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Abstract approved [signature] Daryl G. Richardson, PhD.

Blackberry varieties were evaluated with modified atmosphere packaging, using films Cryovac D-940 and D-955 in 0° and 5°C storage. Moisture loss was kept extremely low (less than 3%) in packaged fruits, but mold infection was excessively high because of high humidity accumulated inside the container. Blackberries selectively harvested into 3 different maturity stages, and stored in modified atmosphere packaging, developed significantly different rot with low levels in early ripe (<5%) and mature ripe (<15%), but high in overmature stages (>30%). Soluble solids concentration did not change over storage but anthocyanin concentration increased after storage for all maturity stages. Citric and malic acid, present in high concentrations, were found to decrease during storage. Sensory evaluation of blackberry varieties revealed fruity flavor intensity as the main factor affecting overall quality and acceptance by consumer panels. 'Marion'

blackberry was the most promising variety among those tested.

Seven different blueberry varieties were evaluated for suitability in long term storage. Fruits kept at 0°C for 15 days developed 50% less rot than fruits stored at 5°C. Fruits stored in commercial 1/2 pint hallocks developed almost 50% less mold than those in 1 pint hallock. Differences in soluble solids contents, anthocyanin and organic acids concentrations were found among cultivars, as well as susceptibility to rot. Sensory evaluation of blueberry varieties showed juiciness and fruity flavor intensity as the highest factors correlated with overall quality of the fruit. From this study, 'Patriot', 'Bluecrop' and 'Jersey' appeared to be most suitable for fresh market.

Storage Quality of Fresh Blueberry and Blackberry Varieties and Evaluation of Modified Atmosphere Packaging

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This thesis is dedicated to
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CHAPTER I

INTRODUCTION

Small fruits and grapes are among the seven major categories of high value crops produced in Oregon, and no other state produces the variety of berry crops that are commercially grown in the Willamette Valley. In 1986 Oregon ranked first among blackberry producer states, and sixth for blueberries (Crabtree and Weiser, 1988).

Caneberry production in Oregon and Washington has been mainly aimed at the processing market, but with increasing planted areas, new interest in diversifying the market into U-pick and fresh fruit shipments has developed (Richardson, 1988).

Harvested areas for blackberries and blueberries were estimated to be 4,400 and 1,300 acres in 1988 respectively, both crops yielding about 4 ton/ha.

Soft fruits in general have a very short storage life, so a rapid reduction of temperature to 0°C serves to minimize metabolic activity and inhibit fungal decay (Ben-Yehoshua, 1985; McGlasson, 1989; Varseveld and Richardson, 1980).

Storage life can be extended by means of modified atmospheres, provided that these fruits are able to withstand high concentrations of carbon dioxide and/or low concentrations of oxygen (Ben-Yehoshua, 1985; Kader et al, 1989; Aylsworth, 1989).

Recent advances in design and manufacturing of polymeric films have stimulated interest in modified atmosphere packaging (MAP) which markedly reduces weight loss and extends storage life (Miller et al, 1983; Smith et al, 1987).

Blueberries and blackberries flower over a period of weeks and therefore fruits ripen over a period of time. This leads to a wide variation in ripeness of fruits at any one harvest time and thus requires several pickings. Stage of maturity plays an important role in quality factors of fruits such as appearance, flavor, texture and mold incidence. Additionally, large variations in general are found among different cultivars.

Defining the appropriate stages of maturity and the most suitable cultivar for a particular use, is a major factor in extending postharvest shelf-life of fruits, and assuring consumer acceptance.

CHAPTER II

LITERATURE REVIEW

a. BOTANICAL CHARACTERISTICS

Blackberry

Blackberries, classified in the genus Rubus, belong to the Rosaceae family and subgenus Eubatus. They differ from raspberries in that the drupelets cohere to the receptacle, the whole structure comes off the plant, becoming part of the edible fruit (Jennings, 1988).

Blackberries are borne in terminal inflorescences and the clusters vary from 3 to 75 flowers depending on cultivar and species. Flowers consist of many pistils stacked on a succulent receptacle, and each of them develops into a single miniature drupe fruit (drupelet), containing a single hard seed. What is commonly called the fruit is a large aggregate of drupelets held together on a common receptacle, the torus (Moore and Skirvin, 1990).

A number of cultivars have developed through the years in North America, and some of the most common, as described by Moore and Skirvin (1990), are:

Erect cultivars:

'Cherokee': midseason, berries medium large, black, firm, excellent flavor, vigorous bushes, thorny.

'Shawnee': midseason, long fruiting season, berries very large, shiny-black, medium firm, good flavor, bushes vigorous, thorny, very productive.

Trailing cultivars:

'Boysen': midseason, very large berry, deep maroon, rather soft, excellent flavor, thorny.

'Chester': late season, berries medium, black, good flavor, thornless.

'Kotata': midseason, large berries, glossy-black, firm, good flavor, thorny, very productive.

'Logan': early season, berries medium, long, dark red, soft, good flavor, thornless.

'Marion': midseason, berries large, bright black, medium firm, excellent flavor, thorny.

'Olallie': midseason, berries medium to large, bright black, firm, good shelf-life, productive

'Silvan': early to midseason, berries large, black, medium firm, excellent flavor, thorny, very productive.

'Waldo': midseason, berries medium, glossy black, firm, small drupelets, good mild flavor, thornless.

Blueberry

Many species of the blueberry (Vaccinium sp) are native to different parts of the United States. The highbush Vaccinium corymbosum, is the most important (Johnston et al., 1969).

Flowers are borne on a raceme which is usually urnshaped and inverted. Clusters occur basipetally along the shoot axis and there is a period of 1.5 to 2 months from bloom to ripening (Eck, 1966).

Berry size is apparently correlated with shoot vigor. Earlier ripening fruits are often larger than those that ripen later and fruit size is greatly dependent on seed number (Eck et al., 1990).

A large number of cultivars are available for fresh market and processing purposes. For fresh market or U-pick operations, cultivars with long, loose fruit clusters and large berries are easiest to hand pick . For a grower, it is an advantage to choose various cultivars in order to be able to offer a succession of ripening over time (Eck et al., 1990).

The following major commercial cultivars are listed in order of ripening (Strik, 1989).

Early cultivars

'Earliblue': fruit cluster medium-loose, berries medium large, light blue, medium scar, good flavor, sweet, aromatic, doesn't drop quickly once ripe and ships well, suitable for fresh market, U-pick and machine harvest.

'Patriot': fruit cluster tight, berries very large, slightly flat, medium blue, firm, small scar, excellent flavor , concentrates ripening in 2 main pickings, suitable for machine harvest.

'Bluejay': fruit cluster loose, berries medium large, light blue, very firm, small scar, pleasant flavor, slightly tart, fruit doesn't drop quickly once ripe and retains quality. Ships well.

<u>Midseason cultivars</u>

'Bluecrop': fruit cluster loose, berries very large, light blue, firm, small scar, very good flavor, slightly aromatic, suitable for machine harvest.

'Berkeley': fruit clusters large and loose, berries large to very large, light blue, firm, small to medium scar, flavor fair, mild, less acid than most cultivars, slightly aromatic, popular for U-pick.

<u>Late season</u>

'Jersey': fruit clusters half tight, berry size medium, medium blue, firm, medium scar, flavor fair, no aroma, suitable for machine harvest.

'Elliott': fruit cluster loose, berries medium, light blue, small scar, flavor mild to good, slightly tart, fruit ripening is concentrated.

b. HARVEST MATURITY AND RIPENING

Harvest Maturity

The maturity of harvested perishable commodities plays an important role in the way they are handled, transported and marketed, and on their storage life and quality (Reid, 1985).

In blackberries, the ripening time varies from 40 to

70 days after pollination, depending on cultivar and environmental factors (Jennings, 1988). Blueberry fruits usually mature in 60 to 90 days after flowering (Eck,1966).

Blueberries are extremely firm when green, soften appreciably as they ripen to red stages, but only slightly thereafter (Ballinger et al, 1973). Additionally, these fruits vary in degree of ripeness at harvest because of irregular fruit development in the cluster and the lack of immediate abscission of ripe fruit (Bunemann et al, 1957).

Harvesting at an earlier stage of horticultural maturity than optimum for processing or immediate use has been recommended for years on raspberries (Ramsey, 1924).

Sjulin and Robbins (1987) showed that stage of maturity has a major effect on shelf-life and quality components of red raspberries in storage. They found that firmness and titratable acidity of fruits decreased while pH and rot increased as fruit turned from inception to red-ripe to processing ripe maturity.

Blueberries harvested immediately after obtaining a blue skin color (hard ripe), stored more satisfactorily than ripe and firm-ripe stages, and were still free of mold after 8 weeks at 0 °C. Soluble solids content averaged 11, 12 and 13,5% respectively for hard-ripe, firm-ripe and red fruit. The last two stages were similar in taste, but hard-ripe berries were markedly tart and lacking in sweetness (Bunemann et al, 1957).

Ballinger et al (1978) found that overripe blueberries (Soluble solids to Acid ratio of 40) greatly increased mold incidence, even at low temperature. They defined various maximum degrees of ripening (SS/Ac) to estimate whether the fruit could be shipped or had to be immediately processed. From their results, fruit determined for long distance shipment should have a SS/Ac ratio no higher than 20.

After reaching its final color, blueberries change little in size, although for several days continue to improve in sweetness and flavor (Eck, 1966). In addition, blueberries will continue to ripen after harvest and so, soluble solids content will increase gradually (Eck et al, 1990).

The best index of maturity in blackberries is the ease of separation of the fruit from the pedicel. Fruit color is a poor indicator since most blackberries color before they are fully ripe (Moore and Skirvin, 1990).

The fruiting period in blackberries varies from 4 to 7 weeks depending on cultivar. They should be harvested as frequently as every second or third day, because berries left on the plant until overripe become soft and moldy (Moore and Skirvin, 1990).

Blackberries are picked by gently lifting with thumb and fingers, placing them carefully in the final marketing container (Moore and Skirvin, 1990). Similarly, hand harvested blueberries (for fresh market), are deposited directly into pint containers in field trays (Eck et al, 1990).

Fruit Ripening

According to their respiratory behavior during ripening, fruits can be classified as climacteric and non-climacteric (Biale and Young, 1981; Arpaia et al, 1982; Biale, 1960).

Climacteric fruits undergo a pronounced increase in respiration coincident with ripening, that declines when fruits approach senescence. The intensity and duration of this respiratory climacteric varies widely among fruit species (Wills et al, 1989).

The climacteric rise in fruits is accompanied by marked changes (McGlasson, 1985). Climacteric fruits commonly soften, pigments change and ethylene is detected (Sommer, 1982). Sugars usually increase, starches and acids decrease, chlorophyll is lost, yellow and red pigments increase and volatile constituents develop in ripening fruits (Biale and Young, 1981).

In fruits that do not exhibit a climacteric pattern, the rate of respiration decreases gradually after harvest. They exhibit certain color changes and softening, but it is difficult to pinpoint when ripening begins because changes occur very slowly (Sommer, 1982; McGlasson, 1985).

Fruits of blueberry are classified as climacteric

(Kader, 1985), while those of blackberry are non-climacteric (Lipe, 1978; Kader, 1985). Recently, Walsh et al (1983) suggested that thornless blackberries should be classified as climacteric. They found that ethylene evolution rate and SSC increased with maturity and ripening while acidity decreased. Following harvest, respiration and ethylene increased during 7 days at 25°C.

Blackberries exhibit high rates of respiration ranging from 18-20 mg CO_2/kg/hr at 0°C whereas blueberries are moderately high with 2-10 mg CO_2/kg/hr at 0 °C (Hardenburg et al, 1986).

c. STORAGE

Refrigeration

The storage life of soft fruits is limited, similarly to other fruit, by the physiological processes of ripening and by deterioration caused by fungi (Ballinger and Kushman, 1970). Therefore, the most important factor in prolonging shelf life of these very perishable fruits is low temperature, as close to 0°C as possible (Richardson, 1988). There is also great need to minimize evaporative losses (Robinson et al, 1975).

Low temperature is recommended for many perishable commodities because it not only retards aging, undesirable metabolic changes and respiratory heat production, but it also slows moisture loss and spoilage due to invasion of fungi and other rot organisms (Ben-Yehoshua, 1985; Hardenburg et al, 1986; Richardson,1988).

The humidity of the air in the storage rooms directly affects the keeping quality of products. If too low, wilting or shriveling may occur (Hardenburg et al, 1986). Very high humidity, optimal for most commodities, could only be attained by enclosing the containers of produce in plastic sheeting (Robinson et al, 1975). High humidity (greater than 95%) within a closed container may, however, encourage mold development.

Due to their perishability, blackberries should be kept from -0.6 to 0°C and 90 to 95% relative humidity, especially when they are destined for distant markets (Salunkhe and Desai, 1984). They can hardly be stored for more than 2 or 3 days, because longer storage results in loss of good marketing quality (Hardenburg et al, 1986).

Blueberries in good condition could be stored at -0.5 to 0°C with high relative humidity (90-95%) with no loss in quality for about 2 weeks, and with some loss in quality, the time could be extended to 4 weeks (Salunkhe and Desai, 1984; Hardenburg et al, 1986).

Mold incidence is closely associated with storage temperature at high relative humidity. Varseveld and Richardson (1980), found that mold was restricted below 10% for at least one week when raspberries and blackberries were held at 0°C compared to 5 or 10°C.

Robinson et al (1975) also defined 0°C and 95% relative humidity as optimum conditions for storage of blackberries, raspberries and strawberries, but they point out that commercial stores rarely provide the precise control of temperature which is obtained in a small experimental store.

Often commodities with best marketable prospects are also short lived. Application of Modified Atmosphere (MA) or Controlled Atmosphere (CA) technology, in addition to precise temperature management, could allow for longer storage periods and a means of reaching more distant markets (McGlasson, 1989).

Controlled Atmosphere (CA)

In this technique O_2 and CO_2 concentrations, controlled at the optimum specific level for each commodity, are used along with refrigeration (Smith et al, 1987). This method requires a high degree of regulation, which is capital intensive and may not be suited for small quantities of produce or individual fruits (Mannaperuma et al, 1989).

Modified Atmosphere (MA)

With increasing consumer awareness of quality in fresh produce, methods have been developed to create microclimates surrounding small quantities of produce, that would continue the beneficial effects of CA through marketing (Smith et al, 1987).

MA storage and packaging provide a method that requires minimum capital, minimum energy and is not expensive to operate (Jing, 1989). Therefore it may be better suited for short term storage of smaller quantities (Mannaperuma et al, 1989).

d. MODIFIED ATMOSPHERE PACKAGING (MAP)

MAP consists in trying to obtain a specific concentration of O_2 and CO_2 in the package at the time of sealing and to maintain it thereafter (Aylsworth, 1989). In this case the respiration of the commodity is used to reduce O_2 and increase CO_2 under restricted air-exchange conditions using some type of barrier such as plastic film (Kader, 1985). The result is a slowed metabolism and potentially longer storage life (Zagory and Kader, 1988).

In a MA system there is little or no possibility to make adjustments in gas composition during storage. The purpose of these atmospheres is usually to extend postharvest life as a consequence of suppression of the rate of respiration. Another objective is to suppress diseases (Sommer, 1985; Kader 1985). Venatcher et al (1986) showed that different combinations of MA at 0°C greatly limited the growth of most fungi on tomato and strawberry, except for _Botrytis cinerea_ and _Mucor mucedo_. However, since these are two of the most devastating fungi, measures beyond MA would be required to make MAP successful.

The benefits of a CA or MA depend upon the commodity, variety, physiological age, atmospheric composition, and temperature and duration of storage (Kader, 1985). A commodity that is exposed to O_2 levels below and/or CO_2 above its tolerance limit for a specific temperature-time combination will suffer stress which might end in irregular ripening, physiological disorders, off-flavors and off-odors, and a greater susceptibility to decay (Kader et al, 1989).

Any MAP packaging should maintain O_2 and CO_2 at adequate levels, and not exceed the limits of tolerance, which may increase the risk of detrimental effects. The most marked positive effects of reduced O2 are seen at levels below 4%, but below 1% problems of physiological disorders and alcohol formation may occur (Hardenburg et al, 1965; Ben-Yehoshua, 1985; Kader et al, 1989).

A number of fruits such as blueberries and strawberries tolerate O_2 levels between 0.25 and 1% for up to 10 days at 0 to 5°C (Ke and Kader, 1989, Kosittrakun, 1989).

Hardenburg (1971) names the following advantages for MAP: a) protection of produce from mechanical damage, b) reduction of respiration rate and thus retardation of aging, c) reduction of water loss by maintaining high relative humidity, and d) possible inhibition of pathogen growth.

Among disadvantages, plastic films retard the rate of cooling of the commodity making it necessary to precool fruit before packaging (McGlasson , 1989). On the other hand, films used in MAP have usually low permeability to water vapor, therefore high relative humidity is maintained or established, that can cause condensation and favor development of mold and bacteria (Kader et al, 1989). Additionally, condensation on the film package surface can adversely affect the gas permeability properties of the film, leading to development of unfavorable atmospheres (Zagory and Kader, 1988).

Some other practical problems involve trying to obtain a good seal and avoiding punctures, especially with very thin films (McGlasson, 1989). It has been shown that even a small hole can affect the package atmosphere significantly (Mannaperuma et al, 1989).

Creating a Modified Atmosphere Packaging (MAP)

MAP can be achieved either by active or passive modification.

a) Active Modification: The fruit, picked at the correct stage of maturity, is placed into a container, which is in turn placed into a flexible packaging film. Air is then removed by pulling a slight vacuum and replaced with a specific desired mixture. Finally, the film is sealed

(Powrie et al, 1987).

In this case the atmosphere can be modified immediately after packaging, the gases surrounding the fruit slow down the activity of enzymes associated with ripening and postharvest deterioration (Kader et al, 1989). Although this implies some additional costs, it ensures the rapid establishment of the desired atmosphere (Zagory and Kader, 1988).

b) Passive Modification: The atmosphere within the package is created through respiration of the commodity and therefore it depends on the characteristics of both the film and the commodity (Kader et al, 1989).

The film acts a diffusion barrier that leads to a modification of CO_2, O_2 and ethylene concentrations. At any given temperature, a greater resistance to diffusion of O_2 and CO_2 will result in higher CO_2, lower O_2 and lower respiration rate. Finally, this lower respiration rate, leads to establishment of a new equilibrium concentration of gases surrounding the fruit (Kader et al, 1989).

e. FILMS SUITABLE FOR MAP

Recent improvements in film wrap manufacturing provide a wide selection of films with varying properties and different permeabilities to suit the specific needs of a particular product (Miller et al, 1983).

Usually films are more permeable to CO_2 than O_2, so that the rate of CO_2 accumulation from respiration is less than the corresponding rate of O_2 depletion (Hall et al, 1975). Permeability of polyethylene films to water vapor and O_2 is related to thickness of the film (Purvis, 1983), as well as the nature of film itself.

Various films have been tested through the years including polyolefins, several polyethylene types of high and low density and polypropylene (Ben-Yehoshua, 1985). Table II.1 lists the characteristics of some of the films available (Hall et al, 1975).

Table II.1: Available polymers for plastic films formulation

Film Type	Permeabilities (a) O_2	CO_2
Polyethylene low density	3,900-13,000	7,700-77,000
Polypropylene	1,300- 6,400	7,700-21,000
Polystyrene	2,600- 7,700	10,000-26,000
Cellophane	15-77	15-95
Saran	8-26	52-150

(a) $ml/m^2/24hr$

The new films are adapted to specific requirements of each fruit and packaging machine, and the technology of film shrinkage to form a tight, smooth package has also been developed (Ben-Yehoshua, 1985).

Usually in a MAP system, the film is shrunk by blowing hot air in a tunnel through which the packaged fruit moves. Ease of shrinkage depends on temperature of the hot air, rate of the air flow, and the time that fruit is kept in the hot tunnel (Ben-Yehoshua, 1985).

A well designed tunnel will supply just enough heat to shrink the film but not enough to harm the packaged product (Ryall and Lipton, 1978).

f. EFFECT OF FILM ON WEIGHT LOSS AND MOLD INFECTION

Low-density polyethylene and polyvinyl chloride are the main films used in packaging fruits and vegetables (Zagory and Kader, 1988). Table 2 shows permeation rates of Cryovac films (low density polyethylene) that were used in the present study, as reported by the manufacturers.

Table II.2: Specific permeation rates of Cryovac films

Film Type	Permeation rates		
	O_2(a)	CO_2(a)	H_2O(b)
D-940 (60 gauge)	16,500	50,000	5.2
D-955 (60 gauge)	8,900	27,000	1.48

(a) $ml/m^2/24hr$
(b) $g/100in^2$

One of the most marked effects of film wrapping is reduction in weight loss. With films, weight loss is related to the water vapor transmission rates (WVTR) of the material, which are independent of CO_2 and O_2 permeability. Materials with low WVTR can form excessive high relative humidity, causing condensation thus increasing the risk of pathological infection (Smith et al, 1987).

This problem could be solved by creating small perforations in the package, but then the control of O_2 and CO_2 is eliminated (Mannaperuma et al, 1989).

Anderson and Hardenburg (1959), showed that weight loss was least on strawberries kept in completely overwrapped containers compared to film caps or open tops. On the other hand, the lowest mold infection was found in the open-top baskets, clearly showing the importance of not allowing relative humidity to become excessive.

Similar results were found by Miller et al (1984) with blueberries packed in overwrap film (EH50 DuPont), compared to conventional package or polystyrene plastic containers with plastic caps.

Shirazi and Cameron (1987) developed some humidity absorber compounds to control relative humidity inside polymeric film packages. Using different elements ($CaSiO_4$, KCl, Xylitol, NaCl and Sorbitol), they were able to maintain relative humidities from 75% (NaCl) to 90-95% (KCl, $CaSiO_4$) nearly constant for 21 days. They reported that MAP was optimum to extend storage life of tomatoes, both in mature green and ripe stages.

g. USES OF MODIFIED ATMOSPHERE PACKAGING (MAP)

Powrie et al (1987) reported that MAP could be used for prolonging storage life of soft fruits such as strawberries (4 weeks), raspberries (6 weeks), blueberries (8 weeks) and cherries (10 weeks).

A study of MAP of blueberries showed that film packages greatly reduced moisture loss compared to the control, but a high incidence of decay was reported when no decay control was employed (Ahmedhullah et al, 1989). Patten and Neuendorf (1986) found that SO_2 emitter pads and $KMnO_4$ absorbent pads were able to decrease mold in film wrapped blueberries by about 60% compared to normal pint overwrap containers.

MAP has been successfully used for citrus, but in this case, it is mainly to maintain high relative humidity and reduce shrinkage (Ben-Yehoshua, 1985). Further, if one fruit develops mold, it is isolated from infecting other fruits.

Film wrapping with Cryovac D-955 reduced weight loss and respiratory rates and increased the concentration of CO_2 internal atmospheres of lemons (Eaks, 1986).

Variable results have been found with tomatoes, because respiration rates vary greatly with variety, maturity and onset of climacteric respiration (Saguy and Mannheim, 1975).

MAP has been used for broccoli where high CO_2 (5-

20%) and low O_2 (1%) are effective in retarding senescence. In this case increasing CO_2 seems to be more effective than decreasing O_2 (Rij and Ross, 1987).

Finally, film wrapped potatoes in Cryovac D-950 and D-955 (polyolefins) stored at 24°C or room temperature lost less fresh weight and showed minimal physical changes compared to non-wrapped controls (Shetty et al, 1989).

h. QUALITY CHARACTERISTICS AND CHEMICAL COMPOSITION

Quality of any horticultural product can be defined as the sum of various attributes including appearance, texture, flavor, nutritional value and presence or absence of defects (Duckworth, 1966; Arthey, 1975). The relative importance of each quality factor depends on the commodity and its intended use (Kader, 1985).

Quality has different meanings to producers, receivers, market distributors and consumers. Consumers buy on the basis of appearance and feel. However repeat purchases are dependent upon good edible quality (Kader, 1985), largely determined by flavor, aroma and texture.

Morphological and physical defects, such as shriveling, wilting, mechanical damage, as well as pathological defects (fungal infection), can greatly influence quality (Kader, 1985).

Appearance and Color

Color is the quality factor that contributes the most to the appearance of horticultural products,and it is highly influenced by cultivar and maturity (Arthey, 1975).

