Preharvest Factors Affecting Postharvest Quality of Berry Crops

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Various horticultural reviews or texts include some reference to preharvest effects on postharvest quality of berry crops in general (Beverly et al., 1993; Kader, 1988; Salunkhe et al. 1991). Some publications consider specific berry crops, such as 'Concord' grapes (*Vitis labrusca* L.) (Morris, 1985), kiwifruit [*Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson var. *deliciosa*] (Beever and Hopkirk, 1990), raspberry (*Rubus idaeus* L.) and related species (*Rubus* spp.) (Given, 1985; Robbins and Fellman, 1993), and strawberry (*Fragaria × ananassa* Duch.) (Given, 1985; Morris and Sistrunk, 1991; Sistrunk and Morris, 1985). Unlike these previous reviews, this review summarizes the effects of preharvest factors on postharvest quality of all the major temperate berry crops, i.e., strawberry, raspberry and related species, currant [*Ribes nigrum* L. (black), and *R. rubrum* L. (red)], blueberry [*Vaccinium corymbosum* L. (highbush), *V. angustifolium* Ait. (lowbush), and *V. ashei* Reade (rabbiteye)], cranberry (*Vaccinium macrocarpon* Ait.), kiwifruit, and grape (*Vitis* spp.).

The preharvest factors considered in this review are the same as those affecting other horticultural crops, such as genotype; climate; nutrient and water management, and other cultural practices; pests and diseases; and bioregulators. The same is true for the postharvest quality characteristics that are considered in this review, e.g., fruit size, shape, color, weight loss, firmness, decay, soluble solids concentration (SSC), titratable acidity, flavor, aroma, and nutritional value.

CROP GENETICS

Virtually all postharvest quality factors are genetically controlled and can vary with the cultivar (Beverly et al., 1993). Therefore, from a quality standpoint, cultivar selection may be the most important management decision in berry crop production. Successful breeding for fruit quality is best accomplished by integrating research in breeding, postharvest physiology, and food technology (Sistrunk and Morris, 1985).

The less perennial the berry crop, the less the impact of genetic makeup, as environmental and cultural practices exert more influence. For example, cultivar is considered the most important single factor affecting postharvest quality in a long-lived perennial berry crop like kiwifruit (Beever and Hopkirk, 1990), whereas it may be less dominant in strawberry. Variation in strawberry fruit quality at the same location due to seasonal temperature variation from one season to the next has been repeatedly observed (Sistrunk and Morris, 1985). Plocharski (1989), in a 24-year study of total solids, SSC, total acidity, and ascorbic acid in over 40 strawberry cultivars, observed that the largest variation among cultivars is in ascorbic acid content and the smallest in total solids. However, he noted that these four characteristics depend not only on genetic makeup but also on the season and degree of ripeness. Similar conclusions have been reached for raspberries (Lenartowicz et al., 1982).

Shaw (1990) indicates that, in strawberry, genetic expression of acidity is stable across test location and cultural treatments, whereas SSC in strawberry may depend more on environmental conditions than on genetic control. In raspberry, organic acid profiles are affected by cultivar and weather conditions from season to season (Riaz and Bushway, 1994).

Recent research shows that genetic control of berry fruit morphology influences not only fruit size and shape but also other quality factors. Olcott-Reid and Moore (1995) studied strawberry genotypic variation in flesh firmness, raised necks and reflexed calyxes, and subsequent fruit rot. Fruit rot was reduced not only with greater flesh firmness but also with raised necks and reflexed calyxes. In raspberry and related aggregate fruits, fruit morphological characteristics that influence fruit firmness include overall fruit size, hairiness, number and size of drupelets, receptacle cavity depth and width, and individual pit weight (Robbins and Fellman, 1993). The postharvest quality of the strawberry fruit types (primary, secondary, and tertiary) differs (Osman and Dodd, 1992). From primary to tertiary, titratable acidity increases and there is a reduction in size, with a corresponding increase in surface area to volume and loss of moisture and glossiness.

