Maintaining Cranberry Fruit Quality during Storage and Marketing

Charles F. Forney*

Atlantic Food and Horticulture Research Centre, Agriculture and Agri-Food Canada, 32 Main St., Kentville, Nova Scotia, B0P 1T0 Canada
Correspondence: * Charles.Forney@agr.gc.ca

ABSTRACT

The American Cranberry (Vaccinium macrocarpon Ait.) produces a tart red fruit and is native to northeastern and north central North America. In recent years its popularity has increased due to claims of potential health benefits. While most fruit are processed into juice, sauce or other products, a growing market for fresh fruit exists. To expand fresh market opportunities, fruit must be stored for extend periods of time. During storage, substantial losses of fresh cranberries can result from decay and physiological breakdown. Incidence of both decay and physiological breakdown are influenced by cultural practices, harvest methods, and storage conditions. Plant cultivar, age and vigor, soil fertility, water availability, and the presence of both abiotic and biotic stresses can influence fruit quality and market life. Bruising that occurs during harvest and postharvest handling can induce physiological breakdown and substantially reduce market life. Proper management of relative humidity (RH) and temperature during storage are also critical to maximize storage life. High RH can increase rates of decay and physiological breakdown; optimum storage humidities are around 80%. Cranberry fruit have been reported to be chilling sensitive and fruit stored at 0°C often have greater quality loss than fruit stored at 2 to 7°C. However, greater losses at low temperatures could be a result of high RH rather than low temperature. A variety of postharvest technologies have been tested to extend cranberry storage life, including controlled atmospheres, heat treatments, irradiation, and fumigation, but none have been shown to provide consistent benefits.

Keywords: decay, physiological breakdown, relative humidity, temperature, Vaccinium macrocarpon

Abbreviations: ABA, abscisic acid; FW, fresh weight; IAA, indole-3-acetic acid; LPE, lysophosphatidylethanolamine; RH, relative humidity; UV, ultraviolet

CONTENTS

INTRODUCTION .......................................................... 67
FRUIT BIOLOGY ........................................................ 68
CAUSES OF QUALITY LOSS ...................................... 68
Decay ........................................................................... 68
Physiological breakdown .......................................... 68
CULTURAL FACTORS AFFECTING MARKET LIFE ...... 69
Cultivar........................................................................ 69
Fertility ....................................................................... 69
Bog management ......................................................... 69
Fruit maturity ............................................................. 70
HARVEST METHOD .................................................. 70
STORAGE CONDITIONS ........................................... 71
Humidity ..................................................................... 71
Temperature ............................................................ 72
Atmosphere modification .......................................... 72
POSTHARVEST TREATMENTS .................................. 73
Heat .......................................................................... 73
Irradiation ................................................................... 73
Fumigation .................................................................. 73
Coatings ...................................................................... 74
CONCLUSIONS ....................................................... 74
ACKNOWLEDGEMENTS .......................................... 74
REFERENCES .......................................................... 74

INTRODUCTION

The American or large-fruited cranberry (Vaccinium macrocarpon Ait.) has been growing in popularity in North America for the past century and has been a traditional part of many Thanksgiving and Christmas meals. The cranberry is native to northeastern and north central North America where it grows in peat bogs and marshes (Roper and Vorsa 1997). Wild stands of the fruit were originally harvested and consumed by Native Americans and later European colonists. In the early 1800’s cranberries were first cultivated in Massachusetts and New Jersey (Caruso et al. 2000). Over
the years production has increased and spread to other areas of North America and the world. In recent years, increasing evidence has demonstrated health benefits due to the consumption of cranberry and cranberry products. Much of this focus has been on the benefits of cranberry in preventing urinary tract infections (Cimolai and Cimolai 2007; Jepson and Craig 2007) with some evidence suggesting possible reductions in cardiovascular diseases (Ruel and Coulombe 2002) and cancer (Netto 2007). This increasing interest in the health benefits of cranberries has further stimulated the demand for cranberry fruit and products.

While about 95% of cranberries are processed into juice, sauce, sweetened dried cranberries, and other processed products (Roper and Vorsa 1997), there is a potential growing market for fresh fruit. While cranberries are normally not consumed without some form of processing, the interest in fresh and natural foods is driving the increased consumption of fresh fruit. In addition, cranberry consumption has been growing beyond the traditional holiday meals creating new demand for fresh fruit in the late winter and spring months. In order to supply this growing demand, improved technologies are needed to maintain fruit quality and minimize storage losses.

Factors determining fresh fruit quality and storage life were recently reviewed (Forney 2003a). Since the publication of that review, additional research has been conducted to reassess optimum storage conditions and evaluate the effects of various technologies on the storage life of fresh cranberries. This paper reviews factors that determine fruit quality and storage life of fresh cranberries in light of this recent research.

FRUIT BIOLOGY

Cranberry fruit are true berries that are borne on short vertical uprights from the trailing stems of the cranberry plant. Fruit set occurs in late June and fruit ripeness appears by mid-September through early October depending on cultivar, season, and location. While up to seven flowers may be pollinated on each upright, generally only 1 to 3 fruit will successfully develop to full maturity (Hawker and Stang 1985; Brown and McNeil 2006). Fruit growth, when determined as an average of a population of fruit, was linear (Forsyth and Hall 1967; Hawker and Stang 1985) and driven by days at optimum growing temperatures of 16 to 30°C (DeMoranville et al. 1996).