The characteristic color of blackberries and blueberries is due to the anthocyanins,(Eck, 1966; Sagi et al, 1973 and Jennings, 1988), which have a maximum absorption in the 510-550 nm region (Fuleki and Francis, 1968). Anthocyanins usually increase as the fruit ripen (Ballinger et al, 1970).

Torre and Barritt (1977) found Cyanidin-3-glucoside to be the major pigment in blackberries. In the case of blueberries cyanidin-arabinosides and cyanidin-galactosides have been reported (Ballinger et al, 1970 and 1979; Torre and Barritt, 1977; Sapers et al, 1984; Eck, 1988; Jennings, 1988).

Several chemical factors influence the color of anthocyanin solutions, but pH is probably the most important. This could explain why unripe blackberries change from black to red when they are frozen (Jennings, 1988).

Color expression in fresh blueberries is influenced as much by the amount of wax bloom on their surface as by the anthocyanin content (Ballinger et al, 1979; Sapers et al, 1984). Blueberry cultivars differ significantly in total anthocyanin content ranging from 85 to 270 mg/ 100 g

FW (Sapers et al, 1984).

Eck (1966) mentions that a light blue color for blueberries is highly desirable because they appear fresher after several days on the market.

Another important factor in blueberries is the scar, or point of attachment of the fruit to the pedicel. A small dry, clearly abscised scar is desirable to avoid fungal infections and shriveling (Eck, 1966). Fruits separated from the stem with small tears or tabs in the attachment site are highly prone to fungal infection at that site. In fact, virtually all mold observed on blueberries is localized at the stem scar.

Flavor

Flavor is fundamentally the balance between sugars and acids (Whiting, 1970) ,the dominant components of fruits which have a lower susceptibility to changes during processing and storage than other constituents (Wrolstad et al, 1980; Reyes et al, 1981). However, there are important flavor impacting compounds which are unrelated to simple sugars or acids. An example is the strawberry 4-hydroxy-2.5-dimethyl-3(2h)-furanone (ALDRICH Catalogs, 1990). Glucose and fructose are the main sugars in blackberries (Lee et al,1970; Wrolstad et al, 1980) and blueberries (Kushman and Ballinger, 1968; Hammet and Ballinger, 1972). In both cases only small amounts of sucrose have been found.

Variability in sugar content of fruits has been reported. Reyes et al (1981) found that sucrose was almost completely hydrolyzed in overripe fruits of strawberry, and Wrolstad et al (1980) reported that fructose is the dominant sugar of blackberries at all stages, except the unripe.

Total sugars were also found to increase in blueberries as fruit begin to ripen (Kushman and Ballinger, 1968) and tend to remain constant when fruit is fully ripe (Woodruff et al., 1960).

Quantitatively, organic acids make the second largest contribution to soluble solids of soft fruits (Green, 1970). Citric is the predominant organic acid in blueberries, followed by traces amounts of shikimic and quinic (Hammet and Ballinger, 1972). Lack of malic acid in the blue ripe stage has been reported by Kushman and Ballinger (1968) and Ballinger (1972).

In the case of blackberries, isocitric (and not citric) has been reported as the main acid, followed by malic in large amounts (Nelson, 1925; Mehlitz,1957; Josych, 1962). Traces of shikimic, quinic and galacturonic acids have also been found (Mehlitz, 1957).

Woodruff et al (1960) followed the chemical changes associated with ripening of blueberries and found the percentage of acids to decrease after coloration of the fruit.

There is evidence that proportions of different acids change with ripening (Jennings, 1988). In general, as fruits ripen they increase in dry weight, soluble solids, total sugars and decrease in acidity. The increase in sugar to acid ratio during this period, appears to be due mainly to increases in fructose and a decrease in citric acid (Kushman and Ballinger, 1968).

Finally, the main factors affecting quality of any fruit are major contributors to changes in flavor, and these are stage of maturity and cultivar (Arthey, 1975).

Texture

Texture is one of the most important characteristics for eating and cooking quality, although the term is difficult to define. Some people use cell morphology in their description, while others refer to the sensory factors associated (Arthey, 1975).

Isherwood (1960) considers that changes in texture are related to cell composition and structure, including both non-cell wall constituents (starch, enzymes) and cell wall constituents, cellulose and pectins, which give rigidity to the plant cells.

Referring to the sensory factors, Meilgaard et al (1987) describes texture as the sensory manifestation of the structure or inner make-up of products in terms of their reaction to stress and tactile feel properties.

The components of texture according to Kader (1985) can be divided into: a) firmness, hardness and softness; b) crispness; c) succulence and juiciness; d) mealiness and grittiness and e) toughness and fibrousness.

The texture of raspberries and blackberries depends largely on the seeds and the size and cohesion of drupelets, which is achieved by entanglement of epidermal trichomes. Blackberries are less prone to disintegration than raspberries because the plug of the blackberry is retained with the fruit at harvest, while it separates and remains on the cane in the case of raspberries (Arthey, 1975).

Maturity is again a very important factor affecting texture, because as fruits mature they soften (Arthey, 1975). For blueberries it has been found that berries soften appreciably as they ripen from the green to red stage, but very little from red-purple to overripe stage (Ballinger et al, 1972).

Defects

Pathological defects, including decay caused by fungi, bacteria or virus can also influence the appearance quality of horticultural crops (Kader, 1985).

Decay is the most important factor that shortens the shelf-life of fresh marketed blueberries (Cappellini and Ceponis, 1976), and the stem scar is particularly vulnerable (Ceponis and Cappellini, 1978; Smittle and

Miller, 1988). These authors showed that decay was 6 to 10 times more prevalent on stemless berries compared to fruits with attached stems.

The most important causes of postharvest decay in blueberries are <u>Botrytis</u> <u>cinerea</u>, <u>Alternaria</u> <u>alternata</u>, <u>Colletotrichum</u> <u>sp.</u> and <u>Gloesporium</u> <u>sp.</u> (Cappellini and Ceponis, 1976; Ceponis and Cappellini, 1979; Snowdon, 1990).

Since the stem scar is the main locus of infection in harvested blueberries, Ceponis and Cappellini (1979) suggest that any fungicidal treatment should be applied soon after the berries are picked in order to protect it.

Dipping the fruit for chemical treatment has not proven to be effective, and it seems that keeping blueberries dry and protecting the stem scar from fungal invasion are requisites for prevention of postharvest decay (Cappellini and Ceponis, 1976).

Dodge and Wilcox (1941) found <u>Colletotrichum</u>, <u>Rhizopus,</u> <u>Botrytis</u> and <u>Alternaria</u> as the diseases causing most of the fruit rots in raspberries and blackberries.

Overripe fruits are particularly susceptible to <u>Rhizopus</u> infection, so this type of fruit should be avoided in the commercial pack (Ryall and Pentzer, 1974). In addition, blackberries shouldn't be picked with dew or rain because wet berries mold very quickly (Moore and Skirvin, 1990).

i. SENSORY EVALUATION OF FRUITS

Sensory evaluation is a scientific discipline used to measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing (Amerine et al, 1965; Schaefer, 1979).

Consumer tests are usually conducted in order to assess the personal response (preference and/or acceptance) by the current or potential customers of the product.

Several considerations must be taken, such as designing an appropriate questionnaire and adopting a useful and easy scale (Moskowitz, 1983; Meilgaard et al, 1987).

Sensory responses can be measured in various ways, and usually scaling methods are used for consumer tests. These scaling techniques involve the use of numbers or words to express the intensity or reaction to a perceived attribute. Where words are used initially, the analyst might assign numerical values to the words so that the data can be treated statistically (Meilgaard et al, 1987).

The linear scale, (used in all of the tests conducted in this study) is a method in which the panelists are asked to "rate" the intensity of a given stimulus by making a mark on a horizontal line which corresponds to the amount of the perceived stimulus. The marks are converted to numbers by manually measuring the position of each mark on each scale using a ruler. In this way, the data can be subjected to statistical analysis of variance (Meilgaard et al, 1987).

CHAPTER III

EFFECT OF MODIFIED ATMOSPHERE PACKAGING (MAP) , CULTIVAR, MATURITY STAGE AND STORAGE TEMPERATURE ON STORAGE LIFE AND ORGANOLEPTIC CHARACTERISTICS OF BLACKBERRIES

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ABSTRACT

Fruits of 'Waldo', 'Kotata', 'Cherokee', 'Chester' and 'Shawnee' blackberries were evaluated with modified atmosphere packaging using Cryovac D-940 and D-955 films, in 0° and 5°C refrigerated storage. Weight loss was greatly reduced in the packaged film compared to the non-covered control; but mold infection was excessive because high humidity accumulated inside the package. Internal atmosphere of film-packaged blackberries tended to equilibrate at 13% O_2 by the second day when stored at 0°C, but decreased to 5% O_2 for fruit kept at 5°C. Fruits of 'Cherokee', 'Chester' and 'Shawnee' selectively picked at early ripe, mature ripe and overmature stages developed significantly different rot, with acceptable levels in the early (< 5% rot) and mature ripe (< 15% rot) stages. Soluble solids (SSC) did not change during the storage

period, but differences (1-3% SSC) were detected between stages of maturity. Anthocyanin (Acy) concentrations of fruits increased after storage at all maturity stages. Stages of maturity differed in glucose and fructose content with the higher values in mature ripe and overmature fruit. Both sugars were found to decrease, fructose more dramatically, during storage. Citric and malic acids were present in high concentrations in blackberries with greater values in early ripe and mature ripe stages. Both acids decreased during storage, but malic acid decreased more. Sensory evaluation of blackberry varieties were carried out through taste panels . Regression analysis of the data revealed that fruity flavor intensity as the major factor along with juiciness and sweetness related to overall quality and acceptance by consumer panels.

INTRODUCTION

Blackberries are among the most perishable fruits, so in order to extend their shelf life they must be kept at low temperatures, preferably near 0°C (Salunkhe and Desai, 1984; Richardson, 1988). However, commercial stores rarely provide optimum temperatures for these commodities (Robinson et al,1975).

Refrigeration is the main technique used to preserve fruits and vegetables, because it controls growth of many decay producing microorganisms, retards respiration and moisture loss and slows metabolism (Smith et al, 1987). Often decay caused by fungal infection is the major factor that limits shelf life of blackberries and berries in general (Ballinger et al, 1978).

Applications of modified atmospheres in addition to precise temperature management can allow a longer storage period, and the ability to reach more distant markets (McGlasson, 1989).

With increasing consumer awareness for quality in fresh products, methods have been developed to create microclimates within packed produce that continue the beneficial effect of CA through marketing (Smith et al, 1987). Recent improvements in film wrap manufacture provide a wide selection of films with varying properties and permeabilities. These have renewed interest in modified atmosphere packaging (MAP), (Hall et al, 1975; Miller et al, 1983, Ben-Yehoshua, 1985).

One of the most marked effects of film wrapping is reduction in weight loss. However, films with low permeabilities to water vapor can lead to high relative humidity causing condensation and increased risk of pathological infection (Smith et al, 1987).

MAP has been reported to be beneficial for several commodities, and some studies have shown that strawberries, raspberries, blueberries and cherries can be stored and/or transported this way (Powrie et al, 1978).

Stage of maturity has proven to have major effects on shelf-life and quality components of berries in storage (Sjulin and Robbins, 1987). In blackberries, fruit color is a poor indicator of maturity, since most blackberries color before they are fully ripe and there is a tendency of most pickers to harvest fruit that is underripe and sour (Moore and Skirvin, 1990). On the other hand, overripe fruit increases mold incidence which can easily spread to the entire container.

Sensory evaluation of fruits is a helpful tool to conduct consumer tests and assess the preference or acceptance of a product by a potential customer (Meilgaard et al, 1987). Quality of any horticultural product can be defined as the sum of attributes including appearance, flavor, texture, nutritional value and defects (Arthey, 1975), and the relative importance of each of them depends on the commodity and its intended use (Kader, 1985).

The pick-your-own concept of direct marketing has greatly stimulated interest in blackberry culture in many areas of the United States (Moore and Skirvin, 1990). There is a need to identify cultivars that would be suitable for fresh market as well as study methods for prolonging their storage life and assess consumer acceptance of these fruits.

The objectives of this study were: 1) to define consumer acceptance of blackberry cultivars with some potential for extended storage and 2) evaluate some MAP systems under different storage temperatures and different stages of fruit maturity.

MATERIALS AND METHODS

Blackberry experiments were conducted in four different steps, as follows:

a. EXPERIMENT 1

This was a preliminary screening of eight different cultivars to determine varieties suitable for long term storage, as well as consumer acceptance.

Fruits were obtained from the North Willamette Experiment Station, Aurora, Oregon, during June and July 1989, and harvested on two different dates.

In the first harvest, early season fruits of 'Logan', 'Boysen', 'Marion' and '1466' (new selection) were directly hand picked into 1/2 pint (0.23 liter) unwaxed, ventilated pulpboard containers, (10 x 10 x 3.4 cm high) and placed into commercial cardboard flats (44 x 35 x 5 cm high) holding 12 containers.

Upon arrival at the laboratory, 2 hours after picking, each container was labeled and weighed, covered with plastic caps and transferred to the storage room where they were held for 8 days at 0°C and 95% relative humidity.

Following storage each of the trays was weighed to determine weight loss and mold was counted to record percentage of rotten fruit. Any evidence of mold in the berries was counted as a rotten berry. Following storage, a sensory evaluation panel was conducted using a line scale test (see Fig. III.1) as described by Meilgaard et al (1987). Samples consisting of 4 fruits for each treatment were coded with random numbers and given to 24 judges that rated them for general appearance (color, glossiness, shrivel); flavor (sweetness, sourness, fruity flavor intensity, juiciness); texture (firmness) and overall quality.

The marks on the line scale (which corresponded to the perceived intensity of the attribute in question) were converted to distance in cm. from the left most edge of the scale, and the data subjected to Analysis of Variance. Mean differences were detected by LSD , and linear regression coefficients were calculated for overall quality against the rest of the attributes. The Statgraphics software was used for the analyses.

The same procedure was followed for the second harvest, but this time the late season cultivars picked were 'Waldo', 'Kotata', 'Olallie' and 'Silvan'.

b. EXPERIMENT 2

In order to extend storage life of fresh blackberries, a modified atmosphere package was developed using Cryovac D940 and D955 (60 gauge) films. The physical properties of the films were presented previously (Tables II.1 and II.2).

'Kotata' and 'Waldo' were selected as the most suitable blackberry varieties from Experiment 1. Fruits were obtained from the North Willamette Experiment

Station, Aurora, Oregon, on two different dates in July 1989.

In the first harvest, fruits were hand-picked into 1 pint (0.47 liter) unwaxed ventilated pulpboard hallock containers (10 x 10 x 7.2 cm high and placed in cardboard flats containing 12 pints each). During the second harvest, fruits were picked into 1/2 pint (0.23 liter) hallock containers. The following procedures apply for both harvest dates.

After harvest, fruits were taken to the laboratory and placed at 0°C for 3 to 4 hr. in order to remove field heat. They were then taken out , trays were weighed and 5 different packagings assigned to each cultivar: 1) Film D940 Shrunk, 2) Film D940 Non Shrunk, 3) Film D955 Shrunk, 4) Film D955 Non Shrunk and 5) Control, which remained uncovered.

Bags were made with the films that would fit the containers. The hallocks holding the fruit were placed inside the bags and sealed with an L-bar hot wire sealer. For the shrunk-film treatments the film bagged hallocks were conveyed through a heat tunnel.

Six replications of each package type by cultivar combination were used, and stored at 0°C and 95% relative humidity for 15 days.

Internal atmosphere of the packaged fruit was monitored by sampling 2 replicates of each treatment every two days, withdrawing 1 ml of internal atmosphere with a syringe. The puncture hole was immediately sealed with tape. CO_2 and O_2 evolution were analyzed with a Carle model 311 Gas Chromatograph, with thermal conductivity detector connected to a Shimadzu CR3A Chromatopac recording integrator.

After 15 days of storage, samples were weighed and mold incidence recorded. Again, any evidence of mold was considered to be a rotten berry.

Sensory evaluations were carried out only for the packed fruit, and no distinction was made between shrunk and loose containers, because the analysis of gas evolution showed that we failed to obtain a complete seal in any of the packages.

The same quality attributes described for experiment 1 were tested by 24 judges.

c. EXPERIMENT 3

Another cultivar was selected to evaluate the effect of storage temperature on Cryovac films D940 and D955. Fruits of 'Cherokee' (mid to late season variety), were obtained from a commercial field in Hillsboro, Oregon in July 1989.

Berries were hand harvested, placed in 1/2 pint unwaxed ventilated pulpboard containers and taken to the laboratory for preparation. Prior to packaging, fruits were held for 3 to 4 hours at 0°C to remove field heat.

Only two packagings were tested: Film D940 and Film D955, because not enough fruits were available to include another control. In this case a new sealer, Bizerba Vacuum Pac Flush, model GM2000/110GF was used to assure an air tight seal packaging. The packaged fruit was held at either 5° or 0°C and 95% relative humidity. Six replicates of each packaging and temperature combination were used and evaluated at the beginning and end of 10 days storage period.

After storage, all berries in each container were examined for decay, berries with obvious fungal infection, as well as leakers and very soft berries were considered as rotten. Moisture loss was determined as the difference in weight between the first and last day (day 10) of storage.

Every two days, gas composition was measured on 3 containers of each treatment, by withdrawing 1 ml of internal air with a syringe, and then analyzing by gas chromatography as described earlier.

At the end of the storage period sensory evaluation (24 panelists) was conducted on fruits of the four treatments (two films by two temperatures).

From each test, prior to and after storage, samples were taken at random and frozen at -20°C for later measurements of anthocyanins and soluble solids content.

Frozen samples were thawed rapidly in 2 to 3 hours at room temperature to minimize changes in anthocyanin content

(Sapers et al, 1985). Ten grams of fruit were crushed in a test tube and thoroughly stirred. Soluble solids were measured directly from the undiluted juice with calibrated Atago NL-1 hand-held refractometer. The crushed samples were then used to determine anthocyanins spectrophotometrically by the method of Torre and Barrit (1977), with some modifications as follows.

Ten grams of crushed sample were mixed with 5 ml of acidified ethanol (95% ethanol:1.5N HCl, 85:15), blended for 1 min. with a Polytron Homogenizer (Brinkmann Instruments, Westbury, NY), and transferred to a Buchner funnel vacuum filtered trough a Whatman N°1 filter paper. About 30 ml of extracting solvent was used to facilitate washing. The residue, along with the filter paper, was transferred to a small beaker and 35 ml of extracting solvent was used to wash any remaining anthocyanin from the funnel and residue. The filtrate was then quantitatively transferred to a 100 ml volumetric flask and made up to volume. A 1 ml aliquot of the extract was diluted with a measured amount of solvent to an absorbance range of 0.4 to 0.8 at 533 nm, because straight line relationships between concentration and absorbance can be expected only at low concentrations (0-0.8 O.D.) (Fuleki and Francis, 1968). Absorbance was read using a Bausch & Lomb Spectronic 2000 Spectrophotometer at 533 nm. The reading was converted to total mg cyanidin-3-galactoside per 100 g fruit using the formula developed by Fuleki and Francis (1968). Soluble solids and anthocyanin determinations were based on 3 replicates of each treatment. The results were analyzed for a completely randomized split-plot design using a SAS Statistics computer program, with film type as main plots and storage time (beginning and end of the experiment) as the subplots. Means differences were detected by Fisher Protected Least Significant Differences (FPLSD) method, (Petersen, 1985).

d. EXPERIMENT 4

In order to study the effect of maturity stage on storage life of blackberries, fruits of 'Chester', 'Cherokee' and 'Shawnee' were obtained from commercial fields in Hillsboro, Oregon in August 1989.

Berries were selectively hand-picked into 1/2 pint hallocks and divided into three maturity stages based mainly on the difference in force required to pull them off the plant. These stages were defined as early mature, (M1), (black fruit with slight redness, hard to pull from the plant); mature ripe, (M2), (black, shiny and firm berries) and overmature (M3) (softer than M2, a little dullness appears on the surface, very easy to remove from the plant).

Upon arrival at the laboratory, fruits were allowed to cool at 0°C for about 3 hr. Fruits of each of the 3 cultivars and 3 maturity stages were weighed and seal packaged in Cryovac Films D940 or D955, and stored 9 days at 0°C and 95% relative humidity.

Four replications of each cultivar, maturity stage and packaging combination were used to determine percentages of weight loss and fungal incidence after storage.

CO_2 evolution and O_2 consumption of the three maturity stages were monitored from 'Chester' packaged in film D955. To detect any differences between varieties, gas composition of the three cultivars was followed for ripe fruit (M2) packaged in film D940.

At the beginning and end of the storage period, fruits from film D955 for the three cultivars and three maturity stages were frozen and held at -20°C until further analyses. Soluble solids and anthocyanins were determined as explained for Experiment 3. The 80% ethanol extracts were kept at 5°C for later use in organic acids and sugars determination by high performance liquid chromatography (HPLC).

Ten ml of the extract used for Acy determination was pH adjusted to 5.5 - 6.0 and then percolated through a column containing 10 ml of Dowex 50W-X4 (T.J. Baker Chemical Co. Phillipsburg, NJ), cation exchange resin, hydrogen form, 50 - 100 mesh, and then through a similar column containing 9 ml of Dowex 1x8 (Sigma Chemical Co, St. Louis, Mo), strong basic anion exchange resin, 50 - 100 mesh. The Dowex 50 column was stacked over the Dowex 1x8, and both were washed with 350 ml of distilled water to remove sugars.

Columns were then separated and organic acids were eluted from the column containing Dowex 1x8 with 120 ml of 1.5N formic acid. Amino compounds binding to Dowex 50 were eluted with 2N NH_4OH, discarded and the columns regenerated with acid for re-use.

The eluates of both sugars and organic acids were concentrated to dryness in a rotary evaporator under water aspirator vacuum at 65°C. The residues were dissolved in 2 ml of distilled water and filtered through a 0.2um millipore filter prior to HPLC analysis.

Analyses for organic acids were carried out using a Beckman Model 110A pump and Beckman-Altex Model 500 injector fitted with a 20 ul sample loop, equipped with a 7.8 x 300 mm Aminex HPX-87 organic acid column (Bio-Rad Laboratories) heated by a water jacket to 65°C. The mobile phase was 0.002N H_2SO_4 (filtered through a 0.2 um millipore filter and degassed), at a flow rate of 0.6 ml/min. Peaks were detected by a Hitachi Model 100-10 Spectrophotometer UV detector (210 nm) and areas were quantified with a Shimadzu Model CR-3A integrator. Organic acids were identified and quantified by comparison of their retention times and detector responses with that of authentic standards.

HPLC analyses of sugars were accomplished with a Bio-Rad refractive index (RI) monitor, a 4.1 x 300 mm Alltech

600CH carbohydrate column, at 85°C. The mobile phase was 75 % acetonitrile with 1% tetraethylpentamine as a column protectant, in degassed water filtered through a 0.45 um millipore filter and kept at 65 °C with a flow rate of 1 ml/min. and 20 ul loop injection volume. Peak areas were quantified with a Shimadzu Model CR-3A integrator. The sugars were identified and quantified by comparison of their retention times with that of authentic standards.

Three replicates of each cultivar by maturity stage combination from film D-955 were used for chemical analysis. The data were analyzed in a completely randomized split-plot design using stage of maturity as main plots and storage time (initial and final conditions) as subplots. A separate analysis was conducted for each cultivar. Mean differences were detected by Fisher Protected Least Significant Difference (FPLSD) method.

RESULTS

a. EXPERIMENT 1

Decay Incidence

Percentage of mold in blackberry fruits from the first and second harvests are shown in Tables III.1 and III.2, respectively. On the first harvest, 'Marion' showed a very low incidence of decay (only 1.6%), which was statistically different (p=0.05) from the other three varieties ranging from 27.6 to 33.1% rots. Fruits from the second harvest generally developed less decay than those from the first harvest. 'Kotata' (7.2% rot) and 'Waldo' (9,5%) had the least rot, although the mean value for 'Waldo' did not statistically differ from 'Silvan' (13.5% rot). 'Olallie' was quite susceptible to rot (19%). Rain occurrence prior to the first harvest may have contributed to greater decay incidence.

Sensory Evaluation

Table III.3 summarizes the mean values for the attributes evaluated in the taste panel for the first blackberry harvest. 'Marion' and '1466' scored the best for general appearance (glossiness, color and shrivel) and flavor characteristics. Furthermore, they showed adequately firm texture and high acceptance in terms of overall quality.