In some berry crops, such as blueberry, wet stem scars and the appearance of blue pigment before sweetening are undesirable qualities, which can vary among highbush blueberry cultivars (Pritts and Hancock, 1992) and lowbush blueberry clones (Kalt et al., 1995).

Disease resistance through genetics

Some experts consider the most important cultivar characteristic to be disease resistance, including diseases that diminish postharvest quality. The potential benefits and pitfalls of using classical and molecular approaches to breeding berry crops for disease resistance have been reviewed recently (Mehlenbacher, 1995). Control of some postharvest diseases may include breeding for resistance to the vector, e.g., aphid, nematode, leafhopper, or mite, rather than just for the pathogen. Compared to the major field crops, the effort in berry crops is quite small and, for some diseases, sources of resistance or methods of quickly and reliably identifying sources of resistance are not yet available. Using strawberry as an example, screening of new cultivars includes resistance for anthracnose (Galetta, 1981; Morris and Sistrunk, 1991). *Botrytis* resistance in strawberry is moderately heritable but seasonal variation is high (Galetta, 1981). Resistance to *Rhizopus*, *Mucor*, and *Penicillium* spp. (Maas, 1981), and spider mites (Barritt and Shanks, 1981) is also known in strawberry. Genetic transformation of strawberry, as well as other berry crops, is now routine (Mehlenbacher, 1995) but no transgenic cultivars have been produced that are resistant to diseases affecting postharvest quality. Future advances will depend on successful team efforts of plant breeders, plant pathologists, and molecular geneticists.

CLIMATE

The factors controlling photosynthesis, i.e., light, carbon dioxide, temperature, and water, as well as photoperiod, are the major environmental constraints on berry fruit quality (Beverly et al., 1993). On the macroclimate scale, these factors are virtually unmanageable, except through site selection. However, the microclimate within each planting can be influenced by plant spacing, pruning and training, and flower and fruit thinning. The goal is to increase both leaf and fruit exposure to light and to shift more photosynthate into the fruit, producing larger, better quality strawberries, raspberries, and blackberries (Given, 1985; Morris and Sistrunk, 1991) with raised SSC and anthocyanin concentration, firmer kiwifruit (Beever and Hopkirk, 1990), and a higher SSC and better color in grapes (Kliewer, 1977; Morris, 1985). Removing excess vegetative growth can also shift more water and calcium flow to the fruit, and improve fruit quality (Beverly et al., 1993).

High temperatures, e.g., day/night temperature of 37 °C/32 °C,

Received for publication 5 Feb. 1996. Accepted for publication 6 May 1996. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact. Contribution No. 2152 of the Atlantic Food and Horticulture Research Centre. We thank Jerry Miner (Librarian) and Pat Melanson for their assistance in literature searching.

inhibit anthocyanin formation and sugar accumulation in grape berries (Kliwer, 1977). This problem may not persist if the temperature drops, and the vines are in low light while at the high temperature. Grape berries are also physically damaged by excessive temperature. The damage may be only on the part exposed to the sun (producing Almeria spot) or whole berries may shrivel and turn brown (Pearson and Goheen, 1988). Similarly, in raspberries and blackberries, high temperatures and intense solar radiation can decrease anthocyanin concentration and titratable acidity (Given, 1985) and desiccate or bleach sections of the fruit (Ellis et al., 1991). In cranberry, solar injury to fruit is greatest on berries at the top of the canopy when ambient temperatures are above 26 °C, relative humidity is low, solar radiation levels are high (Caruso and Ramsdell, 1995), and soil moisture levels are exceptionally low (Croft, 1995).

