, 10 from each of 3 clamshells.
[w]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[v]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.

Table 3.44. ANOVA for incidence of shrivel severity of 10 blueberry clones stored for 8 weeks at 2°C in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	49	0.66	6.25	<.0001
Clones	9	1.19	11.23	<.0001
Weeks	4	2.93	27.67	<.0001
Weeks x Clones	36	0.28	2.63	<.0001
Error	100	0.11		

R-Square	0.75

No differences in the pH, SSC and TTA concentration were found that consistently separated the "crisp" from the "non-crisp" clones. The pH did separate the three "crisp" clones 'Bluecrisp', FL 97-136 and FL 98-325 from the other seven clones at week 0 (Table 3.45). By the end of the 6 weeks in C.A. storage, the differences between these three clones and the others were no longer significant (Table 3.45). Changes in pH with time in storage were inconsistent from one clone to another (Table 3.45).

There were differences in the SSC of the various clones (Table 3.47), but these did not consistently separate the “crisp” clones from the “non-crisp” clones. Although SSC did not change greatly during the storage period, there was a highly significant week effect (Table 3.47) and the tendency was for SSC to decline slowly over time.

Acid concentrations did not separate the “crisp” from the “non-crisp” clones at week 0, but in Table 3.49 (C.A.) as in Table 3.33 (air storage experiment) the “crisp” clones ‘Bluecrisp’, FL 97-136, FL 98-325 and FL 00-59 and were much lower in TTA then ‘Emerald’, ‘Millennia’, ‘Star’ and ‘Windsor’. The ‘weeks’ effect was highly significant (Table 3.50), and most clones tended to increase in TTA over time, but this was not consistent among clones.

Table 3.45. Mean[z] pH of 10 blueberry clones in a controlled atmosphere over 8 weeks in 2004.

Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	4.10 ab[x]	3.91 b	3.78 bcd	3.82 bc	3.95 bc	-0.016 d[w]	0.3126
FL 97-136	4.41 a	4.35 a	3.93 b	4.10 b	4.22 b	-0.033 ef	0.4213
FL 98-325	4.16 ab	4.36 a	4.47 a	4.57 a	4.61 a	0.053 a	0.0062
FL 00-59	3.95 bc	3.69 bc	3.65 bcde	3.67 c	3.62 de	-0.036 f	0.0088
FL 00-180	3.55 cd	3.35 de	3.44 e	M*	3.42 e	-0.010 cde	0.3669
FL 00-270	3.65 cd	3.49 cde	3.42 e	M	3.52 de	-0.012 de	0.1983
Emerald	3.61 cd	3.68 bc	3.83 bc	3.68 c	3.79 cd	0.024 b	0.0467
Millennia	3.65 cd	3.24 e	3.57 de	3.64 c	3.59 de	0.008 bc	0.7053
Star	3.46 d	3.50 cde	3.45 de	M	3.34 e	-0.018 de	0.0271
Windsor	3.49 d	3.54 cd	3.33 e	3.27 d	3.40 e	-0.015 ef	0.2195
P > F	<.0001	<.0001	<.0001	<.0001	<.0001		

[z]Mean of three clamshells individually sampled.
[y]m is the estimated change in titratable acid per week based on linear regression analysis.
[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey’s test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.
* Missing data

Table 3.46. ANOVA for mean pH of 10 blueberry clones in a controlled atmosphere over 8 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	46	0.390	27.87	<.0001
Clones	9	1.757	125.54	<.0001
Weeks	4	0.060	4.32	0.0030
Weeks x Clones	33	0.054	3.83	<.0001
Error	94	0.014		

R-Square	0.93

Table 3.47. Mean[z] SSC of 10 blueberry clones in a controlled atmosphere over 8 weeks in 2004.