'Logan' was rated low in almost all the attributes, especially appearance, flavor intensity and texture, which resulted in a very low score (2.9) for overall quality.

'Boysen' had intermediate taste panel scores, except for juiciness which was very high (11.5) and comparable to 'Marion' (10.2).

From this first evaluation, '1466' and 'Marion' (which also had a very low mold incidence) showed good quality and promising attributes. However, '1466' is a new selection that hasn't yet been released as a commercial cultivar, and not enough fruit of 'Marion' was available to conduct further experiments. For these reasons, the choices for further experiments were based mainly on fruit from the second evaluation. Future studies should expand evaluation of 'Marion', since this test was quite limited. '1466' is doubtful because of high rot susceptibility.

Results of the second taste panel are shown in Table III.4. In terms of general appearance, 'Waldo' was rated as the highest in glossiness (8.9), whereas 'Kotata' was the darkest (12.4) among the four cultivars. No statistical differences were found for shriveling and fruit appearance was generally good.

In relation to flavor, some statistical differences were found for sweetness ('Marion' and '1466' were high) and sourness ('1466' was low), although the means are within a narrow range. No differences were detected in flavor intensity.

Texture evaluation of firmness showed that 'Waldo' was the firmest (10.3), followed by 'Kotata' (8.1), both with reasonably high scores. 'Logan' was very soft (2.5 score).

Despite some of the individual factor differences described above, no statistical differences were found among the four cultivars in the second taste panel in terms of overall quality making it difficult to choose one or more of the them as the best. Taking both taste panels , clearly 'Marion' was the top variety as dominated by overall quality and rot resistance.

Data from both taste panels were pooled in order to carry out composited regression analyses of overall quality against the other attributes. Table III.5 shows the different equations tested and the increase in correlation coefficients (r^2) achieved by adding an extra variable. From this analysis fruity flavor intensity alone was able to explain 82% of the variability in overall quality. When juiciness was added to the equation, r^2 increased to 0.85. From there on if firmness and sweetness were added (one at a time), only 1% increase in r^2 was detected.

From the choices available, 'Waldo' and 'Kotata' accounted for the best attributes and the lowest amounts of mold on the second harvest so they were chosen for further studies.

b. EXPERIMENT 2

Decay Incidence

There was a big difference in mold infection depending upon whether the fruit was packaged or left uncovered. For both harvest dates, the open control treatments developed about 50% or 30% less infection. No statistical differences were found among the packaged treatments (Table III.6, although both D-955 shrunk and non shrunk showed a slight tendency toward higher mold in the first harvest. In the early harvest a cultivar effect was detected, and there was quite a difference in mold infection between 'Waldo' (40.94%) and 'Kotata' (14.75%) (Table III.7). This effect was not found in the same varieties packaged from the second harvest, where packaging effects were not significant.

Weight Loss

As anticipated, packaging had a dramatic effect on weight loss as shown in Table III.8. Again a great difference in moisture loss was observed between uncovered fruits and the packaged fruits. First harvest fruits packaged in film D-940 (both shrunk and loose) had the least weight loss (about 0.9%), followed by 1.1% in film D-955; as contrasted with a high loss (3.2%) in the control. Results from the second harvest, showed more equal weight loss for the D-940 and D-955 packaged fruit (with 0.2%

weight loss), where the values did not differ statistically, except for the non-packaged control with 3.6% weight loss.

Internal Atmosphere of Film Packaged Blackberries

Figures III.2 and III.3 show CO_2 and O_2 inside the packages of the first attempts at seal packaging 'Kotata' and 'Waldo', respectively. The data shows that all packages behaved as highly permeable barriers, since the percentages of O_2 and CO_2 were maintained at atmospheric equivalence over time. Further experiments confirmed that the L-bar heat equipment used for these treatments was not getting a complete seal despite the appearance of good seal, and therefore the internal atmosphere of the fruit in the container was not being modified. For the subsequent experiments, the new Bizerba sealer was used, which provided an excellent seal of the films.

Sensory Evaluation of MAP Blackberries

Tables III.9 and III.10 show the taste panel results of 'Waldo' and 'Kotata' blackberries in MAP film studies from the first and second harvests, respectively. In general, no differences were detected between film types in most of the attributes.

Fruits of 'Waldo' were rated highest in glossiness (9.5 to 11.2), while those of 'Kotata' were the darkest

(11.1 to 11.5). Color was rated somewhat low on 'Waldo' in the second harvest, which could mean an earlier stage of ripeness. These results are quite similar to Experiment 1, described previously.

Both tests were similar in terms of high ratings for flavor intensity and firmness of 'Waldo' (8.8 to 9.3), and for juiciness of 'Kotata' (8.9 to 9.9). Values for shrivel were relatively low (below 6.2) and all of the samples had a good appearance.

'Waldo' packaged with D-955 in the first taste panel and 'Waldo' in the second, had high ratings for sourness (8.4 to 10.4), along with lower sweetness (6.9 to 7.5) than the other treatments. Despite this, both packagings of 'Waldo' ranked high for flavor intensity (8.7 to 9.3).

No statistical differences among packaging treatments were found for overall quality in either test. All means were above 7.5 (in a scale from 0-15), therefore, on average, all of the treatments were completely acceptable.

When the data of both taste panels were pooled to get the composited regression coefficients, fruity flavor intensity was again the dominant factor influencing quality. Table III.11 shows the different equations fitted and their corresponding r^2 values. When the equation for overall quality was expressed as function of fruity flavor intensity alone, 81% of the overall quality variability was explained by this parameter. The second best correlated attribute was again juiciness raising the r^2 value to 0.87, but if sweetness was added only a 1% increase in the correlation coefficient was found.

c. EXPERIMENT 3

Decay Incidence and Weight Loss

A significant difference was found for film type (Table III.12) and storage temperature (Table III.13) in terms of 'Cherokee' blackberry decay incidence and weight loss. As observed in previous experiments with 'Waldo' and 'Kotata' mold infection was lower (about 17% less) when film D-940 was used, although the percentage of decay was still high in both film types. Weight loss was kept extremely low in both film types (0.3 and 0.2 %) , since the packages were tightly sealed by the Bizerba machine. A significant difference was still detected with fruit packed in film D-955 with a lower percentage of moisture loss (Table III.12).

Fruits held at 5 °C developed twice as much fungal infection as those stored at 0 °C (47.5 vs. 22.6%, respectively). Again, since both treatments were film packaged, the percentages of mold were high. Concerning weight loss, lower temperature (0 °C) resulted in significantly less weight loss (0.12%) compared to the higher (5°C) temperature (0.32%). Despite this, the values are extremely low for both treatments (Table III.13).

CO_2 and O_2 within the Package

Gas composition of the internal atmosphere of the packages is shown in Figures III.4 and III.5. It is evident that an effective seal was obtained with the new Bizerba sealer, evidenced by the variation in internal atmosphere of the packages over time. No significant differences were found for oxygen concentration relative to film type, but a different pattern was found for the two storage temperatures and O_2 did change over storage time. Oxygen levels dropped from 21% to about 13% by the second day of storage at 0°C and the concentration remained almost constant thereafter, thus implying that O_2 equilibrium was approached by day 2. In fruit packages stored at 5°C, oxygen dropped to about 9% the second day and continued decreasing down to about 5 and 6% at the end of the storage period.

Respired CO_2 accumulated in both film types during storage and there was a significant temperature by time of storage interaction. A higher accumulation of CO_2 occurred in the least permeable film (D-955), and the higher storage temperature (5°C), (Figure III.5). CO_2 accumulated with longer periods of time, reaching about 11% in seven days. From 7 days on, the increases in CO_2 were slight up to 10 days, indicating that CO_2 had come close to equilibrium after 7 days.

Sensory Evaluation

Results of the taste panel conducted in this experiment are shown on Table III.14. Although all the packaging treatments for this sensory evaluation were on the same variety, differences in attributes were found among them. In general judges were more capable of distinguishing differences between fruits kept at different temperatures, than differences between the film packagings.

In terms of general appearance, no differences were found for color, but the treatments did differ in glossiness and shriveling. The highest scores for glossiness were obtained for fruit kept at 0°C, as well as the lowest scores for shrivel.

No differences could be detected for the flavor components (sweetness, sourness, fruit flavor intensity) except for juiciness, where fruits in film D-940 (independent of storage temperature) obtained significantly higher scores than those kept in film D-955. Firmness did differ by treatments, and the scores were in general above the mean value.

Finally, regarding overall quality of the treatments, the judges selected fruits in film D-940 (0°C and 5°C) as the best, but in general average values for all treatments were low, ranging from 4.89 to 6.23, (0 to 15 point scale).

The composited regression coefficients of this experiment are shown in Table III.15. In this case sweetness was the highest correlated single attribute with overall quality (r^2 = 0.71). When fruity flavor intensity was added to the equation a 5% increase was found in r^2 (0.77). If juiciness was included in the model, the coefficient increased to 0.79, and this was the highest correlation that could be found. Addition of other attributes did not increase r^2 values and the subsequent coefficients calculated proved to be non significant.

Soluble Solids and Anthocyanin Concentrations

Fruits of 'Cherokee' packed in films D-940 and D-955, and kept for 9 days at either 0 or 5°C presented no changes in either soluble solids content (SSC) or anthocyanin (ACY) concentrations. Table III.16 shows that neither SSC nor anthocyanins changed over time. The values for SSC averaged 11.0% and for ACY 79.4 mg/ 100 g.

d. EXPERIMENT 4 - LATE VARIETIES OF BLACKBERRY- 'CHESTER', 'CHEROKEE' AND 'SHAWNEE'

Decay Incidence

As fruit maturity became more advanced, the incidence of mold in the stored berries dramatically increased.

Stage of maturity greatly influenced decay incidence in the three cultivars tested. Very little infection (< 4%) was found in fruits of the early mature stages (M1) of 'Cherokee' and 'Shawnee', and on early mature and mature ripe stages of 'Chester', (Figure III.6). Mature ripe fruits (M2) of 'Cherokee' and 'Shawnee' developed moderate infection (3.5 to 16.2%), while the highest percentages were found in late mature fruit (M3) (37.5 to 49.8%). 'Chester' had extremely low mold incidence (0.4 to 10.5%). Even the late mature stage of 'Chester' had only moderate to low infection (10.5%), similar to those of mature ripe fruits of 'Cherokee' and 'Shawnee'.

An effect of film type on mold infection was detected only for 'Shawnee', where fruit wrapped with film D-955 developed almost 50% more mold than 'Shawnee' berries packed in film D-940, (Table III.17). This trend, observed in most previous experiments likely relates to the somewhat greater permeability of film D-940. While no measures of internal relative humidity were taken, it is quite likely that more permeable D-940 may well have had lower internal relative humidity, and this may have influenced mold growth.

Nearly all mold waslocalized on the broken end of the pith column in the center of the berry.

Moisture Loss

As expected with wrapped fruits, weight loss was extremely low in all treatments, and not much difference was found in terms of maturity stage or type of film. The highest value (0.51%) was found for 'Chester' early mature fruit with film D-940, (Figure III.7).

No significant differences in moisture loss were detected among treatments for 'Shawnee' (Figure not shown), where the values ranged from 0.15% to 0.27%. In the case of 'Cherokee' (Figure III.8) and 'Chester' an interaction between stage of maturity and the film was found. Overmature stages (M3) of 'Cherokee' as well as mature ripe fruit (M2) in film D-955 showed the lowest values of moisture loss (about 0.19%), followed by early mature (M1) fruit with D-955 (0.2%) and mature ripe (M2) in D-940 (0.3%). Finally, the greatest amount of weight loss was found on early mature stage (M1) wrapped with film D-940 (0.4%). In the case of 'Chester', the greatest weight loss was also found for underripe fruit (M1) in film D-940. No significant differences were found among the rest of these treatments, but there was a trend for overripe fruit to retain moisture better than mature ripe and early ripe stages. Additionally, for fruit of the same stage of maturity, those in film D-940 presented higher moisture loss values than those in film D-955.

CO_2 and O_2 Evolution with MAP

In the case of fruits of 'Chester' packed in D-955, film the internal atmosphere showed a decrease in O_2 along with an increase in CO_2 as storage time passed. No statistical differences were detected among the three stages of maturity although CO_2 tended to be higher for stages M1 and M2 than for M3. Gas concentrations changed through time in storage. The most marked effects were found during the first 3 days , where O_2 levels dropped to about 15% and CO_2 increased to 3.7% (Figure III.9). Thereafter the levels of O_2 and CO_2 remained essentially equilibrated throughout storage.

When the mature ripe stages (M2) of the three varieties were monitored for internal atmosphere composition in film D-940, no differences were found among the cultivars and only the time of storage was significant (Fig III.10). O_2 and CO_2 concentrations in D-940 were similar in trend to that of film D-955. The biggest changes in gas concentrations occurred during the first 3 days of storage, when equilibrium appeared to be established. Although O_2 levels decreased to levels that were similar to those of film D-955, values of CO_2 from fruits packed in film D-940 were lower, due apparently to its higher permeation. The highest CO_2 value found in D-940 was about 2.2% which remained almost invariant until the end of 9 days storage.

In general both film types acted as moderately permeable since neither O_2 dropped nor CO_2 accumulated to extreme values that might adversely affect the fruits.

Soluble Solids Contents

No changes in soluble solids content were detected between the initial and final period of storage. Statistical differences were found between stages of maturity of 'Cherokee' and 'Shawnee' but not of 'Chester', although a trend of increasing SSC was seen (Figure III.11). SSC tended to increase with increasing maturity. 'Cherokee' presented the highest variation in SSC and all three stages of ripeness were statistically different. On average, SSC were found to be 9.4, 10.9 and 12.4% for early mature, mature ripe and overmature fruits respectively. 'Cherokee' at all stages had higher SSC compared to the other varieties at comparable maturities.

'Chester' and 'Shawnee' also had higher SSC in the riper fruits, but the differences were not significant between ripe (M2) and overripe (M3) stages. In this case 'Shawnee' soluble solids varied from 8.2 (M1), 10.4 (M2) and 10.9% (M3) whereas 'Chester' had 8.5 (M1), 8.8 (M2) and 9.1% (M3) soluble solids.

Anthocyanin Concentrations

Stage of maturity and storage time greatly influenced the amount of anthocyanin detected in blackberries of 'Cherokee', 'Chester' and 'Shawnee'. At all three maturity stages there was an increase in pigment after storage. This increase was greater for the mature ripe fruits of both 'Cherokee' and 'Chester', and for the early mature fruits (M1) of 'Shawnee' (Figure III.12).

On average the greatest increases in anthocyanin concentration over storage time were detected in fruits of 'Cherokee' and 'Chester' (Table III.18) with approximately a 35% increase in pigment.

The average content of anthocyanins for each cultivar at the three stages of ripeness are shown in Table III.19. The highest concentrations of the pigment were found in fruits of 'Chester' (67.1 to 143.3 mg/100 g), which also accounted for the largest increment between the early and overmature stages. In all three varieties the change in amount of anthocyanin was greater between the early mature and the ripe stage than between the ripe and overripe fruit stages.

Sugars

Glucose and fructose were the main sugars found in blackberry fruits of 'Cherokee', 'Chester' and 'Shawnee'. (Figure III.13). Differences were detected in both sugars at all maturity stages . Fructose increased from 42 (M1) to 78 mg/g FW (M3) in 'Cherokee'; from 39 (M1) to 79 mg/g FW (M3) in 'Chester' and from 58 (M1) to 80 mg/g FW (M3) in 'Shawnee'. Glucose showed the same trend increasing from 41 to 65 mg/g FW in 'Cherokee'; from 61 to 123 mg/g FW in 'Chester' and from 78 to 113 mg/g FW in 'Shawnee'. Decreases in both sugars were found during the storage period, although the significant differences were found only in fruits of 'Shawnee' and 'Chester' for fructose (70 mg/g before storage and 62 mg/g after storage). In the case of glucose, the significant decreases were found for 'Cherokee' (from 73 before storage to 32 mg/g after storage) and for 'Shawnee' (97 mg/g to 69 mg/g after storage).

Only small amounts of sucrose were detected in some samples, mainly in fruits of 'Cherokee' and 'Chester' , with values that ranged from 0.5 to 1.2 mg/g FW (data not shown).

Organic acids

Differences between maturity stages and storage time were found for (iso)citric and malic acids in the 3 blackberry cultivars (Figure III.15). Our HPLC methodology did not resolve isocitric from citric, therefore we report it as (iso)citric. In general, changes over storage time were greater for malic acid, showing a 40% decrease in 'Cherokee' and 'Shawnee' and about a 60% decrease in 'Chester'. Citric acid decreased by about 20% in 'Cherokee' and 'Shawnee' and 30% in 'Chester".

Both (iso)citric and malic acids tended to decrease with more advanced stages of maturity. On average the highest amounts of (iso)citric and malic acids were found in early mature (M1) and mature ripe (M2) fruits of 'Chester' before storage.

DISCUSSION

a. EXPERIMENT 1 - VARIETY EVALUATIONS

Large variations in quality factors such as appearance, flavor, and texture, as well as in resistance to decay (even at low temperatures), are found among different blackberry cultivars. It is known that storage life of fruits in general is limited by the processes of ripening and deterioration caused by fungi (Ballinger and Kushman, 1970). Therefore when choosing a particular cultivar for long term storage, resistance to mold infection plays a mayor role. From the results of this limited experiment, 'Marion' exhibited very promising characteristics, extremely low infection (1.62%), and high taste panel scores. It is most likely that the low mold infection was influenced by the fact that this is a very firm cultivar (rated as one of the firmest in the taste panel, and still offers good flavor). Therefore 'Marion', presents very promising prospects for long term storage, and it should be considered as a strong candidate for future studies to develop fresh markets for blackberries.

Since consumers buy largely on the basis of appearance, (Kader, 1985), this is an important factor for fresh market products. From the choices available among late season types, 'Waldo' and 'Kotata' scored well for their excellent gloss and color and good flavor. Both varieties had moderately low decay (9.5% and 7.2%

respectively), thus these varieties were chosen for the next experiments. Both cultivars presented less rot incidence, probably due to the fact that they were much firmer than the other two varieties, 'Silvan' and 'Olallie'.

b. EXPERIMENT 2 - STORAGE TEMPERATURE AND PACKAGING FILMS

Low temperature is highly recommended for storage of many perishable fruits, because it slows moisture loss and spoilage due to rot organisms. (Ben Yehoshua, 1985; Hardenburg et al, 1986; Richardson, 1988). High humidity is also necessary in order to avoid wilting or shriveling (Hardenburg et al, 1986). Packaging fruits in plastic films provides reduced water loss, but excessively high humidity within a closed container may encourage mold development (Robinson et al, 1975). It is evident in our study that differences in weight loss were large when the uncovered treatment was compared with the other two film-wrapped packages. Weight loss in the control was higher (3.2%) because there was no barrier to protect moisture from evaporating to the surrounding atmosphere. The difference was even greater because the film packages had no perforations. As reported by Hruschka and Kushman (1963), weight loss of berries was reduced by 50% when film caps were compared to open top containers. Generally, moisture losses greater than 3% are enough to cause a marked loss of fresh produce quality (Hardenburg et al, 1986). Since this is extremely important for fresh market, a covered container should always be considered.

The main problem encountered from both early and late harvest dates was rot infection, above 17% with the sealed film packaged fruit. The high incidence of decay can be explained in part by the fact that fruit was stored for a long period of time. Hardenburg et al (1986) mention that blackberries can hardly be stored for more than three days because of their high perishability. Although the first packaging experiment proved later not to be completely sealed, extremely high humidity accumulated inside that favored greater mold infection than the control. Similar results were found by Ahmedhullah et al (1989) in blueberries. Films used for MAP usually have low permeability to water vapor, (Kader et al, 1989). The high mold incidence for the first harvest date can also be accounted for by the larger sized hallock used (1 pint) versus 1/2 pint in the second. One pint hallocks hold more fruits and while this might be attributed to compression injuries and bruising or softening the fruit, this was not the case. It is more likely that the humidity was high making fruits more prone to fungal attack.

In order to create adequate MAP, it is essential to obtain a good seal on the film and avoid punctures (McGlasson, 1989). Despite the appearance suggesting a good seal the first experiment using the L-Bar sealer clearly demonstrated that even a small hole can affect the internal atmosphere of the package (Mannaperuma et al, 1989). From the beginning all -bar sealed packages behaved as highly permeable barriers, since O_2 and CO_2 contents were essentially equal to the surrounding air over time. Careful examination of the packages at the seals revealed small holes that would allow substantial gas exchange such that the internal atmosphere was not modified.

Sensory evaluations help to assess the personal response to a particular product by its current or potential customer. In both tests, 'Waldo' stood out for glossiness, firmness and flavor. Glossiness in blackberries is very important as an appearance factor, which might encourage customers to buy. On the other hand, firmness must also be considered when fresh marketing berries, because firmer fruits can tolerate longer storage time and the rigors of handling. Finally, flavor, perceived as volatiles and as a balance between sweetness and sourness, may influence the final decision of repeated purchases. 'Kotata' was mainly liked for intense color, because customers expect blackberries to be black, and for juiciness, an important texture component. Looking at the raw data for sweetness, sourness and firmness, revealed a high fruit-to-fruit variability within treatments. This strongly implies that some fruits were at different stages of maturity. It has been shown that stage of maturity has a major effect on quality components of raspberries in storage (Sjulin and Robbins, 1987) On the other hand, blackberries ripen over a period of time leading to a variation in ripeness at one harvest time. Color did not influence the responses, because blackberries are fully colored before they are fully ripe (Moore and Skirvin, 1990).

When overall quality of all treatments was tested against the rest of the attributes the highest correlation coefficient was given by a combination of fruity flavor intensity and juiciness (r^2=0.85). From our study these two major components seem to be enough to explain overall quality of blackberry fruits, in terms of consumer acceptance. One of the goals in sensory evaluation is to design the questionnaire to ask the minimum number of questions to achieve the project objective, (Meilgaard et al, 1987), allowing more samples to be tested in less time with the same precision on the results. Future blackberry studies should concentrate on flavor intensity and juiciness.

c. EXPERIMENT 3 - 'CHEROKEE' BLACKBERRIES

Similar to the report of Varseveld and Richardson (1980), when blackberries were held at 0°C, there was 50% less mold compared to 5°C storage. Spore germination and growth rate of pathogens are greatly influenced by temperature. Fungi such as Botrytis cinerea and Alternaria alternata can still grow although very slowly at -2°C while the limit for Rhizopus spp. is + 2°C (Sommer, 1985). Overripe fruits of blackberries are particularly susceptible to Rhizopus infection (Ryall and Pentzer, 1974). Although 0°C and 95% relative humidity have been defined as optimum conditions for storage of blackberries, commercial stores rarely provide them (Robinson et al, 1975), often temperatures are 2°C to 3°C. Clearly this implies about a 20-30% greater risk for mold than optimum 0°C.

When both film types were compared, decay incidence was about 7% higher in film D-955, most probably because this film has a lower rate of water vapor permeation which leads to higher RH than in package film D-940, (Table II.2). Films used in MAP usually have low permeability to water vapor (Kader et al, 1989), and this can cause high RH or condensation that favors mold growth. Although differences between films were detected, mold incidence was still high (above 30%), even at 0°C, because of the sealed package used. As expected with film packaging, weight loss was extremely low for either film type used or storage temperature, and with values so low that appearance would not be affected. The higher permeability to water vapor of film D-940 resulted in higher values of moisture loss than fruit kept in film D-955 (0.25 and 0.19% respectively). With films, weight loss is related to the water vapor transmission rates of the material, which are independent of CO_2 and O_2 permeability. (Smith et al, 1987). It is clear that the packaging acted as a moisture barrier that impeded evaporation to the surrounding atmosphere. As expected, moisture loss was about 50% greater in fruit held at 5°C than those stored at 0°C. The rate of water loss depends upon the vapor pressure deficit between the fruit and the surrounding air, which is influenced by temperature and relative humidity. Since in this case relative humidity was the same for both storage conditions, water loss increased with the higher temperature.