Given (1985) states that increased sunshine hours and warm dry weather are associated with raised SSC and anthocyanin concentration in raspberries and blackberries. In three primocane-fruiting raspberry cultivars, Privé et al. (1993) conclude that soil temperature and available water are the two most influential climatic elements controlling berry size and yield, while daylength, solar radiation, and aboveground temperature have a lesser influence. Soil temperature has the largest influence during April and May, while water is equally influential at all times during the season. Air temperature and solar radiation have their largest influence during the period of flower initiation and development, i.e., June and July, while daylength is most influential from June to October.

Sunny days and cool nights tend to produce better flavor in strawberries than cloudy, humid days and nights (Morris and Sistrunk, 1991). Reduced light decreases strawberry pH, ascorbic acid concentration, color, SSC, and acidity, while increasing fruit firmness (Kader, 1988; Sistrunk and Moore, 1971). Strawberry fruit is softest immediately after a rain, and mold infections are high on strawberries from plants with heavy foliage, especially during periods of rainfall and high humidity (Morris and Sistrunk, 1991). Pritts and Hancock (1992) state that rain during harvest can adversely affect fruit quality of highbush blueberries because it delays harvest, washes off fungicides, softens berries, moistens stem scars, and splits berries, with an increase in disease as a consequence. High temperature combined with rain exacerbates these problems.

Saxena and Locascio (1968) cite evidence (Brown, 1919) suggesting that weather may have a greater influence on strawberry firmness than either N or K nutrition, with greater fruit softening with increased N during warm than during cool weather.

Air pollutants affect postharvest quality of berry crops. In grapes, ozone slightly reduces sugar content but not berry size or acid content (Pearson and Goheen, 1988).

NUTRIENT AND WATER MANAGEMENT AND OTHER CULTURAL PRACTICES

Nutrient management

Nitrogen (N). The application of N to increase leaf production and yield can lead to negative effects on fruit quality, even if N is not in excess. In a study on highbush blueberries (Ballinger and Kushman, 1969), application of N increased the fruit/leaf ratio, and decreased fruit size and acidity. A decrease in highbush blueberry fruit size has also been observed by Townsend (1973) in 2 of 3 years.

In cranberry, Atwood and Zuckerman (1961) compared five forms of N and concluded that N from slowly available sources and from nitrate result in fruit with the least amount of rot.

In grapes, increasing N reduces fruit color and SSC (Kliwer, 1977). Morris (1985) concluded that excessive amounts of N may adversely affect grape juice quality, mainly by reducing SSC, acidity, and/or tannins. However, the effect of N fertilization may be inconsistent. Sometimes N fertilization does not affect SSC or juice color (Spayd and Morris, 1978) or it may increase SSC (Morris et al., 1983b).

Morris and Sistrunk (1991) conclude that increasing N fertilization of strawberry generally leads to an increase in respiration rate, softer fruit, and lower SSC and total pectins, and these effects become more

pronounced in riper fruits. In frozen, sliced strawberry, the percent of broken slices and syrup flow rates increase and shearpess values decrease as the rate of N application increases.

In cranberry, increasing amounts of N fertilizer can increase fruit size (Eck, 1964), but can also result in soft, poor-storing fruit (Thienes, 1955) with increased fruit rot (Atwood and Zuckerman, 1961; Eck, 1976; Torio et al., 1966) and poorer (less red) berry color (Eaton, 1971; Eck, 1976; Francis and Atwood, 1961).

In kiwifruit, high fruit N results in faster loss of firmness after harvest and shorter storage life (Prasad et al., 1988). Fruit from vines with low N develop higher SSC and dry matter, along with more flavor, as rated by human judges, than the high N fruit.

Phosphorus (P). Szymoniak (1925) reported that P increases the size and firmness of strawberry fruit and reduces the proportion of culls. Application of P does not appear to have a consistent effect on grape juice quality. Some studies report no effect, some show a slight lowering in total acidity, and some report a favorable increase in SSC (Morris, 1985).