Fruit ripening is primarily determined by anthocyanin formation that gives the fruit a dark red color. Ripening appears to be initiated by a combination of environmental factors including accumulation of growing degree days, photoperiod, and light exposure (Hawker and Stang 1985). As fruit turn from white to red, there is an increase in anthocyanin content (Forney et al. 2009). During this transition, the relative proportion of proanthocyanidins, flavonols, and anthocyanins shifts from 80, 20, and <1%, respectively, in white fruit to 50, 15, and 30% in red fruit (Vvedenskaya and Vorsa 2004), with anthocyanin concentration reaching 45 mg kg⁻¹ in the fruit (Ozgen et al. 2002). Soluble solids of ‘Stevens’ fruit were also higher in red fruit (9.2%) compared to white fruit (7.2%) (ÖZgen et al. 2002). Concentrations of glucose, fructose, and sucrose were 70, 12 and 2.3 mg g⁻¹ fresh weight (FW), respectively in red fruit compared to 45, 3.8, and 0.9 mg g⁻¹ FW in white fruit (Forney et al. 2009).

Similarly, the concentration of the dominant organic acids quinic, malic, and shikimic were 0.82, 0.36, and 0.01 mg g⁻¹ FW, respectively in red fruit (ÖZgen et al. 2002). Soluble solids of 0.005 mg g⁻¹ FW in white fruit (Forney et al. 2009). Cuticle thickness was greater in dark red fruit (11.7 μm) compared to white fruit (8.2 μm) and red fruit had a greater resistance to puncture (ÖZgen et al. 2002). As cranberry fruit develop, fruit respiration rates measured as O₂ consumption (Forsyth and Hall 1967) or CO₂ production (Forsyth and Hall 1969; Abdallah and Palta 1989) declined substantially. When CO₂ production was measured in fruit with different degrees of color development, rates decreased from about 28 mg kg⁻¹ h⁻¹ in white fruit to 17 mg kg⁻¹ h⁻¹ in red fruit with rates of light red and pink fruit being intermediate (ÖZgen et al. 2002). No rise in respiration rate has been associated with the initiation of color formation in the fruit (Forsyth and Hall 1967; Abdallah and Palta 1989).

A rise in ethylene production precedes the onset of anthocyanin formation in cranberry fruit and appears to persist during color development (Forsyth and Hall 1967; Forsyth and Stang 1985; Abdallah and Palta 1989). Application of (2-chloroethyl) phosphonic acid (ethephon), an ethylene-releasing compound, to cranberry fruit about 2 weeks prior to harvest can increase anthocyanin content and fruit color (Bramlage et al. 1972; Shawa 1979; Farag et al. 1992). Ethephon treatments were most effective in stimulating color development in immature berries, especially uncolored berries deep in the foliage that received little light (Rigby et al. 1972). While ethylene treatments stimulated color formation in cranberry fruit, it had no effect on fruit soluble solids, acidity or size (Shawa 1979). Application of the phospholipid lysophosphatidylethanolamine (LPE) to fruit 4 weeks prior to commercial harvest was reported to increase fruit anthocyanin content 9 to 27% compared to untreated fruit and it was suggested this effect may be the result of stimulation of ethylene production (ÖZgen et al. 2005). In addition, the preharvest application of the insecticide malathion (Eck 1968; Devlin et al. 1969) and the preemergence herbicide dichlobenil (diclobenil) (Devlin and Demoranville 1968) can stimulate color development. If fruit are harvested prior to obtaining optimum color, exposure of fruit to ethylene causes a slight stimulation of color formation (Craker 1971). However, exposure of fruit to light is more effective to stimulate postharvest color formation (Craker 1971; Zhou and Singh 2004; Forney et al. 2009). Neither preharvest treatments with indole-3-acetic acid (IAA) (Devlin et al. 1969) nor treatment of white harvested fruit with asbcsic acid (ABA) (Forney et al. 2009) stimulated color formation in cranberry fruit.

CAUSES OF QUALITY LOSS

Fruit quality loss during the postharvest storage and marketing of cranberry fruit is primarily the result of decay, physiological breakdown, and mechanical damage. Fruit for the fresh market are typically stored after harvest, and then graded to remove any defective fruit prior to packaging for the market (Hancock 1995). During storage, fruit losses can vary dramatically (Olatinwo et al. 2004) depending on a wide variety of known and unknown factors that affect rates of decay and/or physiological breakdown.