In MAP, the commodity respires to consume O_2 and release CO_2 under restricted air exchange conditions; with the film as a barrier (Kader, 1985). In these experiments, CO_2 increased more rapidly and to higher values, (about 15%) in film D-955 and at 5°C. This is explained by the fact that film D-955 is about two times less permeable to CO_2 than film D-940. Respiration rate (amount of CO_2 produced) is also affected by storage duration and temperature (Hardenburg et al, 1985), and as expected at higher temperatures, higher activity is found. Thus, fruit at 5°C has a greater respiration rate than fruit at 0°C. This could potentially cause off-flavor development if O_2 becomes too low or CO_2 too high, but did not happen in these studies.

The sensory evaluation confirmed the effects of temperature on shelf-life of stored blackberries, since fruits kept at 0°C were classified as the highest in glossiness and the lowest in shriveling with less moisture loss. The regression analysis on overall quality of 'Cherokee' blackberries also revealed fruity flavor intensity and juiciness as important factors, but in this case sweetness was the first single attribute added to the equation.

d. EXPERIMENT 4 - LATE BLACKBERRY CULTIVARS

The quality of harvested fruits cannot be improved but it can be preserved. Good quality is obtained when harvesting is done at the proper stage of maturity (Pantastico et al, 1975). Decay of blackberries strongly increased with more advanced stages of maturity. When immature fruits were picked, decay incidence was extremely low, but internal quality was poor and variant ripening was obtained. If harvest was delayed and overmature fruits were harvested, susceptibility to decay was greatly increased, which also resulted in poor quality, shorter storage life and thus, less market value. Therefore, picking blackberries at the optimum adequate stage of maturity, (M2 for this study), is an important factor to preserve quality and assure a longer storage life. It seems that the most adequate index for blackberries is the ease of separation from the pedicel rather than color. But as Pantastico et al (1975) mention, this is a subjective index, and can be affected by several factors.

The fact that 'Chester' presented very low mold infection in both ripe (M2) and unripe (M1) stages (1.53 and 0.36%), may be a consequence of this being a late cultivar that was probably harvested at a less mature stage than the other two.

Although films were used to pack the fruit in this experiment, percentages of mold on unripe and ripe fruits were much lower than the values found in previous experiments. This could have been due to more careful picking of blackberries, mainly avoiding overripe fruit that could allow for longer storage. Harvesting at the appropriate maturity stage (M2) seems to be extremely important if the use of MAP is intended.

As observed before for experiments 2 and 3, weight loss was extremely low (less than 0.5 %) in all treatments because the film acted as a barrier preventing moisture to evaporate, the trends of higher values were found on film D-940 because it is more permeable to water vapor.

Total sugars have been reported to increase as blackberry and blueberry fruits ripen (Kushman and Ballinger, 1968). Results of this study showed different SSC among stages of maturity in blackberries, averaging 9.4% for unripe, 10.9 % for ripe and 12.4% for overripe, but few changes were found after the storage period. 'Chester' was an exception, as all three stages of maturity had almost the same SSC. This further implies that this cultivar may have been at an earlier stage of ripeness than the others. Similar to the results found by Kenny (1979) on strawberries, SSC of blackberries in this study remained unaltered during the storage period.

Ballinger et al (1970) reported that anthocyanins increase as berry fruits ripen. From this experiment different concentrations of pigment were found between stages of maturity. Additionally, anthocyanins increased in all cases during storage. If fruits of 'Cherokee' and 'Chester' are picked at an early stage of maturity (M1), only a small increase in anthocyanin could be expected, (about 12 mg/100 g); compared to almost a 60% increase developed by the ripe stages (M2). On the other hand, fruits of 'Shawnee' of the unripe stage seem to be able to increase the amount of pigment by two fold, but only slight increases after storage could be expected from the ripe and overripe stages.

As reported by Lee et al (1970) and Wrolstad et al (1980), glucose and fructose were the main sugars found in blackberries. Only small amounts of sucrose were detected. Ripening usually brings about an increase in sugars which give sweetness, a decrease in organic acids and phenolics, and increase in volatile emanations to give the characteristic flavor of a fruit (Mattoo et al, 1975). In this study, sugars were found to increase as fruit ripen, and the greatest changes were found for glucose in

'Chester' and 'Shawnee', and for fructose in 'Cherokee'.

The general trend of changes during storage is an initial increase in sugars followed by a decrease (Biale, 1960). In non-climacteric fruits, changes are slight and slow. In our study both glucose and fructose decreased after storage, with the most significant changes in 'Chester' and 'Shawnee' for fructose and 'Cherokee' and 'Shawnee' for glucose.

Citric is the main acid in the majority of soft fruits (Kushman and Ballinger, 1968) except for blackberries where isocitric is predominant (Wrolstad et al, 1980). Our HPLC methodology did not resolve isocitric from citric. Therefore we report it as (iso)citric. Malic acid has the second highest concentration in most berries. Both acids decreased in blackberries during storage but the decrease in malic was greater. The reduction in acidity in small fruits has been reported before by Varseveld and Richardson (1980) and Nelson (1925), among others.

Both acids were high in early and ripe fruit (M1) and decreased in more advanced stages of maturity (M2 and M3). Rohrer and Luh, cited by Green (1970) determined the acids in developing boysenberries and found a decrease in total tritrable acidity as the fruit developed . In their study the proportion of malic decreased from 17.9% of the total acid in unripe fruit to 8.3% when the fruit was overripe. The higher amounts of acid in early and mature ripe fruits of 'Chester' might help to explain the higher resistance of these stages to mold infection. There is evidence that proportions of different acids change with ripening (Jennings, 1988) and a decrease in acidity is usually due to a decrease in citric acid.

Table III.1: Mold incidence of blackberry varieties after 8 days in storage at 0°C, (First harvest date).

Cultivar	Mold incidence (%)
Marion	1.6 a
Logan	27.6 b
Boysen	27.6 b
1466	33.1 b

Means followed by same letter are not different, FPLSD, p=0.05, (n=6).

Table III.2: Mold incidence of blackberry varieties after 8 days in storage at 0°C (Second Harvest).

Cultivar	Mold Incidence (%)
Kotata	7.2 a
Waldo	9.5 ab
Silvan	13.5 bc
Olallie	19.2 c

Means followed by the same letter are not different, FPLSD, p=0.05, (n=6).

Table III.3: Sensory evaluation of blackberry cultivars after refrigerated storage, (first harvest date).

Attribute	Logan	Boysen	Marion	1466	SE
Glossiness	2.7a	5.0b	10.0c	11.7d	0.4
Color	1.6a	6.4b	11.3c	12.5d	0.4
Shrivel	8.2b	4.8a	3.8a	3.2a	0.7
Sweetness	5.3a	6.9ab	8.4bc	8.6c	0.6
Sourness	5.2ab	6.4b	6.2b	3.5a	0.8
Fruity Flavor	3.8a	6.2b	11.0c	7.6b	0.6
Firmness	2.5a	5.7b	7.0b	9.8c	0.6
Juiciness	6.9a	11.7b	10.2b	6.7b	0.6
Overall Quality	2.8a	7.2b	10.5c	8.4c	0.7

Means within a row followed by the same letter are not different, FPLSD p=0.05. Response range for each attribute was from 0 to 15, (n=24 for each treatment mean).

Table III.4: Sensory evaluation of blackberry cultivars, after refrigerated storage, (second harvest date).

Attribute	Waldo	Silvan	Kotata	Olallie	SE
Glossiness	8.9b	6.2a	6.3a	7.6ab	0.7
Color	9.7a	10.1a	12.4b	10.8a	0.5
Shrivel	4.5a	6.1a	5.3 a	5.6a	0.6
Sweetness	5.9a	7.5ab	6.1ab	8.0b	0.7
Sourness	7.9b	5.2a	5.4ab	5.6ab	0.9
Fruity Flavor	7.9a	6.8a	6.8a	7.7a	0.7
Firmness	10.3c	5.0a	8.1b	7.0a	0.7
Juiciness	6.5a	9.6b	9.0b	10.3b	0.5
Overall Quality	7.9a	7.3a	7.8a	7.4a	0.6

Means within a row followed by the same letter are not different, p=0.05. Response range for each attribute was 0 to 15.(n=24 for each treatment mean).

Table III.5: Regression analyses on overall quality (OAQ) of blackberry fruits, experiment 1, (n=180).

Dependent Variable		Independent Variable and Coefficient	r^2
OAQ	=	0.945 (Fruity flavor intensity)	0.82
OAQ	=	0.664 (Fruity flavor intensity) + 0.273 (Juiciness)	0.85
OAQ	=	0.519 (Fruity flavor intensity) + 0.203 (Juiciness) + 0.274 (Firmness)	0.86
OAQ	=	0.478 (Fruity flavor intensity) + 0.143 (Juiciness) + 0.236 (Firmness) + 0.161 (Sweetness)	0.87

Table III.6: Mold incidence of 'Waldo' and 'Kotata' blackberries after 9 days of storage at 0°C with modified atmosphere packaging. (First and second Harvest).

Film	Treatment	Mold (%) First Harvest	Mold (%) Second Harvest
No film		7.4 a	5.7 a
D-940	Loose	27.8 b	17.7 b
D-940	Heat Shrunk	31.4 bc	18.3 b
D-955	Loose	36.2 bc	21.6 b
D-955	Heat Shrunk	37.3 c	22.6 b

Means followed by the same letter are not different FPLSD, p=0.05 (n=6).

Table III.7: Mold incidence of blackberries after 9 days in 0°C storage, (First harvest).

Cultivar	Mold (%)
Kotata	14.8 a
Waldo	40.9 b

Means followed by the same letter are not different, FPLSD, p=0.05 (n=15).

Table III.8: Weight loss of blackberries stored for 9 days at 0° with modified atmosphere packaging. (First and Second Harvest).

Packaging	Treatment	Weight Loss (%) First Harvest	Weight Loss (%) Second Harvest
D-940	Heat -Shrunk	0.8 a	0.2 a
D-940	Loose	0.9 ab	0.2 a
D-955	Loose	1.1 bc	0.2 a
D-955	Heat -Shrunk	1.1 c	0.2 a
No Film		3.2 d	3.6 b

Means within a column followed by the same letter are not different, FPLSD, p=0.05

Table III.9: Sensory evaluation of MAP film packaged 'Waldo' and 'Kotata' blackberries after 10 days, 0°C. (First harvest)

Attribute	Variety				
	Kotata940	Kotata955	Waldo940	Waldo955	SE
Glossiness	8.1ab	7.7a	9.7b	9.6	0.6
Color	11.1b	11.5b	8.4a	8.5a	0.4
Shrivel	4.5a	4.6a	6.2b	5.0ab	0.5
Sweetness	7.7a	7.5a	8.9a	7.0a	0.8
Sourness	5.1a	5.0a	5.7a	8.4b	0.8
Fruity Flavor	5.8a	6.1a	8.8b	9.3b	0.7
Firmness	6.3a	6.5a	10.9b	10.8b	0.5
Juiciness	8.9c	8.9bc	7.2ab	7.0a	0.6
Overall Quality	7.1a	6.5a	8.3a	7.3a	0.8

Means within a row followed by the same letter are not different, p=0.05. Evaluation scale range 0 to 15, n=24 for each treatment mean.

Table III.10: Sensory evaluation of MAP film packaged 'Waldo' and 'Kotata' blackberries after 10 days 0°C. (Second Harvest)

Attribute	Treatments				
	Kotata940	Kotata955	Waldo940	Waldo955	SE
Glossiness	4.4 a	4.5 a	10.8 b	11.2 b	.4
Color	11.0 b	10.4 b	6.0 a	5.6 a	.5
Shrivel	5.7 ab	6.3 b	4.2 a	5.3 a	.6
Sweetness	9.9 b	7.8 ab	7.5 a	6.9 a	.8
Sourness	4.8 a	6.0 a	10.4 c	8.0 b	.8
Fruity Flavor	7.0 a	6.6 a	9.3 b	9.3 b	.7
Firmness	6.1 a	7.1 a	10.5 b	9.7 b	.6
Juiciness	9.9 b	9.5 b	7.2 a	8.3 ab	.7
Overall Quality	7.5 a	8.4 a	9.5 a	7.6 a	.8

Means within a row followed by the same letter are not different, p=0.05. Ranking scale 0-15. (n=24 for each treatment).

Table III.11: Correlation (r^2) of blackberry overall quality with individual quality factors (Experiment 2, n=160).

Dependent Variable		Independent Variable	r^2
OAQ	=	0.910 (fruity flavor intensity)	0.81
OAQ	=	0.534 (fruity flavor intensity)+ 0.419 (juiciness)	0.87
OAQ	=	0.449 (fruity flavor intensity)+ 0.325 (juiciness)+ 0.189 (sweetness)	0.88
OAQ	=	0.357 (fruity flavor intensity)+ 0.282 (juiciness)+ 0.191 (sweetness)+ 0.137 (glossiness)	0.88

Table III.12: Effect of film type on decay incidence (%) and weight loss (%) of 'Cherokee' blackberries after 9 days 0° or 5°C storage

Film type	Decay (%)	Weight Loss(%)
D-940	31.7 a	0.3 a
D-955	38.5 b	0.2 b

Means within a column followed by the same letter are not significant, FPLSD, p=0.05 (n=6 for each treatment)

Table III.13: Effect of storage temperature on decay incidence and weight loss of 'Cherokee' blackberries under modified atmosphere packaging after 9 days.

Temperature	Decay (%)	Weight Loss(%)
0 °C	22.6 a	0.12 a
5 °C	47.5 b	0.32 b

Means within a column followed by the same letter are not different, FPLSD, p=0.05 (n= 6 for each treatment).

Table III.14: Sensory evaluation of MAP 'Cherokee' blackberries after 10 days at 0 or 5°C.

Attribute	D-940 0°C	D-955 0°C	D-940 5°C	D-955 5°C	SE
Glossiness	8.8 b	8.1 ab	7.0 a	7.6 ab	0.5
Color	7.9 a	8.2 a	8.5 a	9.3 b	0.5
Shriveling	5.7 ab	5.4 a	7.5 c	7.1 bc	0.6
Sweetness	5.8 a	5.9 a	6.5 a	5.9 a	0.7
Sourness	8.4 a	8.0 a	8.8 a	8.9 a	0.6
Flavor Int	6.2 a	6.1 a	5.9 a	6.7 a	0.7
Firmness	8.9 a	8.7 a	8.6 a	9.9 a	0.6
Juiciness	8.9 b	6.8 a	9.0 b	6.4 a	0.6
Overall Qual	5.8 a	5.7 ab	6.2 a	4.9 b	0.6

Means within a row followed by the same letter are not different, p=0.05 (n=24 for each treatment mean).

Table III.15 : Correlation (r^2) of 'Cherokee' overall quality with individual quality factors (n=72). Stored at 0° or 5°C for 9 days.

Dependent Variable		Independent Variable	r^2
OAQ	=	0.828 (sweetness)	0.71
OAQ	=	0.527 (sweetness)+ 0.377 (fruity flavor intensity)	0.77
OAQ	=	0.352 (sweetness)+ 0.225 (fruity flavor intensity)+ 0.273 (juiciness)	0.79

Table III.16: Soluble solids and anthocyanin concentrations of modified atmosphere packaged blackberries under 0° or 5°C refrigerated storage for 9 days.

Time	SSC (%)	ACY(mg/100g)
Initial	10.9	82.7
Final	11.1	75.9
	NS	NS

Table III.17:Effect of film type on mold incidence of 'Shawnee' blackberries after 10 days storage 0°C.

Film type	Decay (%)
D-940	16.9 a
D-955	22.7 b

Means followed by the same letter are not different, FPLSD, $p=0.05$, $(n=6)$.

Table III.18: Anthocyanin concentration (mg/100g)of blackberry varieties with modified atmosphere packaging, before and after 9 days refrigerated storage.

Time	Variety Cherokee	Chester	Shawnee
Before storage	66.8 b	94.5 b	76.6 b
After storage	94.6 a	121.9 a	96.9 a

Means within a column followed by the same letter are not different , FPLSD, p=0.05, (n=6).

Table III.19: Anthocyanin concentrations (mg/100 g) of three maturity stages of blackberry cultivars with modified atmosphere packaging in refrigerated storage

Maturity stage	Variety Cherokee	Chester	Shawnee
M 1	50.2 b	67.0 c	48.2 c
M 2	92.9 a	114.5 b	93.0 b
M 3	98.8 a	143.3 a	119.1 a

Means within a column followed by the same letter are not different, FPLSD, p=0.05, (n=3).

Date_______

Please answer the questions about the 4 coded blackberry samples, by making a mark on the horizontal line corresponding to the amount of perceived attribute. Then place the code number above it. If two samples appear to be equal, place both code numbers above the same mark.

APPEARANCE Please observe the samples and rate appearance in each one

Glossiness

Very dull ____ Very glossy

Color

Red ____ Black

Shrivel

None ____ Extreme

FLAVOR Please taste the samples and rate all of them for each of the following attributes

Sweetness

None ____ Very

Sourness

None ____ Very

Fruity flavor intensity

Very weak ____ Very strong

Firmness

None ____ Very

Juiciness

None ____ Very

How do you feel about the **Overall quality** of the samples?

Dislike ____ Like

Fig. III.1: Line scale ballot used for sensory evaluation of blackberry fruits. (Scale 0-15).

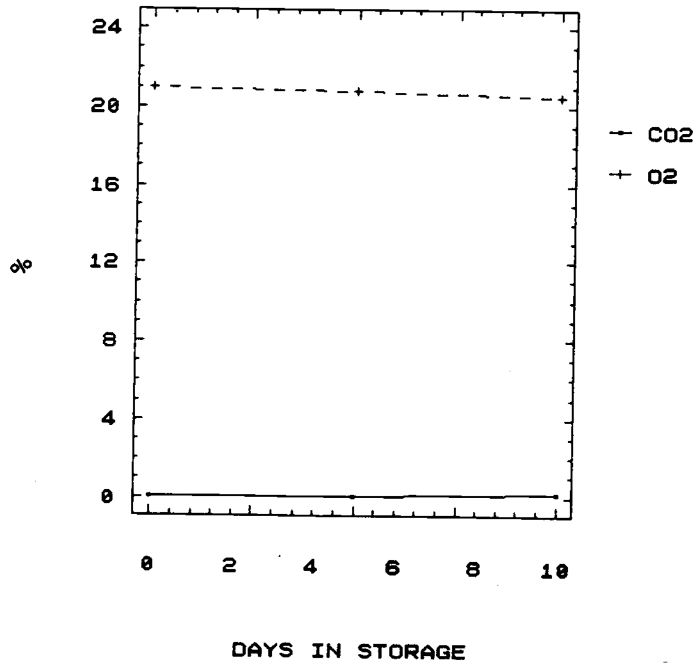


Fig. III.2: CO_2 and O_2 concentrations of poorly sealed film wrapped 'Kotata' blackberries held for 10 days at 0°C.

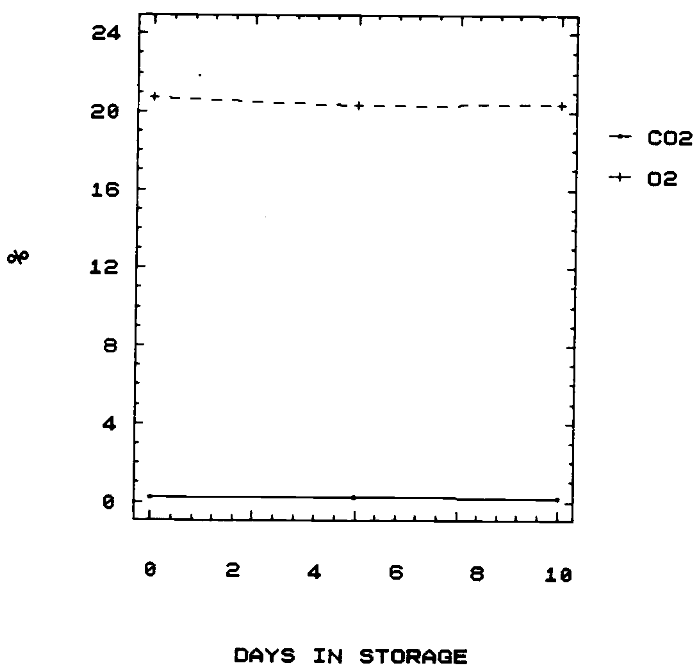


Fig. III.3: CO_2 and O_2 concentrations of poorly sealed film wrapped 'Waldo' blackberries held for 10 days at 0°C.

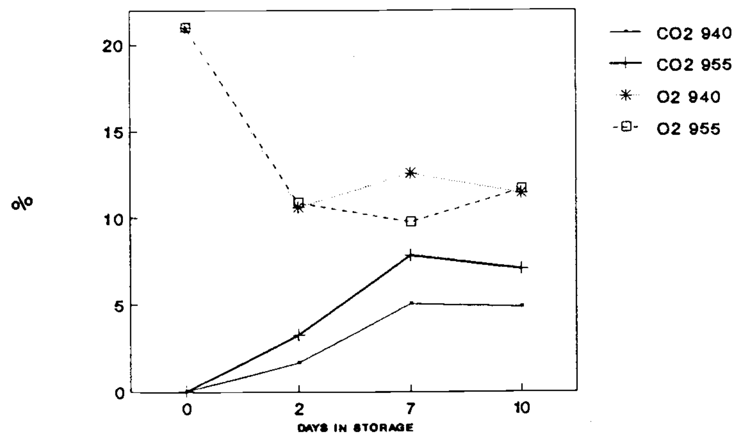


Fig. III.4: CO_2 and O_2 concentrations of film wrapped 'Cherokee' blackberries held for 10 days at 0°C.

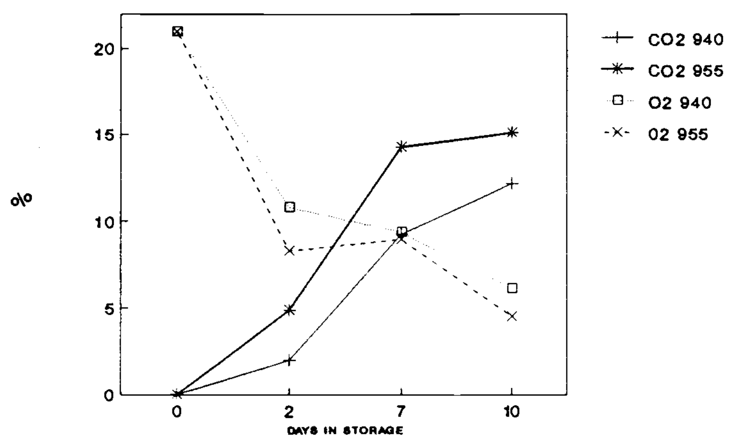


Fig. III.5: CO_2 and O_2 concentrations of film wrapped 'Cherokee' blackberries held for 10 days at 5°C.

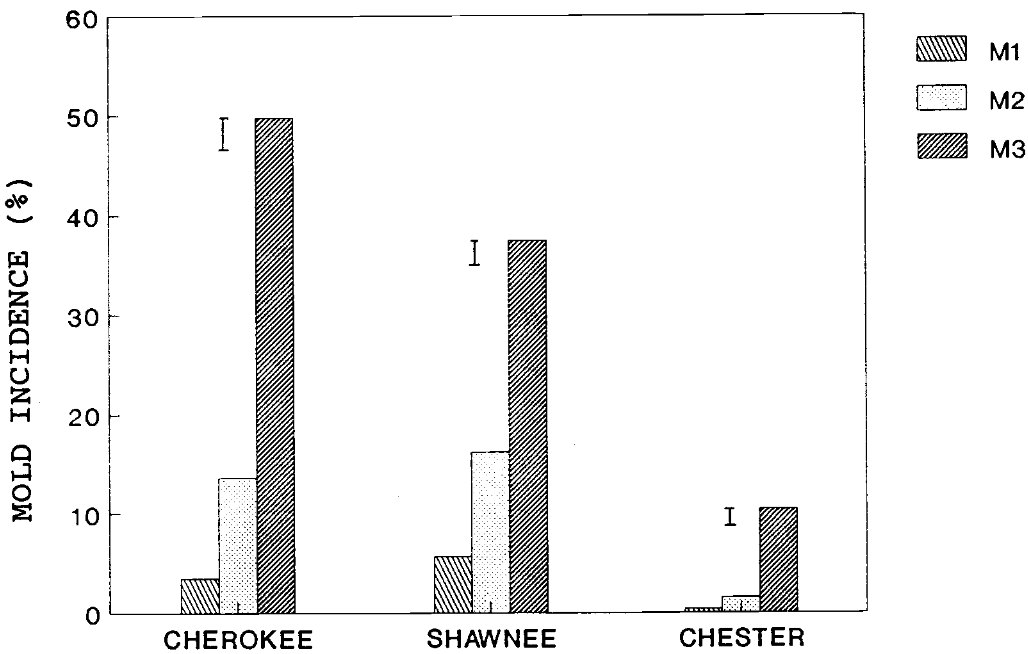


Fig. III.6: Effects maturity stages of 3 blackberry varieties on mold incidence after 9 days 0°C storage.