Eck (1964) claims that P may be the most important mineral nutrient influencing cranberry fruit characteristics since it increases fruit size and reduces fruit decay. Eaton (1971) cites cranberry data suggesting that increased tissue P may be related to an undesirable loss in redness of cranberry fruit. In highbush blueberry, Ballinger and Kushman (1969) state that low levels of P are associated with fewer leaves, a high fruit/leaf ratio, and small fruit, while Townsend (1973) found P application reduced fruit size in 1 of 3 years.

Potassium (K). Ferguson (1980) states that there is a relationship between pH regulation, organic acid levels, and K content of fruit. Potassium, which is the most mobile and abundant cation, is likely to be associated with high fruit acid levels. Fruit titratable acidity can increase with the amount of K fertilization. This has been observed in highbush blueberry (Ballinger and Kushman, 1969) and strawberry fruit (Saxena and Locascio, 1968). If K is deficient, strawberry fruit is soft with insipid flavor (Maas, 1984).

High pH in grapes at harvest can be a problem for the juice and wine industries because high pH values reduce color and stability of processed products (Morris et al., 1983a). Excessive K can contribute to this problem because K⁺ will substitute for H⁺ in the grape tissue and increase the pH. Excess K applications appear to have little effect if the grape acidity is high. However, if the grapes are low in acidity, which is more common in warm production regions, grape juice quality is adversely affected by excessive amounts of K application, mainly by reducing titratable acidity, increasing pH, and increasing color loss (Morris et al., 1980a; Morris and Cawthon, 1982; Morris et al., 1983a; Morris et al., 1987).

Eck (1983) observed that highbush blueberry fruit size is increased by K fertilization in 3 of 6 production years, whereas Townsend (1973) observed a decrease in blueberry fruit size in 1 of 3 years. Thienes (1955) claimed that fertilizing a cranberry bog with just K will reduce berry size and improve firmness and storage quality.

Calcium (Ca). Ever since Delong (1936, 1937) noted a relationship between fruit calcium deficiency and bitterpit, an apple fruit disorder, calcium content in fruits and vegetables has become associated with many aspects of postharvest quality.

In strawberry, if the plants are Ca deficient, the fruits are small, hard, sour, and seedy or with seedy patches (Maas, 1984). Eaves and Leefe (1962) reported that calcium sprays on strawberry plants, commencing at full bloom, result in firmer but less sweet fruit and that sprayed fruit develop necrotic spots during storage. Subsequently, Neal (1965) showed that solutions of various salts of divalent cations, e.g., Cu, Mg, and Ca, are effective in re-firming strawberry fruit tissue after initial softening with EDTA, whereas solutions of salts of monovalent cations, e.g., Na and K, are ineffective.

Foliar application of Ca to strawberries before harvest results in an increase in fruit Ca, and delays the development of gray mold and the progression of several signs of ripening, e.g., slower increase in anthocyanin and free sugar content, and a slower decline in organic acids and firmness (Chéour et al., 1990, 1991). The delay in ripening and gray mold (*Botrytis cinerea* Pers. ex Fr.) development increases with increasing Ca concentration. The ability to accumulate and distribute Ca may vary with cultivar, as the response to Ca treatment

is greater for 'Glooscap' strawberry, which contains less Ca and is softer than 'Kent' strawberry (Chéour et al., 1991).

However, Makus and Morris (1989) observed that soil or foliar applications of Ca to either a spring-flowering or a day-neutral strawberry cultivar only reduces storage decay, but has no effect on fruit Ca or fruit quality (firmness, SSC, pH, titratable acidity, and color).

In raspberry, Eaves et al. (1972) showed that preharvest sprays of Ca beginning 1 week before harvest increase fruit size and reduce softening and decay after harvest. Montealegre and Valdés (1993) indicate that foliar sprays containing Ca can decrease the susceptibility of raspberry fruits to an eventual infection by *Botrytis cinerea* during storage, since the sprayed fruits have a higher Ca content, reduced K/Ca ratio, and better resistance to pressure. In blackberry, preharvest Ca sprays reduce fruit SSC, but slow the rates of softening and acidity loss and darkening after harvest (Morris et al., 1980b).