Decay

The decay of cranberry fruit in the field as well as during storage is caused by a complex of fungal organisms. Multiple fungi are often associated with the development of storage rot in cranberry (Olatinwo et al. 2004). The dynamic interaction of growing degree days, photoperiod, and light exposure (Hawker and Stang 1985). As a result of this disease complex, the visual symptoms of fruit decay often cannot be associated with specific pathogens (Olatinwo et al. 2003). Fungal organisms contributing to storage rot can vary substantially in different growing location and regions (Gourley et al. 1969; Oudemans et al. 1998; Stiles and Oudemans 1999; Olatinwo et al. 2004). Fungal pathogens commonly contributing to postharvest cranberry fruit decay and resulting diseases include Allantopompomopsis lycopodina (Hohn.) Carris (black rot), Allantopompomopsis cytopora (Fr.Fr.) Petr. (black rot), Strasseria geniculata (Berk. & Br.) Höhnel (black rot), Coleophomopsis empetri (Rostr.) Petr. (ripe rot), Fusicoccum putrefaciens Shear. (end rot), Phytophthora elongata G.J. Weidenb. (berry speckle), Physalospora vaccinii (Shear) Arx & E. Müller (blotch rot), and Botrytis spp.
Physiological breakdown

Physiological breakdown, also referred to as sterile breakdown, is characterized by a dull appearance, rubbery texture, and red discoloration of the fruit flesh that renders the fruit unmarketable (Fig. 1) (Terry et al. 2009). The cause of physiological breakdown is not well understood, but it is not caused by a fungal organism as seen in storage rots. Its development during storage has been associated with numerous factors including over-mature fruit (Doughty et al. 1967), bruising (Patterson et al. 1967), chilling injury (Hruschka 1970), freezing (Bristow and Patten 1995), extended water immersion (Ceponis and Stretch 1983), and anoxia (Stark et al. 1974). The occurrence of physiological breakdown increases with storage duration (Forney 2008), but is highly variable depending on cultural and environmental factors.

CULTURAL FACTORS AFFECTING MARKET LIFE

Cultivar

While fruit size, color, and other characteristics are dependent on cultivar (Eck 1990; Trehane 2004), cultivar effects on fruit storage life are less defined. Cultivars, compared within one season and location, have shown significant differences in rates of postharvest deterioration. When different cultivars were grown in Wisconsin and stored at 4°C, ‘Stevens’ and ‘McFarlin’ had the greatest storage life compared with ‘Howes’, ‘Scarles’, ‘Black Veil’, and ‘Metallic Belle’ (Swanson and Weckel 1975). Similarly, when New Jersey-grown cranberries were stored for 12 weeks at 3°C plus 4-d at 21°C, ‘Franklin’ and ‘Pilgrim’ were superior to ‘Early Black’, while ‘Ben Lear’, ‘Wilcox’, and ‘Stevens’ were intermediate (Stretch and Ceponis 1986). More recently Wang and Wang (2009) evaluated 9 cultivars stored for 3 to 4 months at temperatures ranging from 0 to 15°C and found ‘Crowly’, ‘Howes’, and ‘Pilgrim’ had the least amount of decay and physiological breakdown, while ‘Ben Lear’, ‘Cropper’, ‘Early Black’, and ‘Stevens’ had the most following storage at 0°C. However, when differences in rates of storage rot among 8 cultivars produced at 8 locations over 2 seasons were evaluated in Michigan following storage at 5°C for 2 months, considerable variability in storage life was observed and differences among cultivars were not significant (Olatinwo et al. 2004). In a more extensive study in Wisconsin, Boone (1994) evaluated 69 cultivars grown at one location over 10 seasons for development of storage rot following 4 months of refrigerated storage. He found cultivars with the poorest storage life to include ‘Prolific’, ‘Stankovich’ and ‘Pilgrim’, while those with the best storage life included ‘Howes’, ‘Early Black’, and ‘Rezin McFarlin’.

The variability in storage rot among cultivars could reflect possible variability in resistance of cultivars to specific pathogens. When fruit were assayed for fungal infections in Michigan, some cultivars yielded significantly more Colletotrichum acutatum or Phomopsis vaccinii than others (Olatinwo et al. 2004). Differences among cultivars in the incidence of fruit-rotting fungi were also found in Massachusetts (Oudemans et al. 1998). However, Stiles and Oudemans (1999) reported that rot resistance among 11 different cranberry cultivars grown in New Jersey was nonspecific since they had similar fungal profiles. To further complicate matters, cultivars were reported to vary in susceptibility to infection by specific fungi from one growing region to another (Olatinwo et al. 2004), suggesting interactions between genetic and environmental factors.

Fertility

Cranberry bog fertility can affect fruit quality and storage life. Increasing nitrogen fertility can stimulate plant growth, but may reduce fruit storage life. Enhanced vegetative growth can limit air movement, solar penetration, and pesticide penetration in the plant canopy. This may result in reduced fruit color development and increased fruit decay. In a limited study, Swanson and Weckel (1975) found that applications of 18.7 to 37.5 kg·ha⁻¹ of nitrogen (N) did not affect the quality of cranberry fruit following storage at 4 or 20°C. However, in a more extensive multiple year study across North America, fruit from cranberry bogs fertilized with 0, 22.0, or 44.0 kg·ha⁻¹ of N developed more storage rots with increasing N application following storage at 4°C (Davenport 1996). Application of calcium in foliar sprays during the growing season had no effect on incidence of storage rots, fruit Ca content, or resistance of the epidermis to puncture (Blodgett et al. 2002).