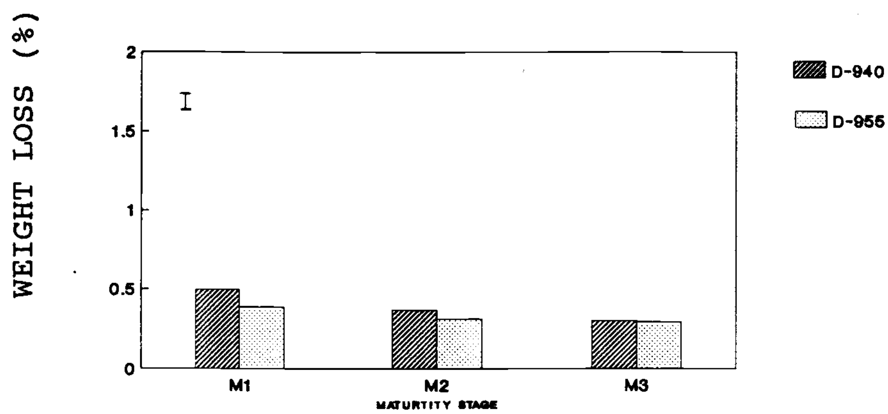


Fig. III.7: Weight loss of 'Chester' blackberries at 3 maturity stages, packed in 2 films, after 9 days at 0°C.

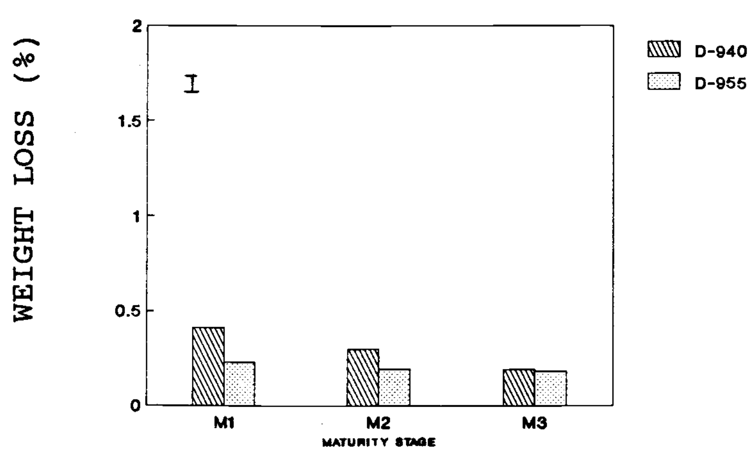


Fig. III.8: Weight loss of 'Cherokee' blackberries at 3 maturity stages, packed in 2 films, after 9 days at 0°C.

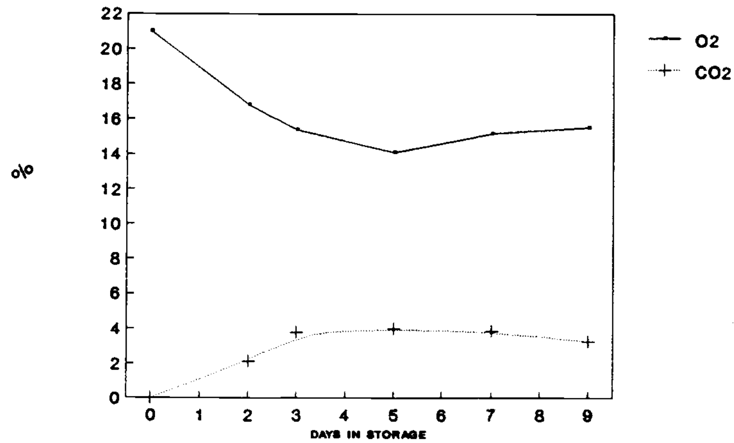


Fig. III.9: CO_2 and O_2 composition of 'Chester' blackberries packaged with film D-955, for 9 days at 0°C.

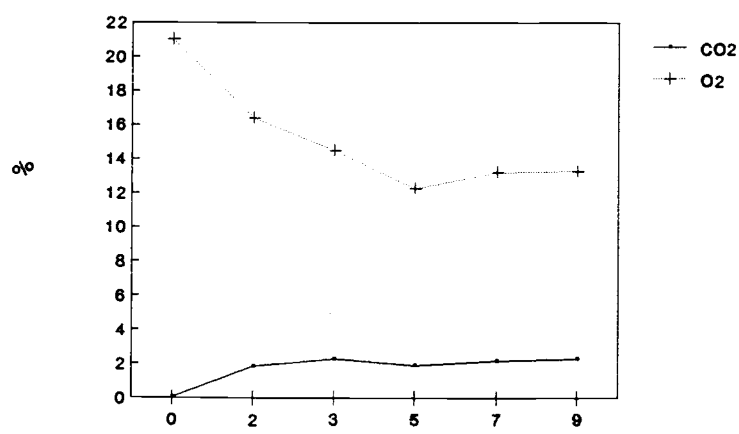


Fig. III.10: CO_2 and O_2 composition of 3 MAP- sealed blackberry varieties at a mature ripe stage, 9 days at 0°C.

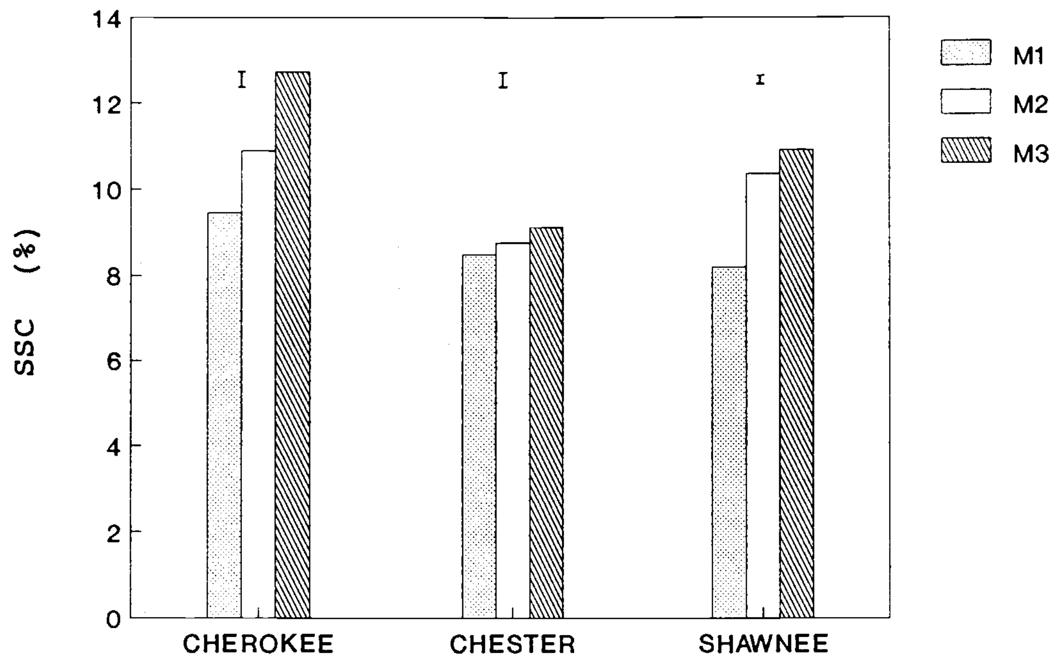


Fig. III.11: Soluble solids contents (SSC) of 3 blackberry cultivars at 3 stages of maturity, stored for 9 days at 0°C.

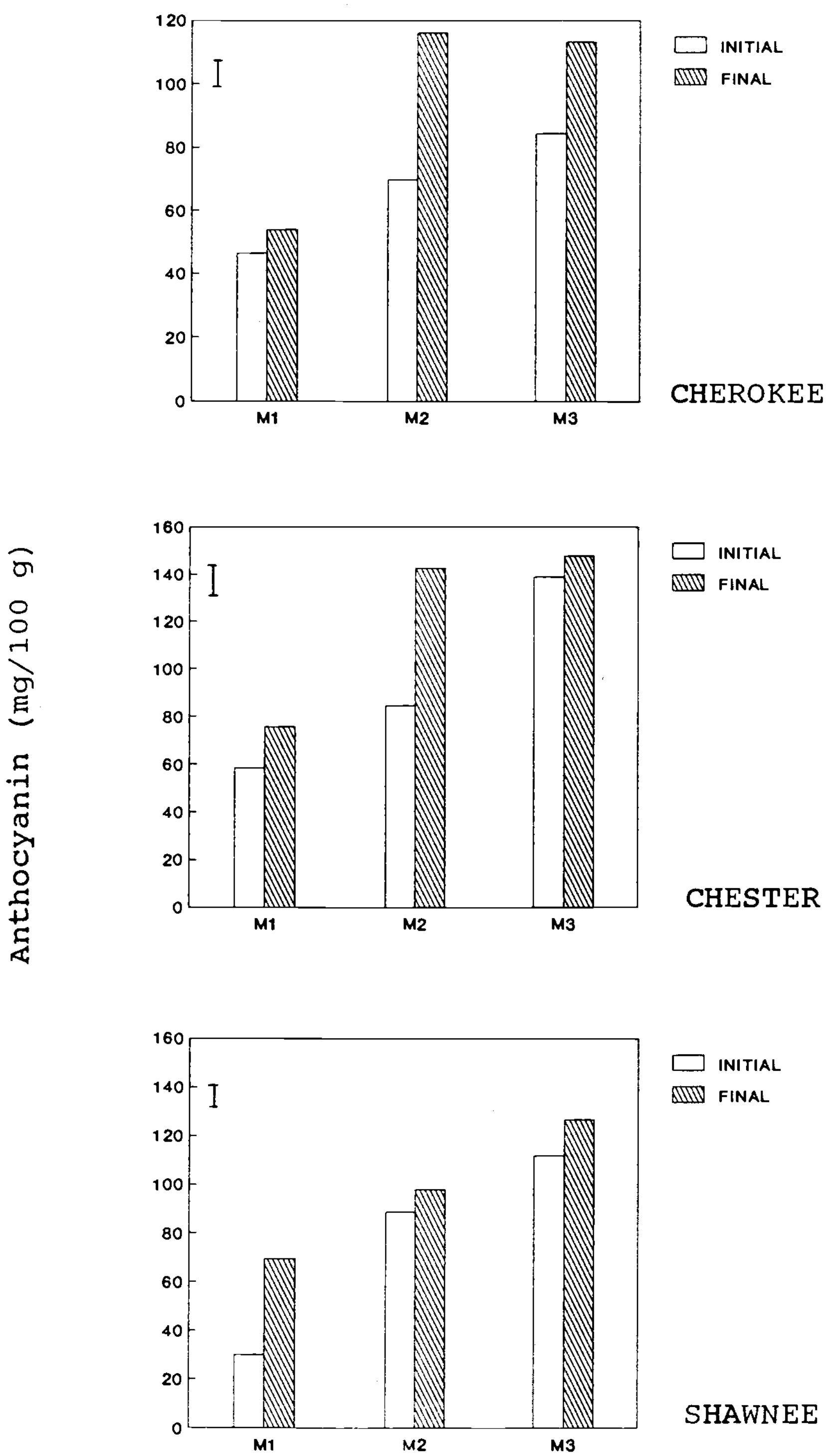


Fig. III.12: Anthocyanin concentrations of 'Cherokee', 'Chester' and 'Shawnee' blackberries on 3 maturity stages before and after 9 days 0°C.

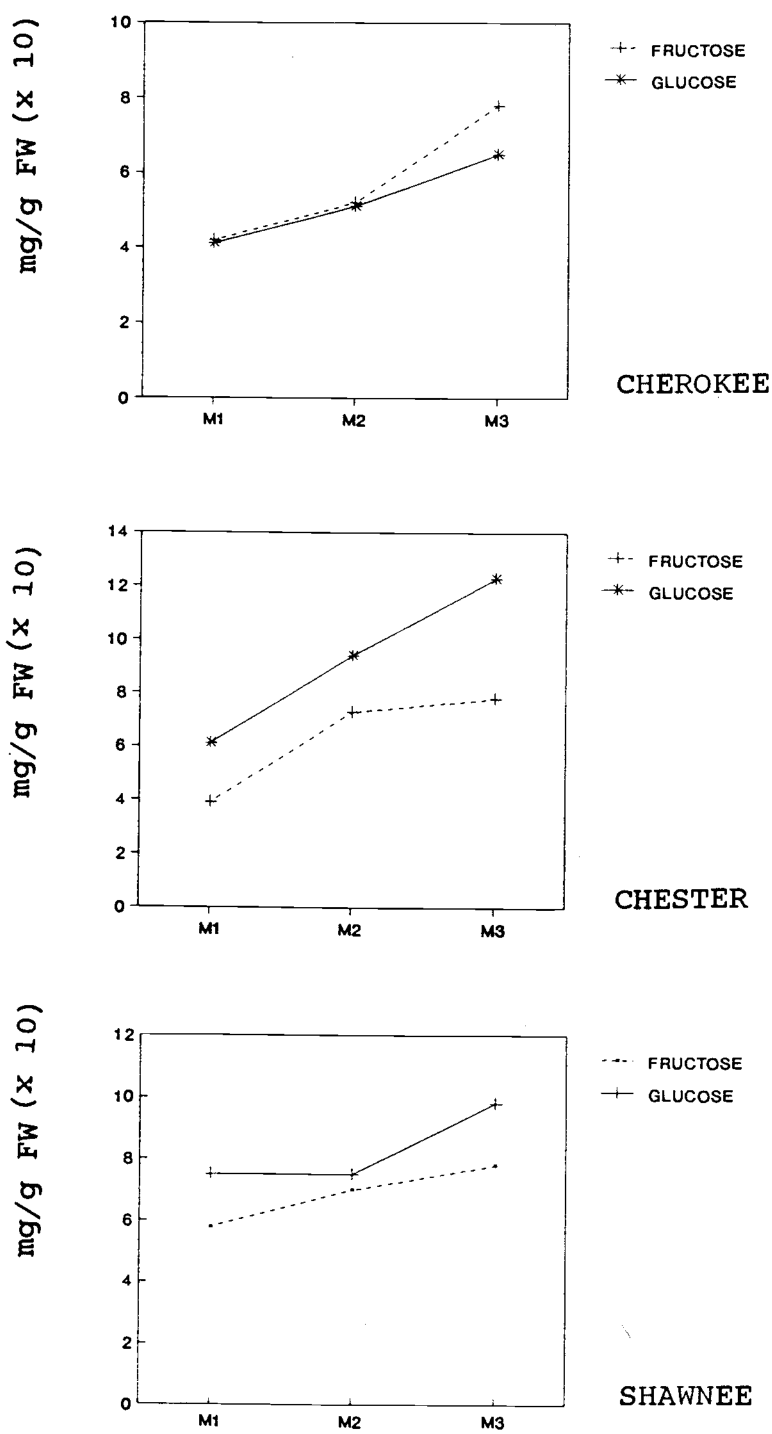
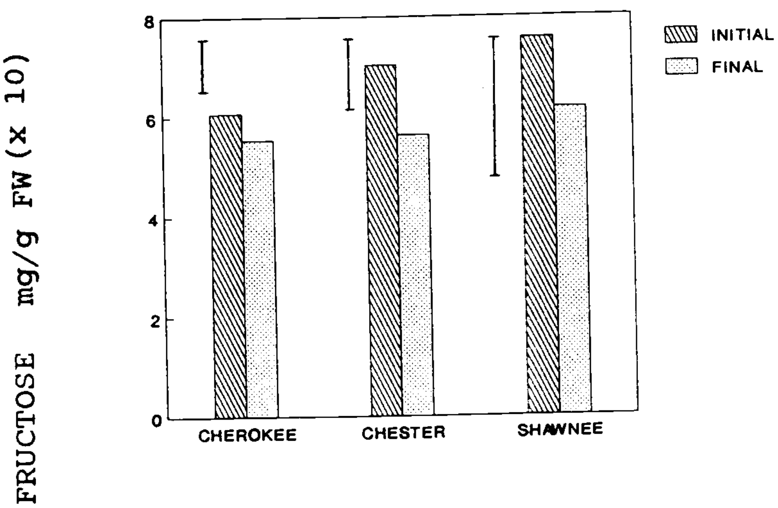


Fig. III.13: Effects of maturity stage on fructose and glucose content of 'Cherokee', 'Chester' and 'Shawnee' blackberries, stored for 9 days at 0°C.



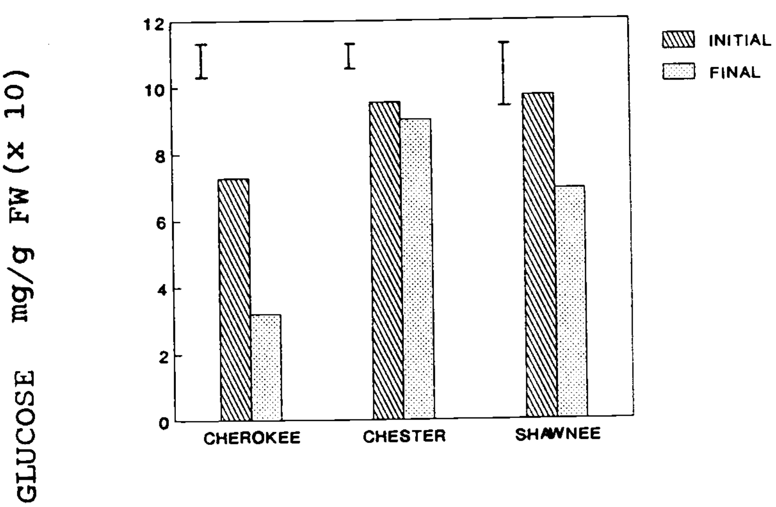


Fig. III.14: Fructose and glucose concentrations of blackberry fruits before and after 9 days at 0°C.

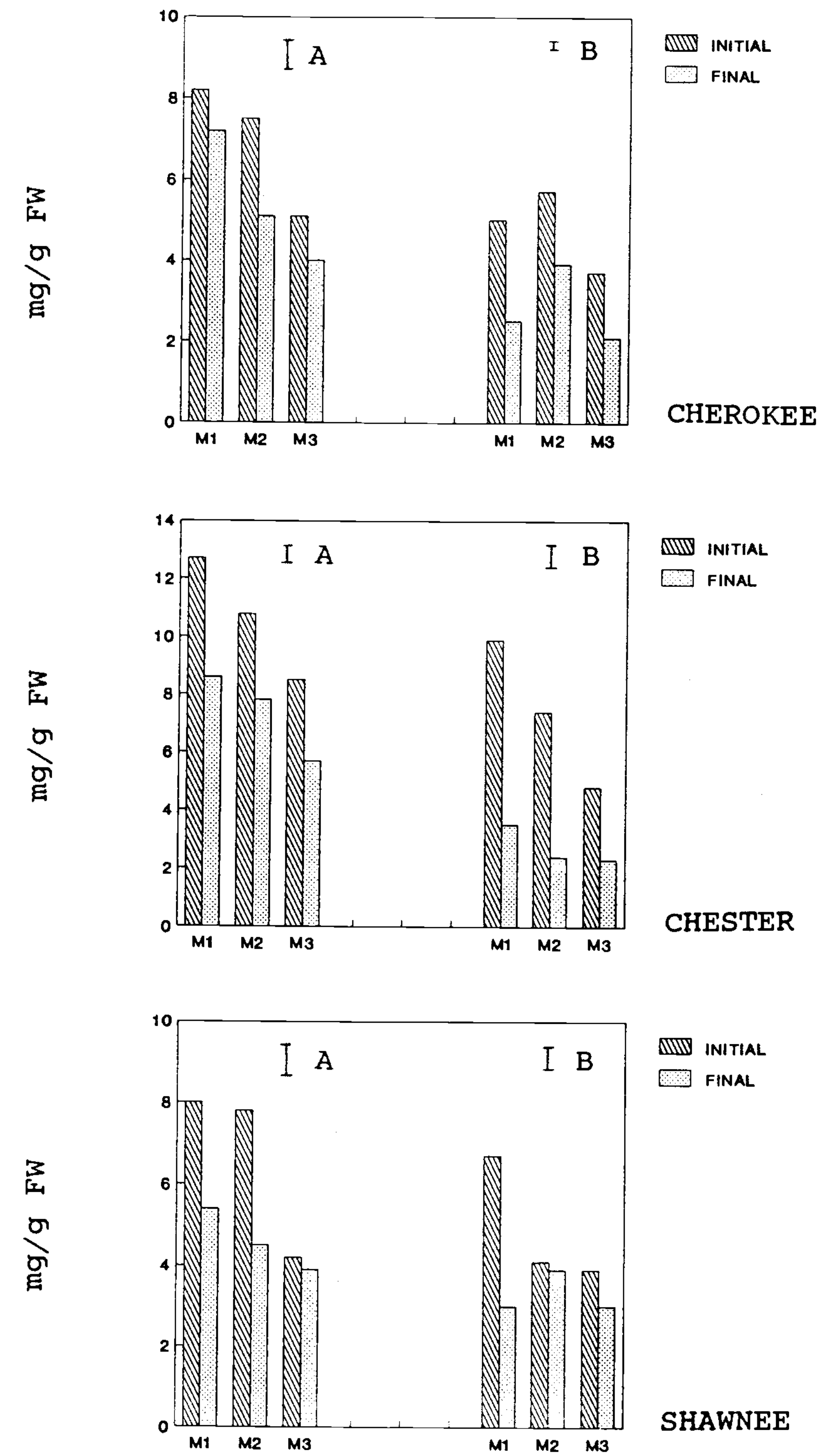


Fig. III.15: (Iso)citric (A) and Malic (B) concentrations of 'Cherokee', 'Chester' and 'Shawnee'blackberries before and after storage, 9 days 0°C.

LITERATURE CITED

Ahmedullah, M., M.E. Patterson, and G.W. Apel. 1989. Modified atmosphere packaging of blueberries (Vaccinium corymbosum). In J.K. Fellman (ed). Fifth Proc. Internat. Controlled Atmosphere Res. Conf. Vol 2, Wenatchee, WA.

Arthey, V.D. 1975. Quality of Horticultural Products. John Wiley & Sons, New York, Toronto, 228p.

Ballinger, W.E., E.P. Maness, and W.F. McClure, 1978. Relationship of stage of ripeness and holding temperature to decay development of blueberries. J. Amer. Soc. Hort. Sci. 103(1):130-134.

Ballinger, W.E., E.P. Maness, and L.J. Kushman. 1970. Anthocyanin in the Ripe Fruit of Highbush Blueberry, Vaccinium corymbosum J. Amer. Soc. Hort. Sci. 95(3):283-285.

Ballinger, W.E., and L.J. Kushman. 1970. Relationship of ripeness to composition and keeping quality of highbush blueberries. J. Amer. Soc. Hort. Sci. 95(3): 239-242.

Ben-Yehoshua, S. 1985. Individual seal-packaging of fruits and vegetables in plastic films - A new postharvest technique. HortScience. 20(1):32-37.

Biale, J.B. 1960. Respiration of fruits. Encyc. Pl. Physiol. 12:536-592.

Green, G. 1970. Soft fruits. In A.C. Hulme (ed). The Biochemistry of Fruits and Their Products. Vol 2, Academic Press, London, New York, 788p. 375-407.

Hall, C.W., R.E. Hardenburg, and E.B. Pantastico. 1975. Principles of Packaging: Consumer Packaging with plastics. In E.B. Pantastico (ed). Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. The AVI Publ. Co., Inc. Westport, Conneticut.

Hardenburg, R.E., A.E. Watada, and C.Y. Yang. 1986. The Commercial Storage of Fruits Vegetables and Florist and Nursery Stock. USDA Agr. Handb. 66, 136p.

Hruschka, H.W., and L.J. Kushman. 1963. Storage and shelf-life of packaged blueberries. USDA. Agr. Mkt. Serv. 612, 16p.

Jennings, D.L. 1988. Raspberries and Blackberries: Their

Breeding, Disease and Growth. Academic Press, London, Boston, New York, 203p.