Clone	Week 0	Week 2	Week 4	Week 6	Week 8	m[y]	Prob m = 0
Bluecrisp	12.70 ab[x]	13.63 ab	12.37 a	11.80 ab	12.73 a	-0.040 bc[w]	0.7219
FL 97-136	14.50 a	13.83 a	12.20 ab	12.97 a	12.40 ab	-0.274 d	0.0215
FL 98-325	10.13 bc	10.47 cd	11.00 abc	10.47 abc	10.43 abcd	-0.100 ab	0.4132
FL 00-59	12.20 abc	11.87 abc	12.60 a	12.43 ab	12.23 ab	0.024 a	0.7538
FL 00-180	8.27 c	8.40 d	7.77 d	M*	8.10 d	-0.034 bc	0.7010
FL 00-270	9.87 bc	9.93 cd	9.20 cd	M	8.97 cd	-0.128 c	0.1667
Emerald	11.30 abc	10.20 cd	9.50 cd	10.03 bc	8.73 cd	-0.309 d	0.0072
Millennia	11.87 abc	12.07 abc	11.17 abc	12.10 ab	10.07 bcd	-0.250 cd	0.0343
Star	10.33 bc	10.73 cd	10.93 abc	M	9.63 cd	-0.099 abc	0.5232
Windsor	10.27 bc	11.23 bc	9.33 cd	8.80 c	10.93 abc	0.031 bc	0.7512
P > F	0.0015	<.0001	<.0001	0.0008	<.0001		

[z]Mean of three clamshells individually sampled.
[y]m is the estimated change in SSC per week based on linear regression analysis.
[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests.
* Missing data

Table 3.48. ANOVA for mean SSC of 10 blueberry clones in a controlled atmosphere over 8 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	46	7.76	7.55	<.0001
Clones	9	33.19	32.30	<.0001
Weeks	4	3.88	3.78	0.0068
Weeks x Clones	33	1.26	1.22	0.2251
Error	94	1.03		

R-Square	0.79

Table 3.49. Mean[z] TTA of 10 blueberry clones in a controlled atmosphere over 8 weeks in 2004.

Clone	week 0	week 2	week 4	week 6	week 8	m[y]	Prob m = 0
Bluecrisp	0.24 bcd[x]	0.26 cd	0.34 bc	0.30 cd	0.28 ef	0.004 d[w]	0.4769
Fl 97-136	0.14 d	0.15 d	0.31 bc	0.24 de	0.19 f	0.008 cdfg	0.2948
Fl 98-325	0.15 d	0.13 d	0.12 c	0.12 e	0.12 f	0.004 e	0.0586
Fl 00-59	0.23 cd	0.32 bc	0.31 bc	0.34 cd	0.44 cde	0.025 b	0.0001
FL 00-180	0.30 abcd	0.45 b	0.40 ab	M*	0.51 bcd	0.022 bc	0.0364
FL 00-270	0.29 abcd	0.44 b	0.45 ab	M	0.41 cde	0.011 cdg	0.2002
Emerald	0.44 ab	0.37 bc	0.36 bc	0.46 bc	0.38 de	-0.005 ef	0.4194
Millennia	0.42 abc	0.88 a	0.55 ab	0.51 ab	0.55 bc	0.001 eg	0.9773
Star	0.46 a	0.44 b	0.52 ab	M	0.77 a	0.042 a	0.0024
Windsor	0.43 abc	0.39 bc	0.65 a	0.63 a	0.61 ab	0.021 b	0.0873
P > F	<.0001	<.0001	<.0001	<.0001	<.0001		

[z]Mean of three clamshells individually sampled.
[y]m is the estimated change in TTA per week based on linear regression analysis.
[x]Weeks followed by the same letter are not significantly different (P<0.05) by ANOVA and Tukey's test.
[w]Slopes followed by the same letter are not significantly different (P<0.05) by two-sample t-tests
*Missing data

Table 3.50. ANOVA for mean TTA of 10 blueberry clones in a controlled atmosphere over 8 weeks in 2004.

Source	DF	Mean Square	F value	Pr > F
Model	46	0.087	17.93	<.0001
Clones	9	0.329	67.90	<.0001
Weeks	4	0.058	12.04	<.0001
Weeks x Clones	33	0.025	5.06	<.0001
Error	94	0.005		

R-Square	0.90

Discussion

Postharvest storage of blueberries has been studied extensively over the past several decades (3, 5, 7, 30, 31, 35, 38, 46). From these studies it has been determined that low temperatures and CA storage can delay senescence in blueberries by several weeks. Our 2004 CA storage study confirms these results with the lack of decay (Table 3.37) and reduced severity of shrivel (Table 3.43) on blueberries during the 8 weeks they were stored. The 2004 air storage experiment (Table 2.31) confirms past research (4, 25, 29, 30, 32, 37) showing that blueberries kept at 1 to 5°C in an air atmosphere can store for 2 weeks without decay.