Bog management

Cultural management of cranberry bogs can affect fruit quality and decay in storage. Cultural practices, including pruning, that reduce vine overgrowth and increase air circulation and solar penetration in the cranberry canopy can reduce fruit rot (Oudemans et al. 1998). Removal of plant debris from the bog and good sanitation practices are also advised to minimize fungal inoculum (Oudemans et al. 1998). Management of flooding may also be a tool to reduce fruit decay and promote fruit ripening. Draining bog...
in early March for a month and then reflooding for a month, which is referred to as “late water”, is effective in reducing some disease and insect problems and improving fruit storage life in Massachusetts (Zuckerman 1958). However, this practice has not been beneficial in other growing areas. The practice of sanding, which entails the even distribution of 1.3 to 2.5 cm of sand over the bog during the winter every 2 to 5 years, improves vine vigor by burying runners and stimulating new root growth. Sanding can also reduce fruit decay by burying inoculum sources and thus reducing the amount of pathogen inoculum present (Oudemans et al. 1998).

Application of fungicides during bloom and early fruit set may reduce latent infections and fruit decay during storage, but its effectiveness is dependent on the fungicide used and timing of application (Jeffers 1991; Oudemans et al. 1998). Due to the diverse nature of the fungal pathogens affecting cranberry fruit, broad spectrum fungicides are most effective. Many of the newer fungicides that are more specific in their action are not effective in controlling fruit rot (Caruso 1990; Jeffers 1991). In a study assessing fruit from cranberry bogs throughout Michigan, the incidence of storage rot was not related to fungicide use (Olatunwo et al. 2004). Oudemans et al. (1998) suggest that many of the fungal organisms responsible for decay of cranberries take several years to complete an infection cycle and therefore the build up of inoculum and infection in the field may take years to develop. When fungicide applications were stopped, fruit rot increased progressively reaching about 50% after 3 years compared with an incidence of 2 to 10% in plots receiving fungicides (Oudemans et al. 1998).

Environmental factors during the growing season also affect cranberry fruit storage potential. Stevens (1932a) first suggested that factors such as temperature and rainfall impact fruit keeping quality, possibly by affecting rates of fungal infection and fruit physiology. Using weather data and storage records, he developed a model to predict fruit keeping quality. This predictive model was further refined by Franklin and Cross (1948), who also considered hours of sunlight. This model is still used in Massachusetts to predict the keeping quality of the current year’s cranberry crop.

**Fruit maturity**

Cranberry fruit maturity at the time of harvest can affect storage life. The thickening of the cuticle and slowing of respiration as the fruit ripens has been associated with longer storage life (Özgen et al. 2002). Özgen et al. (2002) observed that dark-red ‘Stevens’ fruit maintained more marketable fruit than light-red, blushed, or white fruit following storage. Ceponis and Stretch (1981, 1983) also found that within a harvest highly colored ‘Early Black’ fruit had less physiological breakdown than less colored fruit during storage, but when harvest was delayed, greater amounts of physiological breakdown occurred. They suggested that there may be a subtle distinction between color and maturity and that higher concentrations of fruit soluble solids and titratable acidity with reduced rates of physiological breakdown. Swanson and Weckel (1975) also found that green and white immature ‘McFarlin’ fruit break down more rapidly than mature fruit during storage at 4°C. In another study, ‘McFarlin’ fruit grown in Washington had less physiological breakdown and pathological rot when harvested 2 weeks prior to commercial maturity (11 weeks past full bloom) than when harvested at commercial maturity (13 weeks past full bloom) (Doughty et al. 1967). However, the method of harvest used for each fruit maturity was not reported. As discussed below, differences in physical abuse that could have occurred during the harvest process could have negated maturity effects in this study.