Changwen and Shouru (1990) observed that preharvest Ca sprays on grape clusters increase fruit Ca, storage life, strength of attachment of stems to the fruit, and berry turgor pressure. Ca sprays also lower polyphenoloxidase activity and solute leakage, decrease the loss of soluble pectin, tannin, and ascorbic acid and reduce the incidence of internal grape berry browning.

Prasad et al. (1988) state that higher concentrations of fruit tissue Ca are related to slower softening of kiwifruit. Resnizky and Sive (1991, 1993) report a low correlation exists between fruit Ca at harvest and softening, but when they measured fruit firmness after long-term storage, the firm fruit had higher Ca levels than soft fruit. Gerasopoulos et al. (1996) showed that preharvest Ca sprays of kiwifruit increases harvest values for tissue calcium content, fruit firmness, and titratable acidity, but decreases SSC. In storage, the kiwifruit sprayed preharvest with Ca soften slower and storage life can be extended by 10 weeks and 18 weeks, at 20 °C and 0 °C, respectively.

In highbush blueberries, Ballinger and Kushman (1969) found that soil applications of Ca increase the F/L ratio (fruit count/leaf count) and decrease fruit size. Hanson (1995) reported that preharvest calcium sprays do not improve highbush blueberry quality.

Other Mineral Nutrients. In Mg-deficient strawberry plants, the berries may be soft and lighter in color than nondeficient berries (Maas, 1984). In kiwifruit, Resnizky and Sive (1991) found firmness after long-term storage to be positively associated with fruit Mg content.

In New Zealand kiwifruit orchards, excess soil B results in excessively high B in the leaves, which has no effect on fruit SSC or size, but reduces fruit count (Smith and Clark, 1989). Fruit on affected vines with excessive B prematurely soften, which is associated with a marked decline in fruit Ca.

Water Management

A deficiency or excess of water can influence postharvest quality of berry crops. Management of water frequently poses a dilemma between yield and postharvest quality. Extreme water stress will reduce yield and quality; mild water stress reduces crop yield but may benefit some quality attributes in the fruit; and no water stress will increase yield but may reduce fruit postharvest quality.

Reduction of water stress during maturation by natural rainfall, irrigation, or anti-transpirants may impair postharvest quality characteristics, especially if water is applied during the harvesting season, e.g., decreased firmness and sugar content and more favorable conditions for mechanical fruit injury and rot in strawberry (Sistrunk and Morris, 1985); reduced SSC content and pH, and poorer fruit color in blackberry (Morris and Sims, 1985); and lower SSC and poorer juice quality in grapes (Morris and Cawthon, 1982; Spayd and Morris, 1978).

If strawberry plants are over-irrigated, especially at harvest time, the fruit is softer and more susceptible to bruising and decay (Morris and Sistrunk, 1991). Sometimes the fruit color may become mottled (albino fruit) (Maas, 1984). The interior flesh of these fruit is more firm than normal fruit and the fruit tastes sour.

Other Cultural Practices

Ballinger and Kushman (1969) claim that the fruit count/leaf count ratio (F/L) influences highbush blueberry fruit quality more than

mineral nutrition. A high F/L results in later ripening, lower SSC, and smaller berries. During the harvest season, as berries are picked, SSC increases when the F/L ratio drops to between 1 and 2. They suggest this increase is due to fewer fruit competing for available substrate from the leaves. Sparks and Larsen (1966) observed a similar increase in grape SSC as the F/L declines but they noted that decreasing the ratio without leaf exposure to sunlight will not increase fruit SSC.