Air storage tests were done in 2003 and 2004. With respect to decay rates, the 2003 air experiment more closely resembles previous studies (5, 7, 23, 31) than the 2004 study. The constant air flow through the buckets in 2004 may be the reason for the lack of decay. Weight loss increased over time in the 2003 air storage test. The same was found by Miller and Mcdonald (30), and Smittle and Miller in 1988 (46). Firmness decreased over time in the 2003 air storage test and in the 2004 CA storage, as had been previously seen by Ferraz (15).

Comparing the air and CA storage tests done in 2004 shows that the blueberries stored in air decayed faster (Tables 3.21 and 3.37) and shriveled more than berries stored in CA. These results agree with Ceponis and Cappellini's study done in 1985 (7) and the Smittle and Miller study done in 1988(46). Comparing the different parameters in each storage treatment to each other did not reveal any connection between them. Clone FL 00-59 was the only blueberry that did not show any signs of decay (Tables 3.21 and 3.37) in the air and CA storage test. The clone also had the lowest levels of leaking and shriveling in both the air and CA storage tests. Reasons for its exceptional storage life are yet unknown.

A few studies (30, 31) have shown that differences in the storage life of blueberry clones can best be seen if the berries are kept at room temperature for a few days before examination. Tests should be conducted to determine if the "crisp" clones could be distinguished more easily from the "non-crisp" clones if this procedure was followed.

The properties that cause the crisp texture in blueberries is yet unknown. When the skin of one of the “crisp” clones is pealed away, the pulp has a consistency very similar to that of “non-crisp” clones. Examination of the “crisp” and “non-crisp” blueberries at the cellular level could help uncover the properties responsible for the crisp texture in blueberry.

CHAPTER 4
CONCLUSIONS

One of the major goals of these experiments was to find some objective test that could distinguish the six clones that had been subjectively identified as being “crisp” from other blueberry cultivars that had been identified as not “crisp”. The consumer sensory panel study in 2004 confirmed that most untrained subjects could recognize “crispness” in blueberries, although they did not necessarily prefer it. This indicates that there is some objective reality to the “crisp” phenotype.

Shear-cell testing appeared to be the most promising objective test for the “crisp” phenotype clones. These tests had good repeatability over two sample dates and gave good separation between the “crisp” clones ‘Bluecrisp’, FL 00-59 and FL 00-180 and other clones in the test. However, putatively crisp clones FL 98-325 and FL 00-270 were not separated from conventional cultivars by shear-cell testing.

Another goal of the experiments was to see if “crisp” clones, when compared with “non-crisp” clones, showed a unique softening pattern as they went from white to blue on the plant. Firmness decreased from white to pink stages among all clones, with a similar pattern for all the clones. This decrease in firmness matches that of previous studies done on blueberry ripening. In this study it was hypothesized that “crisp” berries would soften less as they ripened when compared with “non-crisp” clones, but this was not the case.

The next objective of this study was to see if the “crisp” texture could be distinguished by firmness testing. The resistance to deformation of 99 clones was tested along with four of the six “crisp” clones. The only clone that was statistically different from the other clones by this measure was the "crisp" clone FL 98-325. From this it can be seen that the crisp characteristic is not closely associated with the resistance to deformation of the blueberry.

The final objective of this study was to determine if the "crisp" characteristics contributed to longer postharvest life. In 2003, the "crisp" clones did not store longer in air than the "non-crisp" clones. In 2004, the "crisp" clone FL 00-59 had a longer postharvest life than any of the other clones in air storage. Also, the same "crisp" clones that distinguished themselves in the shear-cell tests, 'Bluecrisp', FL 00-59 and FL 00-180, also showed great resistance to shriveling in air storage. A correlation between high shear-cell values and low shriveling during storage is possible. Comparing the air storage and C.A. storage tests of 2004 showed that if the "crisp" characteristic contributes to a longer postharvest life, it is only in an air atmosphere. When the "crisp" blueberries were placed into C.A. storage, their advantage over regular clones was lost.

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BIOGRAPHICAL SKETCH

Les Padley Jr. was born in Largo, Florida, on January 9, 1980, to Les and Pam Padley. He graduated high school from the Center for Advanced Technologies in 1998, and received his Bachelor of Science degree from Florida Southern College in environmental horticultural and business. Moving to Gainesville in 2002, he began studies for his Master of Science degree in plant breeding at the University of Florida.

On November 20, 2004, Les Padley Jr. was married to Michelle Cook in Gainesville, Florida. He plans on continuing his education with a PhD in the field of Horticulture studying plant breeding in cucurbits.