**Harvest Method**

Methods for harvesting cranberry fruit have evolved over the years with continued efforts to improve efficiency and reduce injury to the fruit (Eck 1990). Harvest methods have progressed from hand picking and scooping to dry and wet mechanical harvesting. Mechanical harvesting, which dominates the industry today, includes dry harvesting with machines using raking or scooping mechanisms. Since cranberry fruit float, they also can be harvested wet by flooding the bog and removing fruit from the plant with a water rake or a water reel harvesting machine. Wet harvesting can improve harvest efficiency, but water must be cool, immersion time limited and fruit dried after harvest to limit storage rot and physiological breakdown (Eck 1990). The harvesting process can cause significant damage to the fruit, which may result in increased rates of decay and physiological breakdown during storage and marketing. When 6 bogs containing ‘Stevens’ or ‘Bergman’ cranberry fruit were harvested by hand raking or mechanically by wet raking, mechanically harvested fruit had a reduced storage life (Forney 2005). After 1 month of storage, mechanically harvested fruit had 21% less marketable fruit than hand raked fruit, and this difference increased to 44% after 3 months (Fig. 2A). Mechanical harvesting increased both decay and physiological breakdown while reducing fruit storage life (Fig. 2C, 2E, 2G). When marketable fruit were held an additional week at 20°C, mechanically harvested fruit continued to have greater amounts of decay and physiological breakdown (Fig. 2D, 2F). Similarly, when cranberry fruit were harvested dry with a Ford Dry Harvester, 55% of the fruit were injured or developed breakthrough compared to only 3% for hand raked fruit (Davis and Shawa 1983). Modifications of the Ford harvester to reduce damage included a mechanical harvester to reduce fruit storage life. ‘McFarlin’ cranberries harvested with a water reel harvester also had several fold greater rates of spoilage during storage than fruit harvested by wet or dry raking (Swanson and Weckel 1975). Similarly, fruit losses during storage of 6 cultivars harvested with a water reel harvester were 2- to 4.6-fold greater than with hand picked fruit (Stretch and Ceponis 1986). The incidence of black rot during storage was greater in wet than dry harvested fruit (Stretch and Ceponis 1983, 1986). Prolonging water immersion during...
wet harvest increased both decay and physiological breakdown during storage (Ceponis and Stretch 1981, 1983). Bruising and other physical damage that occurs during harvest and postharvest handling may not be immediately apparent visually, but is expressed by increased fruit respiration, and subsequent softening, physiological breakdown, and decay of cranberry fruit (Forney 2005). Increasing numbers of 1-m drops to simulate commercial damage, increased respiration rates of cranberry fruit after 1 day. Respiration rate of fruit dropped 8 times doubled while that of fruit dropped only once increased 25% when compared to respiration rates of fruit that was not dropped (Fig. 3). Respiration rates remained elevated even after 7 days. Following 3 months of storage at 3°C, fruit dropped 1 m had 13% fewer marketable fruit, which declined a further 5% after an additional 7 days at 20°C when compared to fruit that was not dropped (Forney 2005). When ‘McFarlin’ cranberries were bruised by dropping a 100 g weight onto individual berries from a height of 23 cm, 90% of the bruised fruit softened during 60 d of storage while < 15% of unbruised berries softened (Graham et al. 1967). Bruise-induced softening was primarily a result of physiological breakdown, but fungi were associated with 9 and 39% of the fruit stored at 2 or 20°C, respectively. Fruit damage that occurs during harvesting, screening, grading and packaging of fruit may not be immediately apparent and can take hours to develop depending on the severity of the bruising (Massey et al. 1981). Fruit subjected to commercial screening, grading, and packaging had 39% of the fruit unmarketable due to heavy bruising or breakdown after 12 weeks of storage at 2.2°C compared to 27% unmarketable fruit in unhandled stored fruit (Massey et al. 1981). In observations made over 5 seasons, Norton (1982) reported that bruised fruit stored for several months had about 5 times more rot than unbruised fruit. Fruit softening that occurred with bruise-induced physiological breakdown was associated with induced polygalacturonase activity in the bruised fruit (Patterson et al. 1967). Impact bruising is cumulative and repeated small impacts are detrimental to storage life (Massey et al. 1981). Therefore, minimizing handling of fruit can result in improved performance during storage.

**STORAGE CONDITIONS**

**Humidity**

During extended periods of storage, the RH of the storage environment can have a greater effect on fruit storage life than temperature, with the greatest losses of marketable fruit occurring in high RH. In a 3-year study, Forney (2008) reported that after 2 months or longer storage, fruit losses were lower in low RH (75%) than in medium (82 to 88%) or high (~98%) RH, regardless of the storage temperature that ranged from 0 to 10°C (Fig. 4A). After 5 months, fruit stored in low RH had 45 and 244% more marketable fruit than those stored in medium or high RH, respectively. Even after marketable fruit were removed from storage and held an additional week at 20°C, fruit previously held in high RH continued to have the highest loss of marketability. These losses were the result of increases in both decay and physiological breakdown. In storage studies with ‘Early Black’ and ‘Howes’ cranberry fruit, Wright et al. (1937) concluded that a storage humidity of 70 to 75% RH favored better fruit storage life than 90 to 95% RH. Cranberry fruit stored under a 100% nitrogen atmosphere were also reported to have lower rates of decay when the humidity was maintained at 65 to 70% RH compared to 95 to 100% RH (Stark 1967). Similarly, fruit stored in polyethylene bags that maintained a high RH had more decay and physiological breakdown than fruit stored in boxes, well-ventilated bags, or unlined cartons (Anderson et al. 1963; Hruschka 1970). Adequate ventilation to maintain lower RH is beneficial to extend cranberry fruit storage life. Norton (1982) reported that fruit stored in ventilated bins for several months had lower < 40% rot compared to <20% in ventilated bins. Following a series of additional commercial-scale experiments, he found that storage rot was reduced when adequate ventilation was supplied through storage containers and RH was held near 70%. He concluded that proper air circulation removes moisture and other products of respiration that may be detrimental to fruit storage life.

Storing fruit in low RH with high ventilation increases fruit fresh weight loss. Norton (1982) reported weight loss of 1% every 12 days when fruit were stored in 70% RH with forced air ventilation, but he concluded that the resulting dehydration was an acceptable sacrifice to maintain satisfactory fruit quality. In another report, fruit held in 75% RH had twice the rate of fresh weight loss than fruit held in 98% RH (Forney 2008). While fruit firmness decreased during storage, the RH of the storage environment did not affect firmness. After 6 months of storage, firmness of marketable fruit was not significantly different among different storage humidities (Forney 2008). Interestingly, the cranberry fruit is able to maintain fruit firmness even with the potential loss of turgor in the low humidity storage.