In general, berry crops have better postharvest fruit quality when the plant microclimate is improved by having an open canopy and maximum air circulation. Open canopies and optimum air circulation can be attained by the proper combination of plant spacing, vegetative thinning, and training. Plant vigor can be controlled by stem training and by avoiding high levels of N. This improves light penetration to leaves, ensuring that they continue to produce photosynthate and do not prematurely senesce and become pathogen hosts. An open canopy lowers the humidity around the plant, reduces wetting periods, and improves spray penetration, which reduces disease and insect problems and improves foliar nutrient application. An open canopy enables the pickers to harvest more rapidly, thereby decreasing the likelihood of overripe fruit (Pritts and Hancock, 1992).

Numerous studies show that improving light penetration into the canopy improves fruit composition of grapes (Bledsoe et al., 1988; Morrison and Noble, 1990), including increased SSC, anthocyanins, and total soluble phenols, and reduced titratable acidity, malate, pH, and potassium content. Shading results in significant differences in the aromas of fruit and wine (Morrison and Noble, 1990).

In kiwifruit, increases in shading reduces fruit count rather than individual fruit weight, delays harvest maturity, decreases SSC, and increases the rate of fruit softening during storage (Snelgar et al., 1991). In strawberry, Ferree and Stang (1988) found that shading reduces fruit count, increases individual fruit size, and delays maturity, whereas Osman and Dodd (1992) failed to find any shading effect on strawberry fruit weight or other quality criteria. In rabbiteye blueberry, fruit picked from more shaded parts of the canopy do not weigh less but are less blue than those more exposed (Patten et al., 1987).

Some berry crops suffer from postharvest insect and disease problems because of the presence of alternate hosts. The alternate hosts can be weed species or, in some cases, such as raspberry and blackberry, wild plants growing next to the crop. Some insects, such as the blueberry maggot (*Rhagoletis mendax* Curran), use weeds for shelter from wind and adverse weather conditions in lowbush blueberry fields, leading to higher fruit infestation levels (Geddes et al., 1992). In lowbush blueberry, the use of burning as a pruning method, instead of mowing, reduces some postharvest diseases (Lambert, 1990a, 1990b).

In cranberry, increasing weed competition, and concomitant shading decreases fruit size and color, but has no effect on fruit rot (Patten and Wang, 1994).

The balance between vegetative and fruit growth can be altered by girdling. Girdling the vines of grapes that have excessive vigor and a history of poor berry and bunch size results in bunch shape and berry size improvement and ripening delay in terms of low sugar/acid ratio and color intensity (Orth et al., 1989). They attributed the ripening delay to an increased yield (crop load) per vine. Girdling also increases fruit rot due to the increase in bunch mass.

In blueberry, poor pollination can reduce fruit quality (Pritts and Hancock, 1992). If there is insufficient pollination, the berries will be smaller and will ripen later. Similarly, honeybee pollination of some strawberry cultivars improves fruit size and quality (O'Dell, 1995).

PESTS AND DISEASES

Virtually all of the pests and diseases that reduce postharvest quality in berry crops attack the fruit before harvest. Detailed information on all pests and diseases will not be provided, as there are excellent publications on this topic, particularly the Compendium series of the American Phytopathological Society, which includes strawberry (Maas, 1984), grapes (Pearson and Goheen, 1988), raspberry and blackberry (Ellis et al., 1991), and blueberry and cranberry (Caruso and Ramsdell, 1995).

In strawberry, insects known to damage or destroy floral parts are the meadow spittle bug (*Philaenus spumarius* L.), tarnished plant bug (*Lygus lineolaris* Palisot de Beauvois), and mites and thrips; the feeding of these insects results in misshaped fruit (Maas, 1984). The strawberry sap beetle and slugs eat cavities into the ripe fruit and also spread fruit rot organisms as they move from fruit to fruit.

In raspberry and blackberry, fruit can be infested by adults of picnic beetles, *Glischrochilus* spp., and larvae of raspberry fruitworms, *Byturus* spp.

Highbush blueberry fruit can be infested by scarab beetles (family Scarabaeidae) and larvae of cranberry fruitworm (*Acrobasis vaccinii* Riley), cherry fruitworm (*Grapholita packardii* Zeller), blueberry maggot, and plum curculio (*Conotrachelus nenuphar* Herbst). Some of these insects also infest fruit of other species of blueberry and cranberry (Pritts and Hancock, 1992).