Kader, A.A., D. Zagory, and E.L. Kerbel. 1989. Modified atmosphere packaging of fruits and vegetables. Crit. Rev. Food Sci. Nutr. 12:1-30.

Kader, A.A. 1985. Postharvest biology and technology: An overview. In A.A. Kader, R.F. Kasmire, F.G. Mitchell, M.S. Reid, N.F. Sommer and J.F. Thompson (eds). Postharvest Technology of Horticultural Crops. Univ. Calif. Coop. Ext. Pub. N#3311:3-7.

Kushman, L.J., and W.E. Ballinger, 1968. Acid and sugar changes during ripening in Walcott blueberries. Proc. Amer. Soc. Hort. Sci. 92:290-295.

Lee, C.Y., R.S. Shallenberg, and M.T. Vittum. 1970. Free Sugars in Fruits and Vegetables. New York's Food and Life Sciences. Bulletin No.1, Geneva, NY.

Mannaperuma, J.D., D.Zagory,R.P. Singh, and A.A. Kader. 1989. p225-233. In J.K. Fellman (ed). Fifth Proc. Internat. Controlled Atmosphere. Res. Conf. Vol 2. Wenatchee, Wa.

Mattoo, A.K., T. Murata, and E.B. Pantastico. 1975. Chemical changes during ripening and senescence. In E.B. Pantastico. Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. The AVI Pub. Co. Inc. Westport, Conneticut.

McGlasson, W.B. 1989. MA a Practical alternative to CA Shipping containers. p 235-240. In J.K. Fellman. (ed). Fifth Proc. Internat. Controlled Atmosphere Res. Conf. Vol. 2. Wenatchee, Wa.

Meilgaard, M., G.V. Civille, and B.T. Carr. 1987. Sensory Evaluation Techniques. CRC Press, Inc. Boca Raton, Florida. 286p.

Miller, W.R., Davis, A.Down, and A.J. Bongers. 1983. Quality of strawberries packed in different consumer units and stored under simulated air-freight shipping conditions. HortScience 18(3):310-312.

Mitchell,F,G. 1985.Cooling horticultural commodities. In A.A. Kader, R.F. Kasmire, F.G. Mitchell, M.S. Reid, N.F. Sommer, and J.F. Thompson (eds). Postharvest Technology of Horticultural Crops. Univ. Calif. Coop. Ext. Pub 3311: 35-43.

Pantastico, E.B., H. Subramanyam, M.B. Bhatti, N. Ali, and E.K. Akamine. 1975. Harvest indices p56-74. In E.B.

Pantastico. Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. The AVI Pub. Co., Inc. Westport, Conn.

Petersen, R.G. 1985. Design and Analysis of Experiments. Marcel Dekker, Inc. New York and Basel, 429p.

Powrie, W.D., B.J. Skura, and C.H. Wu. 1987. Modified atmosphere packaging, an application of postharvest technology. Agrologist. Summer:20-21.

Richardson, D.G. 1988. Fresh marketing berry crops. Proc. 102nd. Ann. Meet. Oregon Hort. Soc. 79:204-206.

Robinson, J.E., K.M.Browne, and W.G. Burton. 1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol. 81:399-408.

Ryall, A.L., and W.T.Pentzer. 1974. Handling, Transportation and Storage of Fruits and Vegetables. Vol.2. Fruits and Tree Nuts. The AVI Pub. Co. Inc. Westport, Conn. 454p

Salunkhe, D.K., and B.B. Desai. 1984. Postharvest Biotechnology of Fruits, Vol.I. CRC Press, Inc. Boca Raton, Florida. 168p.

SAS Institute. 1985. SAS user's guide. Statistics, Version 5. SAS Institute, Inc., Cary, NC.

Sjulin, T.M., and J.A. Robbins. 1987. Effects of maturity, harvest date and storage time on postharvest quality of red raspberry fruit. J. Amer. Soc. Hort. Sci. 112(3):481-487.

Smith, S., J. Geeson, and J. Stow. 1987. Production of Modified Atmosphere in deciduous fruits by the use of films and coatings. HortScience 22(5):772-776.

Sommer, N.F. 1985. Role of controlled environments in suppression of postharvest diseases. Plt. Pathol. 7:331-339.

STATGRAPHICS. 1988. User's guide system. Statistics, Version 4. STSC, Inc., Rockville, MD.

Varseveld, G.W., and D.G. Richardson. 1980. Evaluation of storage and processing quality of mechanically and hand harvested Rubus spp. fruits. ActaHort. 112:265-272.

Wrolstad, R.E., J.D. Culbertson, D.A. Nagaki, and C.F. Madero. 1980. Sugars and nonvolatile acids of blackberries. J. Agric. Food Chem. 28:553-558.

CHAPTER IV

ORGANOLEPTIC AND CHEMICAL COMPOSITION OF BLUEBERRIES AS INFLUENCED BY CULTIVAR, STORAGE TEMPERATURE AND CONTAINER SIZE

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Additional index words: _Vaccinium corymbosum_, sensory evaluation, sugars, organic acids, anthocyanins

ABSTRACT

Fruits of 'Earliblue', 'Bluejay', 'Bluecrop', 'Berkeley', 'Patriot', 'Elliott' and 'Jersey' harvested on two different dates (early and late harvest), were evaluated for suitability in long term storage. Fruits stored 15 days at 0°C in commercial 1/2 pint hallocks developed 50% less rot than those in 1 pint hallocks. Likewise, fruit stored at 0°C for 15 days showed considerably less mold incidence (about 14%) and less weight loss (about 1.5%) compared to fruit stored at 5°C. Differences in susceptibility to rot were found between cultivars. Soluble solids (SSC) showed no change over storage time for early season blueberries and a slight increase for the late varieties. Glucose and fructose were the main sugars found in blueberries and they decreased during storage, especially glucose. Cultivars differed for

sugars, organic acids and anthocyanins tested. Sensory evaluations of blueberry varieties were carried out for the two harvest dates. Regression analyses of the data identified juiciness and fruity flavor intensity as the main factors influencing overall quality and consumer acceptance. From this study 'Patriot (early cultivar), 'Bluecrop' (mid-season cultivar) and 'Jersey' (late) showed promising qualities for fresh market.

INTRODUCTION

A large number of blueberry cultivars are available for fresh market or U-pick operations, and it is an advantage for a grower to choose several varieties in order to offer a succession of ripening (Eck et al, 1990).

Blueberries can be stored in good condition at -0.5 to 0 °C with high relative humidity (90-95%) for about 2 weeks (Salunkhe and Desai, 1984; Hardenburg et al, 1986). Stage of maturity also has a great effect on shelf life and quality components (Sjulin and Robbins, 1987). Blueberries harvested immediately after obtaining a blue skin color, have been shown to store more satisfactorily than riper stages (Bunemann et al, 1957). Overripe blueberries have greatly increased mold incidence even at low temperatures (Ballinger et al, 1978). While resistance to rot and long storability are very important, other quality characteristics and chemical components must be considered in selecting fresh market cultivars.

Color is the quality that contributes the most to the appearance of horticultural quality and it is highly influenced by cultivar and maturity (Arthey, 1975). Color expression in blueberries is due both to the amount of wax on their surfaces and the anthocyanin content, both of which usually increase as the fruits ripen (Ballinger et al, 1970; Ballinger et al, 1979; Sapers et al, 1984).

A small and dry stem scar is desirable to avoid shriveling and fungal infection (Eck, 1966). Studies have shown that decay was 6 to 10 times more prevalent on stemless berries than on fruit with attached stems (Ceponis and Cappellini, 1978; Smittle and Miller, 1988).

All blueberries used in these experiments were obtained from a commercial field near Salem, Oregon in July and August of 1989. Fruits that were full blue and still firm were hand-picked and the study was divided into early and late experiments.

MATERIALS AND METHODS

a. EXPERIMENT 1 - EARLY-MIDSEASON VARIETIES

This experiment was conducted to determine the effect of cultivar and container size on the storage life of blueberries fruiting in early to mid-season harvest.

Fruits of 'Earliblue', 'Bluejay', 'Bluecrop', 'Berkeley' and 'Patriot' were hand picked early morning into 1 pint (0.47 liter) unwaxed ventilated pulpboard hallocks (10 x 10 x 7.2 cm high) or 1/2 pint (0.23 liter) hallocks (10 x 10 x 3.4 cm high) and placed into commercial shipping flats (44 x 33 x 8.5 cm high). Each flat held six 1/2 pint and six 1 pint containers of each variety.

Fruits were transported to the laboratory within 1 hour, weighed, and stored for 15 days at 5 °C, 95 % relative humidity to simulate handling and transit temperatures. The flats containing the fruits in hallocks were covered with large plastic sleeves to prevent water loss.

After storage, weight loss and decay were recorded for the six replicates of each treatment. For decay assessment, all berries in each container were examined and any evidence of mold (hyphae at the stem scar, leaker and/or very soft berries) was counted as a rotten berry. Decay and weight loss were estimated as percentages.

Before and after storage, fruits of 'Earliblue', 'Patriot' and 'Bluecrop' (about 50 g) were taken at random from 1/2 pint containers and frozen at -20 °C for chemical analyses. Similar procedures as those explained for blackberries (Chapter III) were carried out to determine soluble solids, anthocyanins, and sugars at the beginning and end of storage. The statistical analysis utilized a completely randomized Split-plot design, with 3 replicates in each treatment. Varieties were used as main plots and storage time (initial and final), as subplots. The SAS Statistical software was used for the computer analyses.

Finally, a taste panel 16 untrained panelists)was conducted using all 5 cultivars packaged in 1/2 pint hallocks , at the end of the storage period . A line scaling test was used, but in this case the experiment was carried out as an incomplete randomized block design, where only 4 out of the 5 cultivars (coded and randomized) were presented to the judges at the same time. The 5 possible combinations of 4 out of 5 were replicated 5 times in order to get 16 panelists tasting each treatment. Each judge was presented with 4 berries of each variety, and they rated the berries for general appearance, flavor (sweetness, sourness, flavor intensity, juiciness), texture and overall quality. The ballot is shown in Figure IV.1.

The marks on the 15 cm line scale were converted to numbers and an analysis of variance carried out. Mean differences were detected by LSD method. Frequency histograms for the different attributes were plotted and linear regression coefficients calculated for overall quality against the individual quality characteristics. The Statgraphics Software Program was used for statistical analysis.

b. EXPERIMENT 2 - LATE SEASON VARIETIES

This experiment aimed to evaluate the effect of cultivar and storage temperature on the shelf-life of fresh blueberries. At mid to late harvest (August 15, 1989) we sampled the following cultivars: 'Earliblue', 'Bluecrop', 'Berkeley', 'Jersey', 'Bluejay', 'Elliott' and 'Patriot'.

Fruits were hand picked and placed into 1 pint hallocks and held in commercial flats containing 12 hallocks each. Two flats were harvested for each variety.

Fruits were transported to the laboratory within two hours of picking, where each hallock was weighed and 1 flat of each stored at 0 °C with 95% relative humidity and the other flat at 5 °C and 95% relative humidity.

Fruits were held for 15 days in cold storage, using large plastic sleeves around the flats to protect them from water loss. Percentage weight loss between the first and last day of evaluation, and percent of decayed berries were obtained from 8 of the 12 hallocks of each treatment. Mold evaluation was done critically, even the slightest evidence of mold was classed as moldy. At times optical magnifiers were used to ascertain mold presence at the stem scar. Virtually all of the mold occurred at the stem scar.

A 50 g sample of fruits from each treatment was selected at random at the beginning and end of the storage period, and frozen at -20 °C for later determination of soluble solids, anthocyanins, sugars and organic acids. For each of the chemical components data was analyzed as a completely randomized Split-plot design with varieties as main plots and storage time (initial and final) as subplots.

Finally, a sensory evaluation of the fruits stored at 0°C was done at the end of the 15 day storage period. Only 5 cultivars were selected, 'Bluecrop', 'Bluejay', 'Elliott', 'Patriot' and 'Jersey'. Both 'Earliblue' and 'Berkeley' were discarded, the first because of high mold incidence and the second because of very poor acceptance in Experiment 1.

The sensory evaluation was also an incomplete block design, where 4 of the 5 cultivars were presented at a time to a judge. Data from the line scale were transformed to numbers and subjected to analysis of variance. Means were separated by LSD method. (Petersen, 1985).

RESULTS

a. EXPERIMENT 1

Decay Incidence

Mold incidence in this experiment was influenced both by container size (1 or 1/2 pint) and variety. Infection on blueberry fruits kept 15 days at 0°C in 1 pint hallocks was 30 % more than blueberries stored in 1/2 pint hallocks (Table IV.1). Varieties differed in percentages of decay at the end of the storage period as shown on Table III.2. After 15 days of storage, 'Bluecrop' had the lowest incidence of mold (16.2%) while 'Earliblue' accounted for the highest with 47.2%. It is worth noting that 'Bluecrop' had the lowest mold incidence (11 and 21%) for both 1 and 1/2 pint hallocks, indicating good possibilities for long term storage.

Soluble Solids Concentrations

Soluble solids concentration was monitored at the beginning and end of 15 days storage on fruits of 'Earliblue', 'Patriot' and 'Bluecrop' kept in 1/2 pint hallocks. Soluble solids did not change during the storage period (no statistical significance, data not shown), but different concentrations were detected between the 3 cultivars (Table IV.2). 'Earliblue' had the highest SSC while no differences were found between 'Bluecrop' and 'Patriot'.

Anthocyanin Concentrations

Anthocyanin concentration was also measured from the same three varieties. Differences in pigments were detected for both varieties and storage time. On average, 'Patriot' and 'Earliblue' accounted for the highest amounts of anthocyanins (136 and 118 mg/100 g respectively), while 'Bluecrop' had least (91 mg/100 g). Regarding storage time, anthocyanin concentrations increased from 91 mg/100g before storage to 124 mg/100g after 15 days storage. Figure IV.2 shows that anthocyanin contents increased with storage time in all three varieties, being most marked for 'Earliblue' (48 units increase), and less, about 26 units for 'Patriot' and 'Bluecrop'. While these anthocyanin increases were not discernible externally, the internal color was increasing.

Sugars

Glucose and fructose were the main sugars found in blueberry cultivars, and only small amounts of sucrose were detected. No significant differences were detected between the three cultivars. Glucose values averaged 158, 186 and 191 mg/g fresh weight for 'Bluecrop', 'Patriot' and 'Earliblue', while fructose contents were 123, 139 and 143 mg/g fresh weight respectively (data not shown).

Although no significant differences were detected between the initial and final period of storage (15 days), a trend of decreasing sugars was found, glucose levels dropped from 180 to 172 mg/g fresh weight, while fructose dropped from 149 to 121 mg/g fresh weight.

Sensory Evaluation

Table IV.3 summarizes the mean values for the different attributes tested in this experiment. All varieties were rated high in general appearance, especially 'Berkeley', 'Bluejay' and 'Bluecrop'. Even though 'Berkeley' and 'Bluejay' obtained high values for appearance, they were rated lowest for sweetness. Furthermore, 'Berkeley' was rated low on all other attributes.

As expected, 'Earliblue' was rated least sour (because of a more advanced stage of ripeness), followed by 'Berkeley'; whereas responses for 'Patriot' and 'Bluejay' showed a normal distribution with the highest values in the middle of the scale.

All the values for flavor ranged very high (from 8.0 to 9.9), except 'Berkeley', whose flavor intensity was found to be extremely poor (5.0), probably because low sweetness and high sourness do not accomplish a good flavor balance.

No statistical differences were found for firmness among varieties, and values were relatively high, although there was a trend for 'Patriot' and 'Bluecrop' to be the firmest. These two varieties also had the best scores for juiciness.

'Patriot' obtained the highest value for overall quality, which agrees with the high values obtained on the rest of the attributes. 'Bluecrop', 'Earliblue' and 'Bluejay' obtained just average values, and 'Berkeley' was rated as very poor quality (5.7), despite having excellent appearance.

Taste panel data of both experiments was pooled in order to estimate composited correlation coefficients for overall quality against the rest of the attributes. We tried to define the terms of multiple regression that would best explain overall quality of blueberry fruits. Table IV.4 shows the different evaluations developed. Juiciness was the first variable included, since it accounted for the highest single correlation (r^2=0.84). Similar to the results found previously for blackberries, when fruity flavor intensity was incorporated in the model, the correlation coefficient increased to 0.88. Only small increases were found if sweetness or sourness were included (r^2=0.89).

b. EXPERIMENT 2

Weight Loss

An interactive effect was found between temperature and cultivar on weight loss of blueberries after 15 days of 0°C storage (Figure IV.3). Moisture losses were generally low ranging from 0.74% ('Jersey' at 0°C) to 2.59% ('Earliblue' at 5°C) and neither 0°C nor 5°C storage temperatures caused weight loss greater than 3%. However, in all cases moisture loss was greater in fruit held at 5°C than those stored at 0°C. 'Berkeley' values of moisture loss did not differ statistically between fruits at 0°C or 5°C. This probably was due to the very large size of 'Berkeley' fruits relative to its surface area to lose moisture.

Decay Incidence

Mold incidence of blueberries was also affected by an interaction between storage temperature and variety. Figure IV.4 clearly shows that lower temperatures suppressed mold growth since fruit held at 5°C developed twice as much fungal infection as those stored at 0°C. The exception was 'Elliott', which developed extremely low decay, both at 0°C and 5°C, where no statistical differences were found.

Soluble Solids Concentrations

Soluble solids were found to differ by variety and some increase was detected during storage. No significant differences in SSC were found between 0°C and 5°C storage treatments. On average, 'Earliblue' had the highest values of SSC (18.2%) while 'Patriot', 'Bluejay' and 'Berkeley' were the lowest (13.1% to 12.8%), (see Table IV.5).

Figure IV.5 shows a slight increase in SSC during the 15 day storage period. Although no statistical differences could be detected between temperatures, there seemed to be a weak tendency for SSC to increase at 5°C compared to 0°C.

Anthocyanin Concentrations

Only varietal differences were detected for anthocyanin concentration. No differences were found between storage temperature or time of storage. Very high concentrations (198 mg/100g) were found in 'Elliott', while 'Bluejay' (66 mg/100g) and 'Bluecrop' (45.8) had very low amounts (Table IV.6).

Although no statistical differences were found for storage duration, Figures IV.6 A and B show a weak trend of higher values after 15 days storage in most of the varieties. An exception was 'Earliblue' at 0°C, which measured a slight decrease (10%) in anthocyanin concentration.

Sugars

Figure IV.7 shows the differences in fructose and glucose concentrations found for the different blueberry cultivars stored for 15 days at 0°C and 5°C. In both cases, fructose was highest in 'Earliblue' (224 at 0°C and 212 mg/g fresh weight at 5°C respectively) and lowest in 'Bluejay' and 'Patriot' (less than 130 mg/g fresh weight). The highest glucose concentration was also found in

'Earliblue' (242 at 0°C and 210 mg/g fresh weight at 5°C). A difference in sugar concentration between initial values and 15 days of storage was only detected for glucose, which dropped from 204 and 206 mg/g to 151 mg/g respectively. (Figure IV.8).

Sensory Evaluation

Table IV.7 shows the sensory evaluation of 5 late season blueberry cultivars stored for 15 days at 0°C .

General appearance of all varieties was rated high. 'Elliott' was ranked the best for appearance, followed by 'Jersey', 'Bluejay', 'Bluecrop', and 'Patriot'- all very acceptable.

Sweetness was relatively high for all varieties, except for 'Elliott' , which was statistically different from the rest. The opposite pattern was found in terms of sourness, 'Elliott' accounted for the highest scores and 'Bluejay' had the lowest.

Fruity flavor intensity was high and acceptable for all treatments except 'Bluejay', which was below the mid-point of the 0 to 15 scale. 'Patriot' which showed good balance between sweetness and sourness, had the highest flavor intensity scores, followed by 'Jersey' and 'Bluecrop', 'Elliott' and 'Bluejay'.

No statistical differences were found for firmness, and according to the mean values, none of the varieties were found to be extremely firm or soft by the judges.

'Patriot' was clearly the juiciest of all the varieties tested, and no real differences were found among remaining cultivars.

Despite the differences in the attributes just described, no statistical differences were found for overall quality. When frequency histograms were plotted, 'Jersey', 'Bluecrop', and 'Patriot' showed a large number of responses on the upper zone of the scale used, meaning that they were more liked.

As explained in experiment 1, data from both taste panel were pooled to calculate correlation coefficients for overall quality (Table IV.4). Additional coefficients for each variety were also calculated on this experiment (data not shown). The most relevant aspects are the high correlation found for overall quality (OAQ) of almost all the varieties with fruity flavor intensity. This was especially remarkable for 'Patriot' (r^2= 0.76), which was rated as the best for that attribute by the panelists. Some other interesting relationships , although not as strong, were found for 'Bluejay' with general appearance (r^2=0.46); flavor intensity (r^2=0.34) and juiciness (r^2=0.49). Finally 'Jersey's' quality was best correlated with juiciness (r^2=0.39), (data not shown).

Organic Acids

Citric acid showed almost no changes over time at 0°C or 5°C, but different concentrations were found between cultivars, (Figure IV.9) where 'Elliott' had the highest concentration (4.1 mg/g fresh wt). The other varieties were similar in citric acid content ranging from 2.0 in 'Earliblue' to 2.4 mg/g fresh wt in 'Jersey'.

Malic acid showed an interaction between varieties and storage time , (Figure IV.10), but no effect of temperature was detected. Malic acid content decreased by about 20% during 15 days storage in all cases. The highest values in malic acid before storage were accounted for by 'Elliott' (1.4mg/ g fresh wt) and 'Earliblue' (1.1 mg/g fresh wt).

DISCUSSION

Blueberries which were harvested immediately after obtaining a blue skin color, proved to store more satisfactory than ripe and overripe stages, which were correlated with increasing soluble solids content (Bunemann et al, 1957). In our study, varieties on both harvest dates differed in decay incidence, with 'Bluecrop' (mid season cultivar) having the lowest rot amount (16%) in the first harvest, and 'Bluecrop' and especially 'Elliott', a late cultivar, (less than 10%) on the second. For both harvests, the highest infection was presented by 'Earliblue' which is a very early cultivar (over 40% on overripe). For soluble solids concentration, 'Earliblue' was always the highest (17.8 and 18.8%) while 'Bluecrop' and 'Elliott' contained significantly less (about 14.9 to 15.1%). The results with 'Earliblue' agree with the results reported by Ballinger et al (1978), who found that overripe blueberries greatly increased mold incidence at low temperatures. Container size also influenced the amount of rot in the early harvest. Since 1 pint hallocks hold more fruits than 1/2 pint, excessive compression of the berries in the bigger hallock could cause injuries and bruising that may soften the fruit. Alternatively, and perhaps more likely the increased humidity in the container could make the fruit susceptible to fungal attack. For the late harvest, mold infection was greatly influenced by temperature. Fruit held at 5°C developed twice as much rot as those stored at 0°C, because mold incidence is highly associated with storage temperature at high relative humidity (Richardson, 1988). Fungi such as Botrytis cinerea and Alternaria alternata can grow even at -2°C, whereas Rhizopus spp growth is limited by temperatures lower than 2°C (Sommer, 1985).

Besides the container and temperature effects, the small stem scar characteristic of 'Bluecrop' and 'Elliott' is highly desirable to avoid fungal infections and shriveling. Mold on 'Earliblue' increased much faster than on the other varieties. It is most likely that being an early cultivar, it was overmature at the time we harvested it, specially on the second date. From these two studies, 'Bluecrop' and 'Elliott', which accounted for the lowest decay, are very good possibilities for long term storage, from a mid - to late season harvest.

Anthocyanins usually increase as fruit ripen (Ballinger et al, 1978) and blueberry cultivars differ significantly in total anthocyanin content (Sapers et al, 1984). Similar results were found in this study where 'Earliblue' and 'Patriot' presented the highest concentrations from the midseason harvest and 'Earliblue' and 'Elliott' for the late season harvest. Color expression in blueberries is influenced by the amount of wax bloom on their surface as well as by the anthocyanin content (Ballinger et al, 1979). While total anthocyanin increases were found after the storage period, the changes were not discernible externally.