Contrary to these results showing that cranberry fruit store longer under conditions of low RH and good ventilation, many published recommendations for cranberry storage call for storage RH levels to be ~90% (Hardenburg et al. 1986; Spayd et al. 1990; Kader 1997). It appears that these recommendations are based on the typical benefits of
high RH, which can reduce weight loss, minimize water stress, and slow senescence in many fresh fruits and vegetables. Consideration of the atypical response of fresh cranberry fruit to high RH reported in the literature may not have been fully considered.

**Temperature**

There are various recommendations for the optimum storage temperature for cranberry fruit, which may be due to the confounding factors previously discussed influencing the apparent response to temperature. Cranberry fruit have been considered to be chilling sensitive based on reports of their response to storage temperature (Wright et al. 1937; Levine et al. 1941; Anderson et al. 1963; Hruschka 1970). As a result, various handbooks recommend temperatures for the apparent response to temperature. Cranberry fruit have also have been induced by high RH or freezing if temperature had no significant effect on decay among fruit stored at 0 to 10°C throughout the 6 month storage period. When fruit were held an additional week at 20°C, there was no significant difference in total marketable fruit among fruit stored at 0 to 10°C within each monthly evaluation (Fig. 4B).

The classification of cranberries as chilling sensitive originates from several studies, including Wright et al. (1937) where large amounts of “sterile breakdown” (physiological breakdown) occurred when ‘Early Black’ and ‘Howes’ fruit were held at -1.1°C and to a lesser extent at 0°C. Since the freezing point of cranberries ranges from -1.4 to -0.9°C (Whiteman 1957), the physiological breakdown that occurred at -1.1°C was most likely freezing rather than chilling injury. In fact, they describe the fruit as having “the taste and appearance of frozen berries”. The cause of physiological breakdown that occurred at 0°C may also have been induced by high RH or freezing if temperature fluctuates in the refrigeration system occurred. The next coldest temperature tested was 2.2°C, at which the greatest percentage of marketable cranberries were found. Levine et al. (1941) also reported low temperature breakdown when ‘Early Black’ and ‘Howes’ fruit were stored at -1.1°C, which again was likely a result of freezing injury. They concluded that the best storage temperature was 1.7°C although rates of spoilage did not differ greatly in fruit stored at 1.7 to 7.2°C following 7 to 18 weeks of storage. Anderson et al. (1963) reported little difference in the spoilage of ‘Howes’ cranberries stored at 0 or 3.3°C in storage trials compared during the 1959 season but the following season decay and breakdown was less in fruit stored at 3.3 than 0°C, which suggested chilling injury. In addition to these observations, Hruschka (1970) reported an increase in physiological breakdown of ‘Early Black’ cranberries stored at 0.6°C after 12 to 20 weeks compared to fruit stored at 3.3°C after an additional week at 21.1°C. However, effects of humidity were not considered.

Chilling sensitivity of cranberries in these past studies could have been a response to RH rather than temperature. With the exception of the study by Wright et al. (1937), RH was not controlled in these studies. Since the water holding capacity of air decreases as temperature decreases, lower storage temperatures would tend to give rise to high RH. In addition, rates of air circulation, which affects the actual humidity surrounding the stored fruit, are not reported, but were likely low. Therefore, greater rates of physiological breakdown and/or decay that were attributed to chilling injury could have been a response to high RH at the reported chilling temperature.

In addition to humidity, other factors could affect the response of cranberries to storage temperature. Cultivar differences could contribute to apparent differences in chilling sensitivity. Wang and Wang (2009) compared the effects of storage at 0, 5, 10, and 15°C on the decay and physiological breakdown of 9 cranberry cultivars. After 3 or 4 months of storage at 0°C they reported high amounts of physiological breakdown and decay in ‘Ben Lear’, ‘Cropper’, ‘Early Black’; and ‘Stevens’, moderate amounts in ‘Franklin’ and ‘Wilcox’ and little in ‘Crowley’, ‘Howes’, and ‘Pilgram’. However, the confounding effects of humidity were not considered. Many preharvest environmental factors discussed earlier, including bog location, management practices, and weather conditions, can affect fruit storage life, but also may affect the response of the fruit to storage temperature. Fungal disease organisms responsible for storage decay can vary substantially among bogs (Olatinwo et al. 2004) and their impact on fruit decay may be determined by the fruit’s postharvest environment. In addition, the effects of fruit maturity, method of harvest, and postharvest handling on fruit storage life may each be modified by the storage environment. The potential complex interaction of factors that affect fruit decay and physiological breakdown with conditions of the storage environment could explain some of the reported variable responses to storage temperature and merit further investigation.

Many cranberries are stored in unrefrigerated buildings where fruit temperatures vary during storage depending on ambient conditions. However, using refrigeration to maintain a constant storage temperature can reduce storage losses. When ‘Howes’ cranberries were stored at a constant 4.4°C, 96% of the fruit were good after 6 weeks, 95% after 12 weeks, and 88% after 19 weeks (Ringel et al. 1959). This was superior to a simulated common storage, which was held at 15.6°C for 4 weeks, followed by 10.0°C for 5 weeks and 4.4°C for 10 weeks in which 93, 89, and 76% of the fruit were good after 6, 12, and 19 weeks of storage, respectively.