Leafrollers (Lepidoptera) are the worst pests of kiwifruit (Steven, 1990) because of the fruit scarring they can cause. Greedy scale, *Hemiberlesia rapax* Comstock, is considered the second most important pest, because it can infest fruits and has been considered a quarantine problem when on fruit for export.

In grapes, spider mites, mites, and thrips can attack the fruit, causing fruit scarring that allows the entry of rot organisms and increased water loss (Pearson and Goheen, 1988).

Fruit decay due to fungal pathogens is considered to be a major cause of postharvest quality loss in fresh strawberry (Morris and Sistrunk, 1991), raspberry (Ellis et al., 1991) and blueberry (Cappellini et al., 1982). The most damaging fruit fungal rot in berry crops is *Botrytis cinerea* (gray mold rot) (Dennis, 1983). Gray mold is ubiquitous and will dramatically reduce fruit quality unless control measures are applied throughout the growing season every year. However, gray mold rot can, in certain grape cultivars and under certain climatic conditions during harvest, be beneficial, because it will accelerate water loss and contribute to the production of exceptionally sweet white wines.

Some major fruit diseases are restricted to certain berry crops. The powdery mildew fungus, *Uncinula necator* (Schw.) Burr., is known to attack only grape and other members of the Vitaceae. The fungus can infect the fruit, rendering them unmarketable as fresh fruit and producing off-flavors in wine (Pearson and Goheen, 1988). Grape downy mildew [*Plasmopara viticola* (Berk. & Curt.) Berl. & de Toni] and black rot [*Guignardia bidwellii* (Ellis) Viala & Ravaz] are major causes of fruit rot in grape but not in other berry crops. Similarly, bitter rot, *Greeneria uvicola* (Berk. & Curt.) Punithalingam, is only a problem in grape, making the fruit soft and bitter. The unpleasant, bitter flavor is carried through the winemaking process.

Stamen blight, *Haplospheeria deformans* (Syd.) Syd., occurs only on *Rubus* spp. (Ellis et al., 1991). If the flowers have been infected, the berries can become dry, seedy, and malformed. They are more firmly attached to the receptacle than normal, making harvesting more difficult and resulting in more crushed and wet fruit.

Black sooty molds, which are nonpathogenic fungi, such as *Meliola nidulans* (Schwein.) Cooke (Caruso and Ramsdell, 1995), may lower the quality and marketability of cultivated blueberry (Caruso and Ramsdell, 1995) or kiwifruit (Steven, 1990) due solely to unsightly superficial black stains. They grow on the surface of the fruit using honeydew excretions of various scales, aphids, and mealybugs, or passionvine hopper, *Scolypopa australis* (Walker) (kiwifruit only) as a source of nutrition.

A summary of additional fungal diseases causing quality loss in fresh berry fruits are listed in Tables 1 and 2, with the causal organisms and susceptible berry crops.

Some fungi do not cause a postharvest problem in fresh fruit but can be a problem in processed fruit. These are fungi occurring in the field that contaminate the fruit with heat-tolerant ascospores that may survive pasteurization and cause spoilage in acidic food products, such as processed strawberry products (Hocking and Pitt, 1984; Kavanagh et al., 1963; Olliver and Rendle, 1934; Put and Kruiswijk, 1964; Richardson, 1965), canned blueberry (Raper and Fennell, 1948; Williams et al., 1941), and grape products (King et al., 1969). Heat-tolerant molds have been detected on soil and field-sampled fruit from various tree and berry crops, including strawberry, gooseberry, rasp-

berry, loganberry, blackberry (Olliver and Rendle, 1934; Splittstoesser et al., 1971), grape (King et al., 1969; Splittstoesser et al., 1971), and lowbush blueberry (Lambert, 1990b).