Sugars, either free or combined with other constituents, are important in attaining a pleasant fruit flavor through a sugar to acid balance, attractive color and texture (Mattoo et al, 1975). Glucose and fructose are the main sugars in blueberries (Kushman and Ballinger, 1968), and were the major sugars found in this study. Variability was found among the different varieties, the highest contents of glucose and fructose were detected in 'Earliblue', which also accounted for the highest SSC. Upon prolonged storage (15 days), either at 0°C or 5°C, a decrease in fructose was detected but almost no changes were found for glucose. Many horticultural products suffer shriveling and wilting as a result of water loss during handling and marketing (Mitchell, 1985). The rate of water loss depends upon the vapor pressure deficit between the fruit and the surrounding air, which is influenced by temperature and relative humidity. When fruits were stored either at 5°C or 0°C, weight loss was less than 2.6%, but was greater in all cases in fruit held at 5°C. Since high relative humidity (95%) was used in both storage conditions, in this case water loss was dependent upon temperature, presenting higher values at 5°C than at 0°C.

In the majority of soft fruits, including blueberries, citric is the predominant acid (Kushman and Ballinger, 1968), followed by malic acid as second in importance.

Smittle and Miller (1987) demonstrated that acidity decreased initially in blueberries, but then remained relatively constant during storage. In our study citric acid showed almost no change at the end of the storage period, while significant decreases were found in malic acid. A slight increase in citric acid after storage was reported by Tarmizi (1990).

A large number of blueberry cultivars are available for fresh market and processing purposes. If fresh market of blueberries is intended, consumer tests can help identify the most suitable ones in terms of acceptance by the potential customer. From the taste panel evaluating the mid-season harvest, 'Bluecrop' and 'Patriot' showed the most promising responses; high fruity flavor intensity, adequate firmness in 'Bluecrop', high juiciness, and finally high overall quality on both. From the late season harvest 'Elliott' showed good appearance, but low sweetness and high sourness. No differences were found in fruity flavor intensity or overall quality but 'Jersey' revealed a high number of responses in the upper zone of the scale, as well as a positive correlation for overall quality and juiciness. 'Patriot' again showed the highest values for juiciness and fruity flavor intensity.

The first early pickings of any blueberry crop usually have the best keeping quality (Ceponis and Capellini, 1979). Although 'Patriot' showed excellent consumer acceptance in both taste panels, it also developed high mold infection in storage. Therefore if this early cultivar were to be used for fresh market only top quality fruit from early pickings should be used.

The regression analyses performed on the data of both taste panels clearly demonstrated that overall quality of blueberries is highly influenced by juiciness and fruity flavor intensity (r^2=0.88). It seems that fruity flavor intensity integrates more than sweetness or sourness alone, because only small contributions to explain overall quality were obtained when either was included in the model. The fact that only two attributes (juiciness and fruity flavor intensity) proved to be enough to evaluate overall quality could help future varietal evaluation studies. If a shorter questionnaire can lead to adequate responses, time can be saved with less questions allowing more samples to be evaluated at a time, generating the same precise responses. For a grower it is an advantage to choose various cultivars ranging from early to late maturation, in order to be able to offer a succession of ripening over time. This study suggests that in order of ripening, 'Patriot' for early harvest; 'Bluecrop', mid-season and 'Jersey', late season would be the most adequate ones for fresh marketing.

Table IV.1: Effect of pint and half pint container sizes on decay incidence of blueberries after 15 days, 0°C storage.

Variety	1/2 pint	Decay (%) 1 pint	average
Bluecrop	11.1	20.9	16.1 a
Bluejay	24.6	33.9	29.3 b
Patriot	23.9	38.5	31.2 bc
Berkeley	27.6	46.5	37.1 c
Earliblue	46.0	48.3	47.2 d
average	27.1 a	37.3 b	

Means followed by the same letter are not different, FPLSD, p=0.05.

Table IV.2: Soluble solids concentrations of blueberries after 15 days in refrigerated storage.

Variety	SSC (%)
Earliblue	17.8 a
Bluecrop	14.9 b
Patriot	13.7 b

Means followed by the same letter are not different, FPLSD, p=0.05 (n=3).

Table IV.3: Sensory evaluation of 5 blueberry cultivars after 15 days, 0°C storage.

Attribute	Earliblue	Bluecrop	Patriot	Bluejay	Berkeley
General App	8.0 c	10.2 ab	9.1 bc	10.4 ab	11.3 a
Sweetness	9.0 a	8.1 ab	7.5 ab	6.3 b	6.1 b
Sourness	3.6 b	5.5 ab	6.7 a	7.0 a	5.0 ab
Flavor Int.	8.8 a	9.1 a	9.9 a	8.1 a	5.0 b
Firmness	8.4 a	9.5 a	9.9 a	8.6 a	7.6 a
Juiciness	7.6 bc	8.1 ab	9.5 a	7.2 bc	6.0 c
Overall Qual	7.6 ab	7.9 ab	8.5 a	7.7 ab	5.7 b

Means within a row followed by the same letter are not different, p=0.05.Evaluation scale range 0-15, (n=20 for each treatment mean)

Table IV.4 : Correlation of blueberry overall quality with individual quality factors (n= 72).

Dependent Variable		Independent Variable	r^2
OAQ	=	0.923 (juiciness)	0.84
OAQ	=	0.476 (juiciness)+ 0.481 (fruity flavor intensity)	0.88
OAQ	=	0.393 (juiciness)+ 0.357 (fruity flavor intensity)+ 0.237 (sweetness)	0.89
OAQ	=	0.366 (juiciness)+ 0.333 (fruity flavor intensity)+ 0.249 (sweetness)+ 0.06 (sourness)	0.89

Table IV.5: Soluble solids concentrations of 7 blueberry cultivars kept for 15 days in 0° or 5°C storage.

Variety	SSC (%)
Earliblue	18.2 a
Jersey	15.1 b
Elliott	15.0 b
Bluecrop	14.5 b
Patriot	13.1 c
Bluejay	12.9 c
Berkeley	12.8 c

Means followed by the same letter are not different, FPLSD, p=0.05. (n=8)

Table IV.6: Anthocyanin concentration of blueberry cultivars kept 15 days in refrigerated storage.

Variety	ACY (mg/100g)
Elliott	198.4 a
Earliblue	125.4 b
Patriot	124.1 b
Jersey	104.4 c
Berkeley	88.4 c
Bluejay	66.6 d
Bluecrop	45.8 e

Means followed by the same letter are not different, FPLSD, p=0.05. (n=8)

Table IV.7: Sensory evaluation of blueberry cultivars after 15 days 0°C storage

Attribute	Bluecrop	Bluejay	Elliott	Patriot	Jersey
General App	8.7 ab	9.0 ab	10.9 a	8.6 b	9.6 ab
Sweetness	8.2 a	7.6 a	5.3 b	8.8 a	7.8 a
Sourness	6.0 b	3.5 c	9.4 a	4.9 bc	5.3 bc
Flavor Int	7.9 ab	5.9 c	7.4 bc	9.4 a	8.6 ab
Firmness	8.4 a	6.6 b	6.7 ab	7.9 ab	7.7 ab
Juiciness	7.9 b	8.1 b	6.6 b	10.4 a	7.4 b
Overall Qual	8.8 a	6.6 a	7.1 a	8.6 a	9.0 a

Means within a row followed by the same letter are not different, p=0.05. Response range for each attribute was 0 to 15. (n=20 for each treatment mean).

Date_______

Please answer the questions about the 4 coded blueberry samples, by making a mark on the horizontal line corresponding to the amount of perceived attribute. Then place the code numbers above it. if two samples appear to be equal, place both code numbers above the same mark.

GENERAL APPEARANCE Please observe the samples and rate the appearance in each one:

Non attractive ______________________________ Attractive

FLAVOR Please taste the samples and rate all of them for each of the following attributes

Sweetness

None ______________________________ Very

Sourness

None ______________________________ Very

Fruity flavor intensity

Very weak ______________________________ Very strong

Firmness

Soft ______________________________ Firm

Juiciness

None ______________________________ Very

How do you feel about the **Overall quality** of the samples?

Dislike ______________________________ Like

Fig. IV.1: Line scale ballot used for sensory evaluation of blueberry varieties. (Scale 0-15)

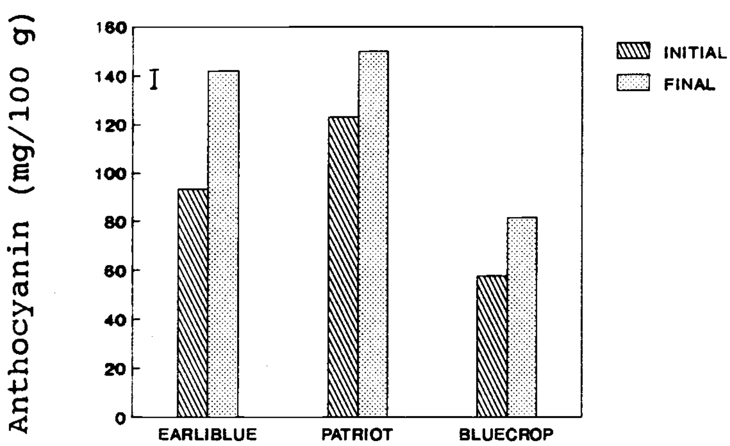


Fig. IV.2: Anthocyanin concentrations of 3 blueberry varieties, before and after 15 days at 5°C.

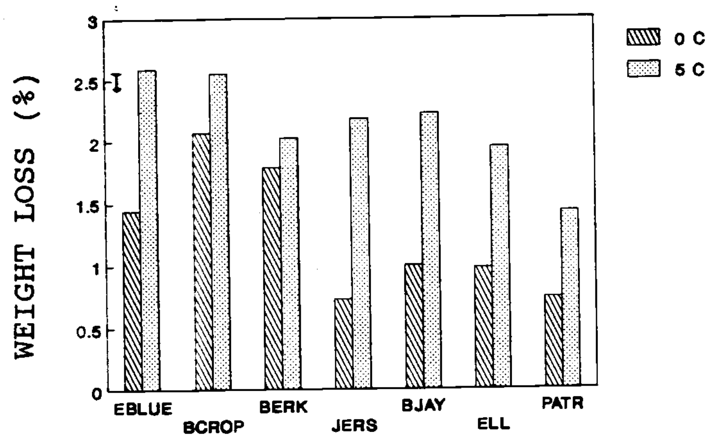


Fig. IV.3: Weight loss of 7 blueberry varieties after 15 days at 0°C and 5°C.

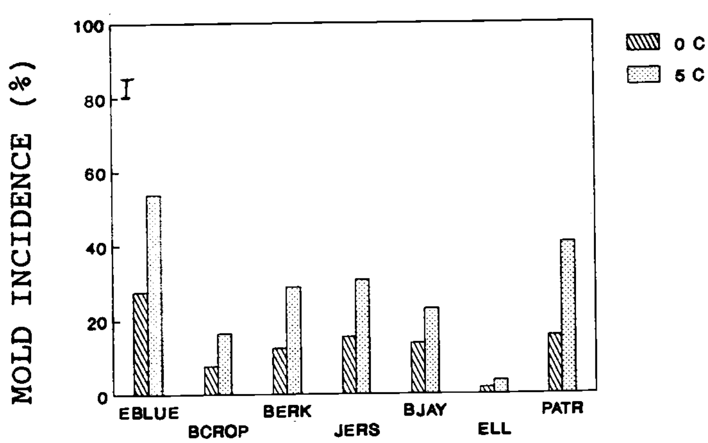


Fig. IV.4.: Effect of storage temperature and cultivar on mold development of blueberries after 15 days of refrigerated storage.

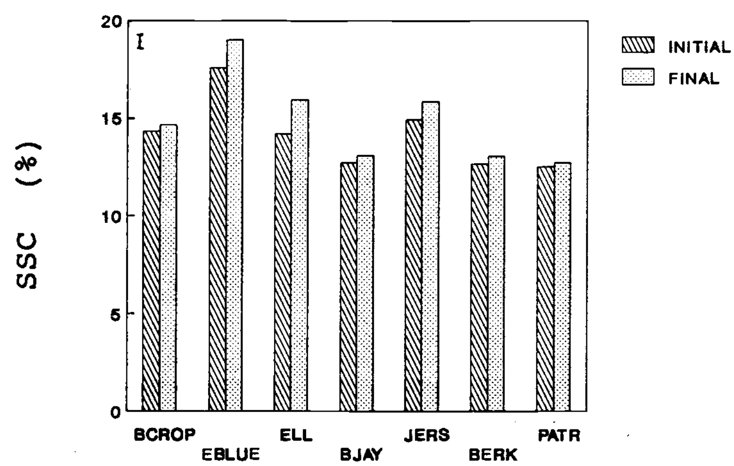


Fig. IV.5: Soluble solids contents (SSC), of 7 blueberry cultivars, before and after 15 days at 5°C.

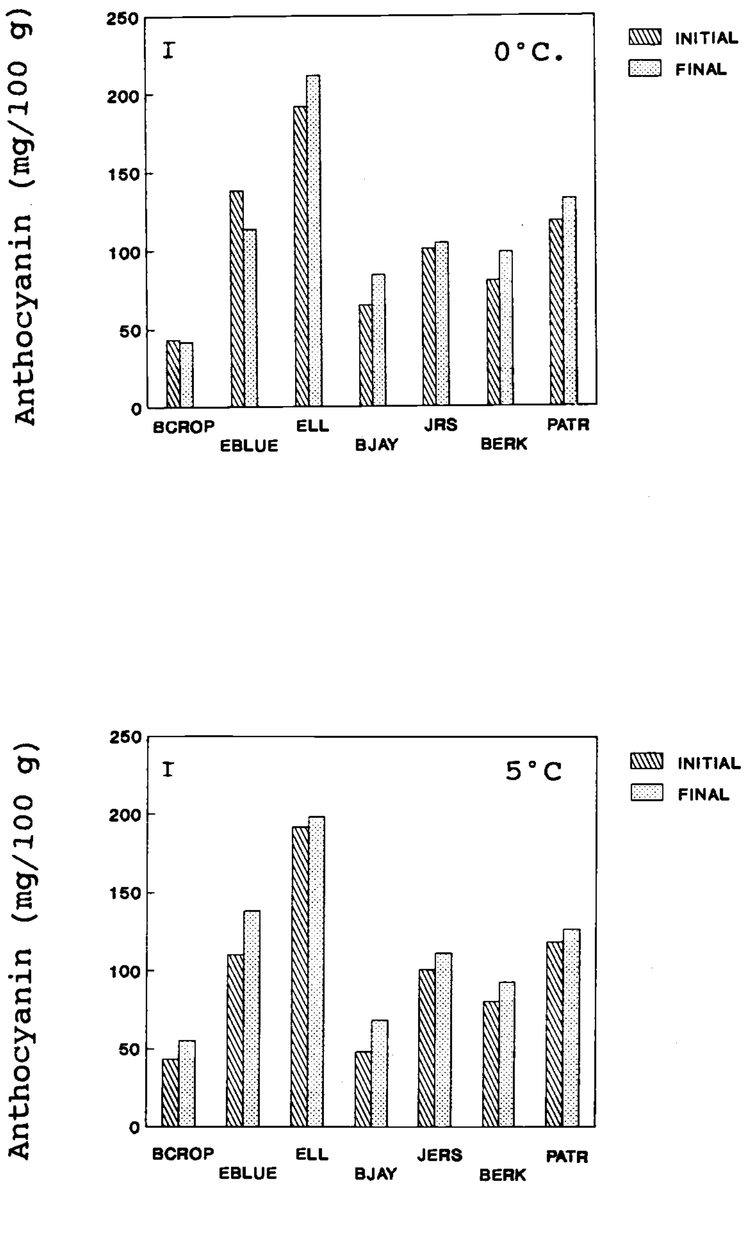
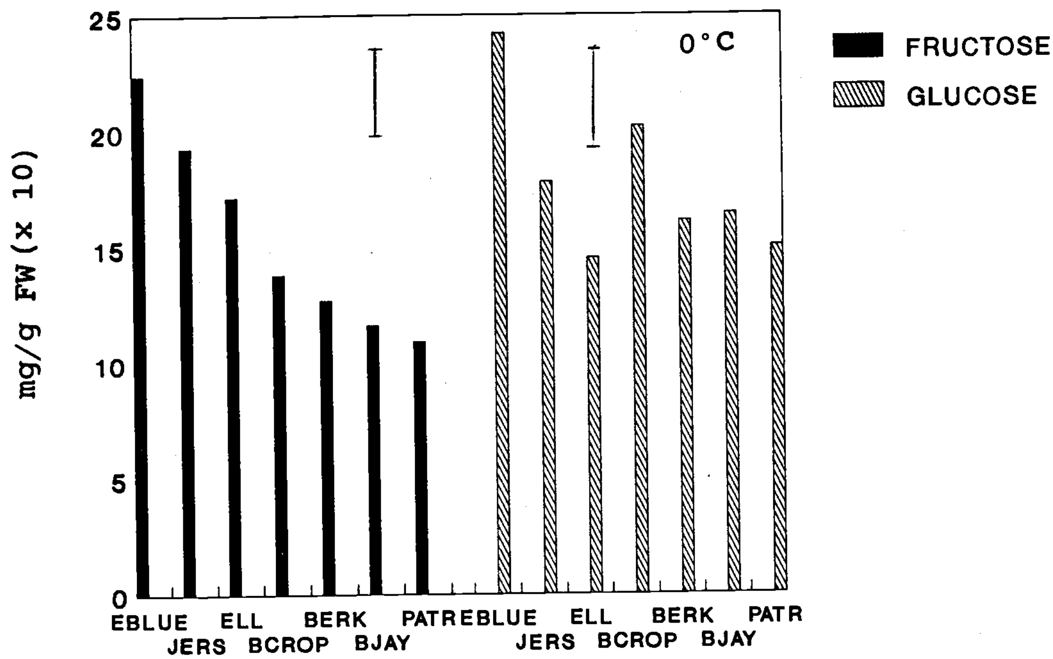


Fig. IV.6: Anthocyanin (Acy) concentrations of 7 blueberry cultivars before and after 15 days storage at 0°C and 5°C.



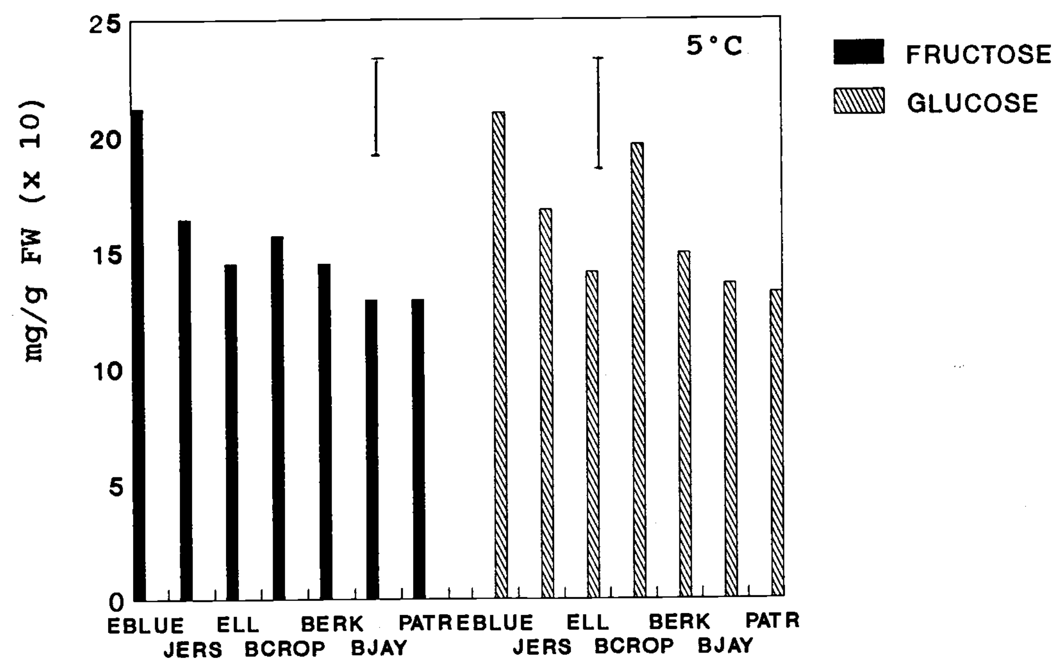
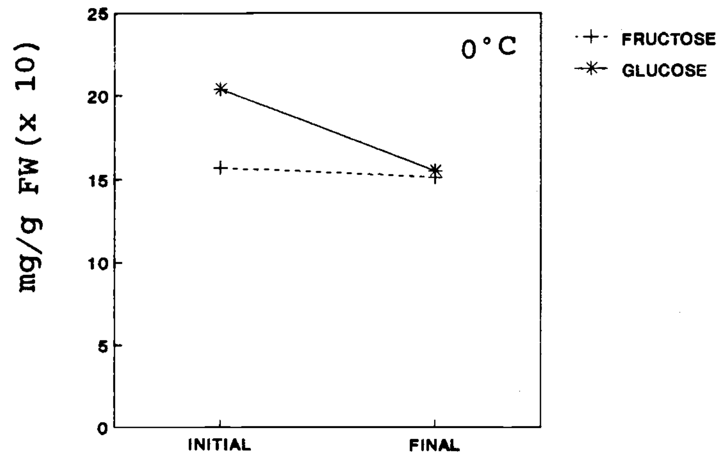


Fig. IV.7: Fructose and glucose concentrations of blueberry cultivars stored for 15 days at 0°C and 5°C. 7



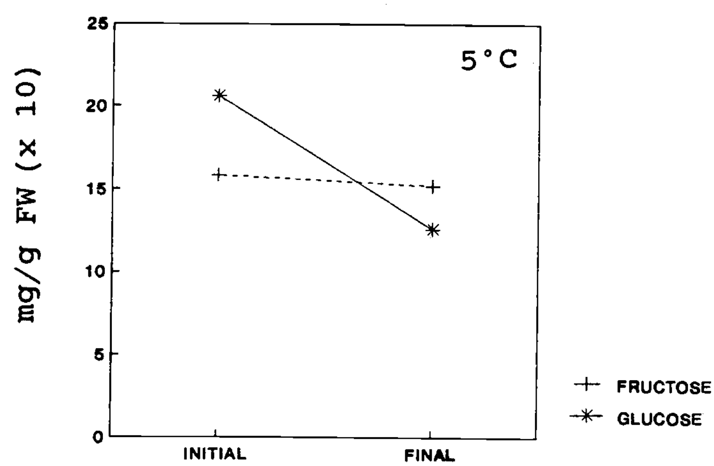


Fig. IV.8: Fructose and glucose concentrations of blueberries before and after storage, 15 days at 0°C and 5°C.

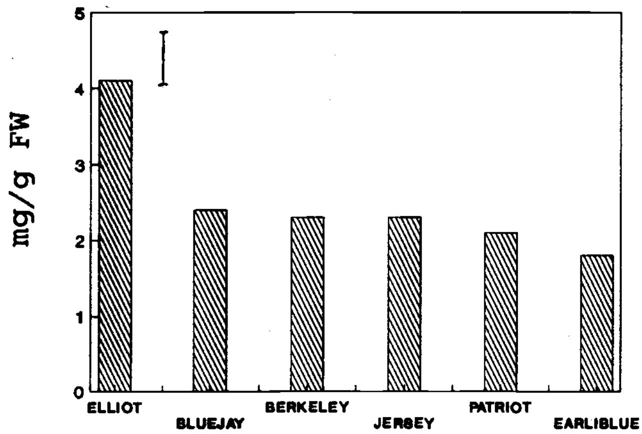


Fig. IV.9: Citric acid concentrations of blueberry varieties after 15 days storage (0 and 5°C, data pooled).

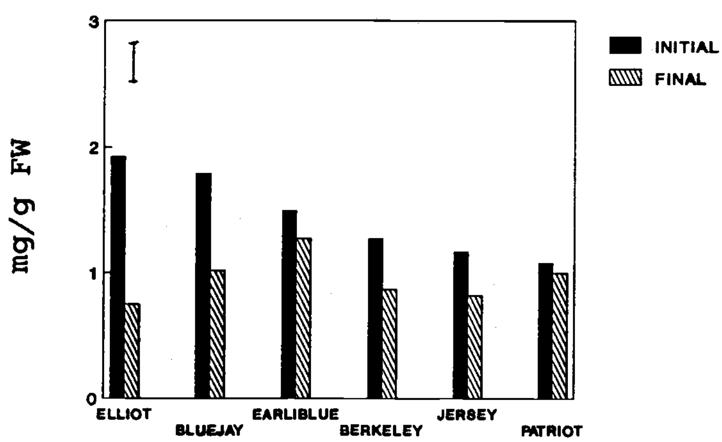


Fig. IV.10: Effect of storage time on malic acid concentrations of blueberry varieties, 15 days at 0 or 5°C, (data pooled).