Precooling is the rapid removal of heat from freshly harvested produce to reduce respiration, retain fruit quality, and slow decay development. This process is commonly conducted on perishable fresh fruits and vegetables to maximize market life (Hardenberg et al. 1986). However, since cranberries are harvested late in the year when field temperatures are normally low, precooling is normally not done. Precooling of cranberries can be performed using cold air (forced-air) or water (hydrocooling). If significant field heat is present at the time of harvest, fruit may benefit from its rapid removal (Kaufman et al. 1958). If good air circulation is maintained through and around the fruit, room cooling can cool fruit to room temperature in 24 to 48 h.

In addition to the effect temperature can have on slowing decay and physiological breakdown, temperature also affects fruit color development during storage. At 2.2°C and above color tends to darken. At 10°C and above berries may become a solid red color, which may be darker than some markets desire (Wright et al. 1937). Color can be improved in early harvested fruit by storing at 7.2 to 10°C for several weeks (Levine et al. 1941).

**Atmosphere modification**

Controlled atmosphere (CA) storage of cranberry fruit does not provide extension of fruit storage life. In CA storage trials conducted with ‘Stevens’ fruit, no reduction of decay or physiological breakdown was observed in fruit stored in 0, 5, 10 or 15 kPa CO₂ in combination with 1 or 15 kPa O₂ at 5°C (Forney 2009). Similarly, ‘Howes’ cranberries stored in combinations of 0, 5, or 10 kPa CO₂ with 3, 10 or 21 kPa O₂ at 0 or 3.3°C had fruit losses greater than the air control (Anderson et al. 1963). If humidity was lowered in the CA chambers, some atmospheres gave results similar to the air controls, but no benefits were found. Stark et al. (1969a,
POSTHARVEST TREATMENTS

Heat

Short treatments using hot water or hot air can reduce decay and spoilage of fresh commodities during storage by killing pathogens or altering the physiology of the product. Hot water treatments of ‘Stevens’ cranberries that were conducted over 2 seasons reduced the loss of marketable fruit (Forney et al. 2003, 2004). In the first season, treatments consisting of 50°C for 90 or 180 seconds increased marketable fruit about 40 and 80% following 3 and 6 months of storage, respectively (Fig. 5A). Decay was reduced by about 20% by the heat treatments, while physiological breakdown was reduced by 13 to 36% after 3 months and 6 to 13% after 6 months. In the second season, where overall fruit loss during storage was higher, a 50°C treatment for 90 or 180 seconds increased marketable fruit 58 and 32% respectively, only after 6 months of storage. Heat treatments had no significant effect on marketability after 2 or 4 months of storage. When marketable fruit were held an additional 7 days at 20°C following storage, quality retention of heat treated fruit was not significantly different from controls in the 2003 season (Fig. 5B) as well as the 2004 season (Forney et al. 2004). A steam treatment of 50°C for 90 seconds also was effective in reducing decay of ‘Stevens’ cranberry fruit 34% and physiological breakdown 21% following storage for 4 months at 7°C (Forney et al. 2004). Anderson and Smith (1971) reported that hot water treatments of 49°C for 150 or 300 seconds and 52°C for 150 seconds had some benefits in prolonging cranberry storage life. However, treatments were less effective on late harvested fruit, where heat treatments increased physiological breakdown.

Irradiation

Ultraviolet (UV) radiation kills microorganisms and can induce resistance to decay in some fresh fruits and vegetables. ‘Howes’ cranberry fruit irradiated with 0.50-1.25 KJ m⁻² of UV-C radiation and then stored in the dark at 9°C and 95% RH for 16 weeks had up to 30% less spoilage than untreated fruit (Desjardins et al. 2000). The UV treatments caused a linear decrease in anthocyanin concentration as UV dose increased up to 5.25 KJ m⁻², but had little effect on soluble solids and titratable acids. However in a similar study, when ‘Stevens’ cranberry fruit were exposed to 0.5 to 2.0 KJ m⁻² of UV-C light prior to storage, no significant effects on fruit decay, physiological breakdown, marketability, firmness, or weight loss were observed following storage at 7°C for 3 or 6 months (Kalt et al. 2006). In addition, no effects of UV-C treatments were observed on phenolic or anthocyanin content or antioxidant capacity of the fruit.

Irradiation of cranberry fruit with 150 or 300 krad using a cobalt-60 source stimulated anthocyanin and flavonol production in red fruit during 1 to 2 months of storage (Lees and Francis 1972). Red pigment formation of the white flesh was observed during storage. Pigment formation in half-red fruit was less then that of red fruit as a result of irradiation, while pigment formation in pink fruit was inhibited. Irradiation caused some softening of the fruit, but it was not considered to be detrimental. No storage life enhancement by gamma radiation treatments was reported.