LITERATURE CITED

Arthey, V.D. 1975. Quality of Horticultural Products. John Wiley & Sons, New York, Toronto, 228p.

Ballinger, W.E., G.J. Galletta, and E.P. Maness. 1979. Anthocyanin in fruits of Vaccinium, Sub-genera Cyanococcus and Polycodium. J. Amer. Soc. Hort. Sci. 104(4):554-557.

Ballinger, W.E., E.P. Maness, and W.F. McClure, 1978. Relationship of stage of ripeness and holding temperature to decay development of blueberries. J. Amer. Soc. Hort. Sci. 103(1):130-134.

Ballinger, W.E., E.P. Maness, and L.J. Kushman. 1970. Anthocyanin in the ripe fruit of highbush blueberry, Vaccinium corymbosum J. Amer. Soc. Hort. Sci. 95(3):283-285.

Bunemann,G., D.H> Dewey, and D.P. Watson. 1957. Anatomical changes in the fruit of Rubel Blueberry during storage in CA. Mich. State Agric. Expt. Stat. Journal Article 2019:156-160.

Ceponis, M.J., and R.A. Cappellini. 1978. Control of postharvest decays of blueberry fruits by precooling fungicide and modified atmosphere. Plt. Dis. Reptr. 63(12):1049-1053.

Eck, P., R.E. Gough, I.V. Hall, and J.M. Spiers. 1990. Blueberry Management. In G.J. Galletta and D.G. Himelrick (eds). Small Fruits Crop Management. Prentice-Hall, Inc. Englewood Cliffs, New Jersey pp 273-315.

Hardenburg, R.E., A.E. Watada, and C.Y. Yang. 1986. The Commercial Storage of Fruits Vegetables and Florist and Nursery Stock. USDA Agr. Handb. 66, 136p.

Kushman, L.J., and W.E. Ballinger, 1968. Acid and sugar changes during ripening in Walcott blueberries. Proc. Amer. Soc. Hort. Sci. 92:290-295.

Mattoo, A.K., T. Murata, and E.B. Pantastico. 1975. Chemical changes during ripening and senescence. In E.B. Pantastico, Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. The AVI Publ. Co. Inc. Westport, Conneticut.

Mitchell,F,G. 1985.Cooling horticultural commodities. In A.A. Kader, R.F. Kasmire, F.G. Mitchell, M.S. Reid, N.F. Sommer, and J.F. Thompson (eds). Postharvest Technology of

Horticultural Crops. Univ. Calif. Coop. Ext.Pub 3311 pp.35-43.

Petersen, R.G. 1985. Design and Analysis of Experiments. Marcel Dekker, Inc., New York and Basel, 429p.

Richardson, D.G. 1988. Fresh marketing berry crops. Proc. 102nd. Ann. Meet. Oregon Hort. Soc. 79:204-206.

Salunkhe, D.K., and B.B. Desai. 1984. Postharvest Biotechnology of Fruits, Vol.I. CRC Press, Inc. Boca Raton, Florida. 168p.

Sapers, G.M., A.M. Burgher., J.G. Phillips, and S.B. Jones. 1984. Color and composition of highbush blueberry cultivars. J. Amer. Soc. Hort. Sci. 109(1):105-111.

SAS Institute. 1985. SAS User's guide. Statistics, Version 5. SAS Institute, Inc., Cary, NY.

Sjulin, T.M., and J.A. Robbins. 1987. Effects of maturity, harvest date and storage time on postharvest quality of red raspberry fruit. J. Amer. Soc. Hort. Sci. 112(3):481-487.

Smittle, D.A., and W.R. Miller. 1988. Rabbiteye blueberry storage life and fruit quality in CA and air storage. J. Amer. Soc. Hort. Sci. 113(5):723-728.

Sommer, N.F. 1985. Role of controlled environments in suppression of postharvest diseases. Plt. Pathol. 7:331-339.

STATGRAPHICS. 1988. User's guide system. Version 4. STSC, Inc., Rockville, MD.

Tarmizi, A. 1990. Storage Quality of Red Raspberries, Blackberries and Blueberries: Effects of Delayed Cooling and Packages types. M.S Thesis. Oregon State University, 165 pp.

CHAPTER V

CONCLUSIONS

a. BLACKBERRIES

Modified atmosphere film packed blackberries developed almost 40% more rot than the non-covered control, due to excessively high humidity inside the packages.

Moisture loss was kept extremely low (0.1 to 0.3%) in fruits packed with films Cryovac D-940 and D-955, compared to the non-covered control (3%).

Cryovac D-940 and D-955 films acted as moderately permeable barriers allowing for enough O_2 and CO_2 exchange inside the packages, but internal atmosphere changed more dramatically over time when fruit was stored at 5°C compared to 0°C.

Blackberries selectively harvested into 3 different maturity stages developed significantly different amounts of rot, with the lowest in early mature (M1) and mature ripe (M2) stages. Late mature (M3) or overmature fruits had high rot incidence (>30%).

The ease of separation of blackberries from the pedicel seemed to be a more appropriate harvest index than color.

If long term storage of blackberries is intended (9-10 days), only mature ripe (M2) and firm fruits should be harvested.

Blackberry cultivars for fresh market should be selected on the basis of rot resistance and firmness to tolerate handling and transportation. Consumer acceptance should be evaluated mainly on fruity flavor intensity, juiciness and sweetness. Marion blackberry was the top fresh market candidate.

b. BLUEBERRIES

Fruits of blueberry kept at 0°C for 15 days developed 50% less rot than fruits stored at 5°C.

Blueberries stored 15 days at 0°C in commercial 1/2 pint hallocks developed 50% less rot than fruits in 1 pint containers.

Sensory evaluation of blueberry cultivars showed juiciness and fruity flavor intensity as the highest factors correlated with overall quality and consumer acceptance.

From this study 'Patriot', 'Bluecrop' and 'Jersey' appeared to be the most suitable early, mid-season and late cultivars for fresh market, both in terms of adequate storage quality and consumer acceptance.

BIBLIOGRAPHY

Ahmedullah, M., M.E. Patterson, and G.W. Apel. 1989. Modified atmosphere packaging of blueberries (Vaccinium corymbosum). In J.K. Fellman (ed). Fifth Proc. Internat. Controlled Atmosphere Res. Conf. Vol 2, Wenatchee, WA.

Amerine, M.A., R.M. Pangborn, and E.B. Roessler. 1965. Principles of Sensory Evaluation of Food. Ch. 9. Academic Press, New York.

Anderson, R.E., and R.E. Hardenburg. 1959. Effect of various consumer baskets, film wraps and crate liners on quality of strawberries. Proc. Amer. Soc. Hort. Sci. 74:394-400.

Arpaia, M.L., F.G. Mitchell; A.A.Kader, and G. Mayer. 1982. The ethylene problem in modified atmosphere storage of kiwifruit p 331-335. In: D.G. Richardson, and M. Meheriuk (eds). Controlled atmospheres for storage and transport of perishable agricultural commodities. Timber Press. Beaverton. Ore.

Arthey, V.D. 1975. Quality of Horticultural Products. John Wiley & Sons, New York, Toronto, 228p.

Aylsworth J. 1989. Packaging keeps fruit fresh. Fruit Grower, September. pp 10-11.

Ballinger, W.E., G.J. Galletta, and E.P. Maness. 1979. Anthocyanin on fruits of Vaccinium, Sub-genera Cyanococcus and Polycodium. J. Amer. Soc. Hort. Sci. 104(4):554-557.

Ballinger, W.E., E.P. Maness, and W.F. McClure, 1978. Relationship of stage of ripeness and holding temperature to decay development of blueberries. J. Amer. Soc. Hort. Sci. 103(1):130-134.

Ballinger, W.E. 1972. Anthocyanins of ripe fruit of a "Pink-Fruited" hybrid of highbush blueberries, Vaccinium corymbosum L. J. Amer. Soc. Hort. Sci. 97(3):381-384.

Ballinger, W.E., E.P. Maness, and L.J. Kushman. 1970. Anthocyanin in the ripe fruit of highbush blueberry, Vaccinium corymbosum J. Amer. Soc. Hort. Sci. 95(3):283-285.

Ballinger, W.E., and L.J. Kushman. 1970. Relationship of ripeness to composition and keeping quality of highbush blueberries. J. Amer. Soc. Hort. Sci. 95(3): 239-242.

Ballinger, W.E., L.J. Kushman, and D.D. Hamann. 1973. Factors affecting the firmness of highbush blueberries. J. Amer. Soc. Hort. Sci. 98(6):583-587.

Ben-Yehoshua, S. 1985. Individual seal-packaging of fruits and vegetables in plastic films - A new postharvest technique. HortScience. 20(1):32-37.

Biale, J.B., and R.E. Young. 1981. Respiration and ripening in fruits-retrospect and prospect. In: J. Friend and M.J.C. Rhodes (eds). Recent Advances in The Biochemistry of Fruits and Vegetables. Academic Press, London, New York, Toronto, Sydney, San Francisco, 275p. 1-37.

Biale, J.B. 1960. Respiration of fruits. Encyc. Pl. Physiol. 12:536-592.

Bunemann,G., D.H. Dewey, and D.P. Watson. 1957. Anatomical changes in the fruit of Rubel blueberry during storage in CA. Mich. State Agric. Expt. Stat. Journal Article 2019:156-160.

Cappellini, R.A., and M.J. Ceponis. 1976. Vulnerability of stem-end scars of blueberry fruits to postharvest decays. Phytopathology. 67:118-119.

Ceponis, M.J., and R.A. Cappellini. 1978. Control of postharvest decays of blueberry fruits by precooling, fungicide and modified atmosphere. Plt. Disc. Reptr. 63(12):1049-1053.

Crabtree, G.D. and C.J. Weiser. 1988. Oregon's high value crops-1987 updates. Proc. 102nd. Ann. Meet. Oregon Hort. Soc. 79:313-322.

Dodge, B.D. and R.B. Wilcox. 1941. Diseases of Blackberries and raspberries. U.S. Dept. Agr. Farmers Bull. 1488.

Duckworth, R.B. 1966. Fruits and Vegetables. Oxford, Pergamon Press, 230p.

Eaks, I.L. 1986. Effect of shrink film wraps on weight loss, respiration and internal atmosphere of lemon fruit. HortScience 21(3):710.

Eck, P., R.E. Gough, I.V. Hall, and J.M. Spiers. 1990. Blueberry Management. In: G.J. Galletta and D.G. Himelrick (eds). Small Fruit Crop Management, Prentice-Hall, Inc. Englewood Cliffs, New Jersey, pp 273-315.

Eck, P. 1988. Blueberry Science. Rutgers University Press; New Brunswick and London, 284p.

Eck. P. 1966. Botany. In P. Eck and N.F. Childers (eds): Blueberry Culture. Rutgers University Press, New Brunswick and New Jersey, 378p, 14-44.

Fuleki, T. and F.J. Francis. 1968. Quantitative methods for anthocyanin in cranberries. J. Food Sci. 33:72-77.

Green, G. 1970. Soft fruits. In: A.C. Hulme (ed). The Biochemistry of Fruits and Their Products. Vol 2, Academic Press, London, New York, 788p. 375-407.

Hall, C.W., R.E. Hardenburg, and E.B. Pantastico. 1975. Principles of Packaging: Consumer Packaging with plastics. In: E.B. Pantastico (ed). Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. The AVI Pub. Co., Inc. Westport, Conneticut.

Hammet, L.K., and W.E. Ballinger. 1972. Biochemical components of highbush blueberry fruit as influenced by nitrogen nutrition. J. Amer. Soc. Hort. Sci. 97(6):742-745.

Hardenburg, R.E., A.E. Watada, and C.Y. Yang. 1986. The commercial storage of fruits vegetables and florist and nursery stock. USDA Agr. Handb. 66, 136p.

Hardenburg, R.E. 1971. Effect of in-package environment on keeping quality of fruits and vegetables. HortScience 6(3):98-101.

Hardenburg, R.E. 1965. Shipping container and consumer packaging. A Review of Literature on Harvesting, Handling, Storage and Transportation of Apples. USDA. Agr. Res. Serv. ARS 51-4.

Hruschka, H.W., and L.J. Kushman. 1963. Storage and shelf-life of packaged blueberries. USDA. Agr. Mkt. Serv. 612, 16p.

Isherwood, F.A. 1960. Some factors involved in the texture of plant tissues, in S.C.I. Monograph Texture in Foods. pp.135-143.

Jennings, D.L. 1988. Raspberries and Blackberries: Their Breeding, Disease and Growth. Academic Press, London, Boston, New York, 203p.

Jing, Z.R. 1989. Physiological aspects of film wrapping of fruits and vegetables. p29-39. In J.K. Fellman (ed). Fifth Proc. Internat. Controlled Atmosphere Res. Conf. Vol 2. Wenatchee, Wa.

Johnston D.G., F.L. Matton, and H.Hull. 1969. Essentials of blueberry culture. Mich. S. Coop. Ext. Bull.

Josych, D. 1962. Soft fruits. In A.C. Hulme (ed). The Biochemistry of Fruits and their Products. Vol 2. 1971. Academic Press, London and New York. 788p.

Kader, A.A., D. Zagory, and E.L. Kerbel. 1989. Modified atmosphere packaging of fruits and vegetables. Crit. Rev. Food Sci. Nutr. 12:1-30.

Kader, A.A. 1985. Postharvest biology and technology: an overview. In A.A. Kader, R.F. Kasmire, F.G. Mitchell, M.S. Reid, N.F. Sommer and J.F. Thompson (eds). Postharvest Technology of Horticultural Crops. Univ. Calif. Coop. Ext. Pub. N#3311:3-7.

Ke, D., and A.A. Kader. 1989. Tolerance and rsponses of fresh fruits to oygen levels at or below 1%. p 209-216. In J.F. Fellman (ed). Fifth Proc. Internat. Controlled Atmosphere Res. Conf. Vol 2. Wenatchee, WA.

Kenny, T.A. 1979. Studies on precooling of soft fruits: strawberries. Ir. J. Food. Sci. Technol. 3:19-31.

Kosittrakun, M. 1989. Effects of Near Anaerobic Storage Conditions on Physiology and Flavor of Various Fruit Types and on Mortality of Apple Maggot (Rhagoletis pomonella). 1989. Oregon State University, Ph.D. Thesis., 174p.

Kushman, L.J., and W.E. Ballinger, 1968. Acid and sugar changes during ripening in Walcott blueberries. Proc. Amer. Soc. Hort. Sci. 92:290-295.

Lee, C.Y., R.S. Shallenberg, and M.T. Vittum. 1970. Free Sugars In Fruits and Vegetables. New York's Food and Life Sciences. Bulletin N°1, Geneva, NY.

Lipe, J.A., 1978. Ethylene in fruits of blackberry and Rabbiteye blueberry. J. Amer. Soc. Hort. Sci. 103(1):76-77

Mannaperuma, J.D.D. Zagory,R.P. Singh, and A.A. Kader. 1989. p225-233. In J.F. Fellman (ed). Fifth Proc. Internat. Controlled Atmosphere. Res. Conf. Vol 2. Wenatchee, WA.

Mattoo, A.K., T. Murata, and E.B. Pantastico. 1975. Chemical changes during ripening and senescence. In: E.B. Pantastico. Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. The AVI Pub. Co. Inc. Westport, Conn.

McGlasson, W.B. 1989. MA: a practical alternative to CA shipping containers. p 235-240. In J.F. Fellman. (ed). Fifth Proc. Internat. Controlled Atmosphere Res. Conf. Vol. 2. Wenatchee, WA>

McGlasson, W.B. 1985. Ethylene and fruit Ripening. HortScience 20(1):51-54.

Mehlitz, A. 1957. Soft Fruits. In A.C. Hulme (ed). The Biochemistry of Fruits and their Products. Vol. 2. 1971. Academic Press, London and New York. 788 p.

Meilgaard, M., G.V. Civille, and B.T. Carr. 1987. Sensory Evaluation Techniques. CRC Press, Inc. Boca Raton, Florida. 286p.

Miller, W.R., R.E. McDonald, C.F. Melvin, and K.A. Munroe. 1985. Effect of package type and storage time-temperature on weight loss, firmness and spoilage of Rabbiteye blueberries. HortScience 19(5):638-640.

Miller, W.R., Davis, A.Down, and A.J. Bongers. 1983. Quality of strawberries packed in different consumer units and stored under simulated air-freight shipping conditions. HortScience 18(3):310-312.

Mitchell,F,G. 1985.Cooling horticultural commodities. In: A.A. Kader, R.F. Kasmire, F.G. Mitchell, M.S. Reid, N.F. Sommer, and J.F. Thompson (eds). Postharvest Technology of Horticultural Crops. Univ. Calif. Coop. Ext. Pub 3311: 35-43.

Moore, J.N., and R.M. Skirvin. 1990. Blackberry management. In: G.J. Galletta and D.G. Himelrick (eds): Small Fruit Crop Management, Prentice-Hall, Inc. Englewood Cliffs, New Jersey, 602p, 214-244.

Moskowitz, H.R. 1983. Product Testing and Sensory Evaluation of Foods. Marketing and R&D. Approaches. Food and Nutrition Press, Westport, Conn.

Nelson, E.K. 1925. The non-volatile acids of the pear, quince, apple, loganberry, cranberry, lemon and pomegranate. Amer. Chem. Soc. J. 49: 1300-1302.

Pantastico, E.B., H. Subramanyam, M.B. Bhatti, N. Ali, and E.K. Akamine. 1975. Harvest indices p56-74. In E.B. Pantastico. Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. The AVI Pub. Co., Inc. Westport. Conneticut.

Pattenn, K., and E. Neuendorf. 1986. Film packaging effects on the storage behavior of Rabbiteye blueberries. HortScience 21(3):676.

Petersen, R.G. 1985. Design and Analysis of Experiments. Marcel Dekker, Inc. New York and Basel, 429p.

Powrie, W.D., B.J. Skura, and C.H. Wu. 1987. Modified atmosphere packaging, an application of postharvest technology. Agrologist. Summer:20-21.

Purvis, A.C. 1983. Effects of film thickness and storage temperature on water and internal quality of seal-packaged grapefruit. J. Amer. Soc. Hort. Sci.108(4):562-566.

Ramsey, H.J., 1924. Factors governing the successful shipment of red raspberries from the Puyallup Valley. USDA Bull. 274.

Reid, M.S. 1985. Product Maturation and Maturity Indices. In: A.A.Kader, R.F.Kasmire, F.G.Mitchell, M.S.Reid; N.F.Sommer, and J.F. Thompson (eds). Postharvest Technology of Horticultural crops. Univ. Calif. Coop. Ext. Pub. 331:8-12.

Reyes, F.G., R.E.Wrolstad, and C.J.Cornwell. 1981. Comparison of enzymic, gas-liquid chromatographic, and high performance liquid chromatographic methods for determining sugars and organic acids in strawberries at three stages of maturity. J. Assoc. Off. Anal. Chem. 65(1):126-131.

Richardson, D.G. 1988. Fresh marketing berry crops. Proc. 102nd. Ann. Meet. Oregon Hort. Soc. 79:204-206.

Rij, R.E., and S.R.Ross. 1987. Effects of shrink film wraps on internal gas concentrations, chilling injury and ripening of honeydew melons. J.Foods Quality 11:175-182.

Robinson, J.E., K.M.Browne, and W.G. Burton. 1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol. 81:399-408.

Ryall, A.L., and W.J. Lipton. 1978. Handling, Transportation and Storage of Fruits and Vegetables. Vol. 1. Vegetables and Melons. 2nd. ed. Pub. Co. Westport, Conn.,586p.

Ryall, A.L., and W.T.Pentzer. 1974. Handling, Transportation and Storage of Fruits and Vegetables. Vol.2. Fruits and Tree Nuts. The AVI Pub. Co. Inc. Westport Conn. 454p.

Sagi, F.,L. Kolloyi, and I. Simon. 1973. Changes in the color and anthocyanin content of raspberry fruit during ripening. Acta Alimentaria 3(4):397-405.

Saguy, I. and C.H. Mannheim. 1975. The effect of selected plastic films and chemical dips on the shelf life of Marmande tomatoes. J. Food Technol. 10:547.

Salunkhe, D.K. and B.B. Desai. 1984. Postharvest Biotechnology of fruits, Vol.I. CRC Press, Inc. Boca Raton, Florida. 168p.

Sapers, G.M., A.M. Burgher., J.G. Phillips, and S.B. Jones. 1984. Color and composition of highbush blueberry cultivars. J. Amer. Soc. Hort. Sci. 109(1):105-111.

SAS Institute. 1985. SAS user's guide: Statistics, Version 5. SAS Institute, Inc, Cary, NC.

Schaefer, E.E., 1979. ASTM. Manual on Consumer Sensory Evaluation. Special Technical Publication 682. American Society for Testing and Materials, Philadelphia.

Shetty, K.K.; W.J. Kochan, and R.B. Dwelle. 1989. Use of heat-shrinkable plastic film to extend shelf-life of "Russet Burbank" potatoes. HortScience 24(4):643-646.

Shirazi, A., and A.C. Cameron (1987). Modified humidity packaging: A new concept for improving the success of modified atmosphere packaging of fresh produce. HortScience. 22(5):1055.

Sjulin, T.M., and J.A. Robbins. 1987. Effects of maturity, harvest date and storage time on postharvest quality of red raspberry fruit. J. Amer. Soc. Hort. Sci. 112(3):481-487.

Smith, S., J. Geeson, and J. Stow. 1987. Production of modified atmosphere in deciduous fruits by the use of films and coatngs. HortScience 22(5):772-776.

Smittle, D.A., and W.R. Miller. 1988. Rabbiteye blueberry storage life and fruit quality in CA and air storage. J. Amer. Soc. Hort. Sci. 113(5):723-728.

Snowdon, A.L. 1990. A Color Atlas of Post-Harvest Diseases and Disorders of Fruits and Vegetables. Vol. 1: General Introduction and Fruits. University of Cambridge. CRC. Press, Inc., Boca Raton, Florida. 302p.

Sommer, N.F. 1982. Postharvest handling practices and postharvest diseases of fruits. Plant Dis. 66(5):357-364.

Sommer, N.F. 1985. Role of controlled environments in suppression of postharvest diseases. Plt. Pathol. 7:331-339.

Strik, B.C. 1989. Blueberry cultivars for Oregon. Oregon State University Extension Publication EC 1308.

STATGRAPHICS. 1988. User's Guide System. Version 4. STSC, Inc, Rockville, MD.

Tarmizi, A. 1990. Storage Quality of Red Raspberries, Blackberries and Blueberries: Effects of Delayed Cooling and Packages types. M.S. Thesis Oregon State University, 165 pp

Torre, L.C., and B.H. Barritt. 1977. Quantitative evaluation of Rubus fruit anthocyanin pigments. J. Food Sci. 42(2):488-490.

Varseveld, G.W., and D.G. Richardson. 1980. Evaluation of storage and processing quality of mechanically and hand harvested Rubus spp. fruits. ActaHort. 112:265-272.

Venatcher, A., E. Van Wambeke, and C. Van Asche. 1986. Influence of modified atmosphere on in vitro growth of storage fungi from tomato and strawberry fruits. HortScience 21(3):839.

Walsh, C.S.: J.Popenoe, and T. Solomos. 1983. Thornless blackberry is a climacteric fruit. HortScience 18:482-483.

Wills, R.H., T.H. Lee., D.Graham, W.B. McGlasson, and E.G. Hall. 1989. Postharvest. An Introduction to the Physiology and Handling of Fruits and Vegetables. AVI Pub. Co. Inc. Westport, Conn.

Withing, G.C. 1970.Constituents of fruits. Sugars. In A.C. Hulme (ed). The Biochemistry of Fruits and Their Products. Vol 1. Academic Press, London, New York, pp 1 -32.

Woodruff, R.E., D.H. Dewey, and H.M. Sell. 1960. Chemical changes associated with ripening and deterioration of blueberries, Proc. Amer. Hort. Sci. 75:387-401.

Wrolstad, R.E., J.D. Culbertson, D.A. Nagaki, and C.F. Madero. 1980. Sugars and nonvolatile acids of blackberries. J. Agric. Food Chem. 28:553-558.

Zagory, D.A., and A.A. Kader. 1988. Modified atmosphere packaging of fresh produce. Food Technology. (1):70-77.