Exposure of cranberry fruit to high voltage electric fields of 2 to 8 kV cm⁻¹ for 30 to 120 minutes reduced the rise of respiration observed during storage at 23°C and 65% RH for 3 weeks (Palamimuthu et al. 2009). Treatments did not significantly affect weight loss, total soluble solids, L*, a* or b* color values, or fruit firmness during the 3 weeks of storage. The authors suggest the lower rates of respiration could extend fruit storage life but this is yet to be tested.

Fumigation

Fumigation treatments have not been effective in prolonging cranberry storage life. Ozone has strong antimicrobial properties and has been reported to reduce decay of some fruits and vegetables (Forney 2003b), however fumigation with gaseous ozone was not effective in maintaining cranberry fruit quality. Decay was not reduced in ‘Early Black’ fruit stored for 2 months at 4.4°C in a 0.27 μL L⁻¹ ozone atmosphere (Norton et al. 1968), while concentrations of 0.60 μL L⁻¹ ozone causes physiological damage in ‘Howes’ fruit after 5 weeks at 15.6°C, resulting in 2-fold more rot than in the controls. Cranberry fruit held in 0.60 μL L⁻¹ ozone had 25% less surface lipids compared to control fruit resulting in 3 times more weight loss than air-stored fruit. Ozone also induced a faint but pleasant flower-like aroma (Norton et al. 1968).

Fumigation with the natural volatile hexanal is reported to reduce decay in some whole and fresh cut fruit and has antifungal properties (Song et al. 2007). However, in studies conducted over 2 seasons where cranberry fruit were treated with 900 or 2000 μL L⁻¹ hexanal vapors prior to storage in air, treatments had no benefit in extending storage life (Forney et al. 2003, 2004). After 2, 4, or 6 months of storage at 3 or 7°C, the hexanal treatments had no significant effect on decay, physiological breakdown, marketability, weight loss, or fruit firmness.
Coatings

Cranberry fruit are normally not subjected to wax or other coatings prior to storage or marketing. However, one study suggests that coatings could extend fruit storage life. When cranberry fruit were coated with formulations of carnauba wax with or without the biological fungicide Biosave® (Ecoculture Produce Systems Division, Orlando, Fla.) prior to storage for 16 weeks at 13°C, fruit decay was reduced (Chen et al. 1999). After 16 weeks, carnauba wax alone reduced decay by 25%, while in combination with Biosave 110°, decay was reduced by about 33%.

CONCLUSIONS

The storage life of fresh cranberry fruit is influenced by many pre- and post-harvest factors. The quality of fruit obtained from cranberry cultivars is influenced by a variety of abiotic and biotic factors such as temperature, water, light, soil fertility, cultural practices and the presence of fungal pathogens. These factors affect the physiology and pathology of the fruit that ultimately determines its response to the postharvest environment and the expression of physiological breakdown and decay. The effects of physical handling of the fruit during harvest and postharvest handling are often not considered when conducting storage experiments or commercial storage of fruit. Bruising caused by handling can stimulate respiration and increase the susceptibility of the fruit to physiological breakdown or decay during storage. The RH of the storage environment has a strong effect on fruit with high RH accelerating the rate of decay and physiological breakdown, while low RH (70 to 80%) preserving fruit quality. The mechanisms by which RH affects fruit storage life need to be determined. Storage temperatures in the range of 0 to 10°C do not have strong and consistent effects on fruit quality and temperature effects may be confounded by RH, which brings into question the classification of cranberry as a chilling sensitive fruit. None of the postharvest technologies that have been tested including controlled atmospheres, heat treatments, irradiation, fumigation, or coatings have proven to be practical to apply or consistent in their benefit. Understanding the physiology and pathology of the cranberry fruit and how these aspects interact with the pre- and postharvest environment, provide many challenges for optimizing fruit market life.

ACKNOWLEDGEMENTS

Contribution no. 2371 of the Atlantic Food and Horticulture Research Centre, Agriculture and Agri-Food Canada. The author thanks Mr. Blake Johnston of Bezanson & Chace Cranberry Co Ltd., Aylesford, Nova Scotia for supplying fruit and financial support, Carol Domtray, Stephanie Bishop, Michele Elliott, Vivian Agar, and Jan Dick for providing technical support and Drs. Wilhelmma Kalt and Paul D. Hildebrand for their critical review of this manuscript.

REFERENCES


Ceponis MI, Strech AW (1983) Berry color, water-immersion time, rot, and physiological breakdown of cold-stored cranberry fruits. HortScience 18, 484-485


Clague JA, Fellers CR (1934) Relation of benzoic acid content and other constituents of cranberries to keeping quality. Plant Physiology 9, 631-636

Craker LE (1971) Postharvest color promotion in cranberry with ethylene. HortScience 6, 137-139


Devlin RM, Zuckerman BM, Demoranville IE (1969) Influence of preharvest applications of malathion and indole-3-lactic acid on anthocyanin development in Vaccinium macrocarpon, var. 'Early Black'. Journal of the American Society for Horticultural Science 94, 52-55

Doughty CC, Patterson ME, Shawa AY (1967) Storage longevity of the 'McFarlin' cranberry as influenced by certain growth retardants and stage of maturity. Proceedings of the American Society for Horticultural Science 91, 192-204

Eck P (1968) Chemical color enhancement of cranberry fruit. HortScience 3, 70-72