Among bacterial diseases, fire blight, *Erwinia amylovora* (Burr.) Winslow et al., is known to infect raspberry and blackberry fruit and reduce the crop quality (Ellis et al., 1991).

Some viruses and virus-like agents can reduce fruit quality. In grapes, tomato ringspot virus and leafroll alter ripening and reduce anthocyanin and sugar content (Pearson and Goheen, 1988). In raspberries and blackberries, quality is reduced by the presence of raspberry mosaic disease, raspberry leaf curl, and tomato ringspot virus (Ellis et al., 1991). In blueberries, blueberry shoestring virus, tomato ringspot virus, red ringspot virus, and mosaic reduce fruit quality (Caruso and Ramsdell, 1995; Pritts and Hancock, 1992). Red ringspot virus also reduces berry quality in cranberry (Caruso and Ramsdell, 1995).

BIOREGULATORS

Ethylene and ethylene-releasing compounds can promote various ripening responses in grape (Morris and Cawthon, 1981), currant, blueberry, raspberry (Bangerth, 1983), cranberry (Eck, 1986, 1990), and blackberry (Burdon and Sexton, 1993; Lipe, 1980; Morris et al., 1978). One of the effects of ethylene is the induction of an abscission layer, which decreases the fruit removal force and improves stem scar healing. More detailed information on plant responses to ethylene is available in other publications, e.g., Abeles et al. (1992).

The responsiveness to ethylene is species, cultivar, concentration, temperature, and growth stage-specific and may not provide desirable results. For example, ethephon (2-chloroethyl phosphonic acid) sprayed on highbush and rabbiteye blueberry before harvest accelerates fruit ripening (Dekazos, 1978; Eck, 1970; Warren et al., 1973). Size, SSC, and acidity changes in these fruit are variable and may depend on the fruit growth stage when ethephon is applied (Dekazos, 1978; Eck, 1970; Warren et al., 1973). Ethephon also reduces postharvest rots in highbush blueberry fruit, because it apparently diminishes the vulnerability of the stem scar to infections that produce postharvest rots (Capellini et al., 1979). Ethephon improves color and increases SSC accumulation in some *Vitis vinifera* grape cultivars, but it does not influence maturation of *V. labrusca* cultivars (Morris and Cawthon, 1981). 'Thompson Seedless' grapes treated preharvest with either chlormequat (CCC) or indoleacetic acid (IAA) store better at 3 °C than grapes treated with gibberellic acid (GA₃) or ethephon (Al-Juboory et al., 1990). Ethephon increases grape shattering, decay, and weight loss, compared with the three other bioregulators. Ethephon does not affect abscission, fruit size, acidity, or SSC in cranberry, but does increase anthocyanin content (Shawa, 1979).

Inhibitors of ethylene biosynthesis and ethylene action can reverse the effects of ethylene or ethylene-releasing compounds. Aminoethoxyvinylglycine (AVG) delays highbush blueberry ripening but does not affect SSC, titratable acids, or fruit size of ripe fruit (Dekazos, 1978). In rabbiteye blueberry, foliar sprays of metabolic inhibitors, abscisic acid, and phenylmercuric acetate, and commercial anti-transpirant sprays are effective, separately or in combination, at increasing SSC, berry weight, volume, and yield, but berry firmness and pH are decreased (Hussin and Basiouny, 1984).

In seedless grapes, GA₃ increases fruit size (Bangerth, 1983). Bangerth (1983) claims that in some seeded fruits, including wine grapes and currants, GA₃ induces a reduction in the number of seeds, advances maturity, and stimulates early sugar accumulation and acid catabolism, which may be of advantage in areas where there is a short autumn season. In highbush blueberry, GA₃ reduces seed weight per fruit, but has no consistent effect on maturity and does not affect SSC content or titratable acidity (Hooks and Kenworthy, 1971). Gibberellic acid may be useful in decreasing cluster compactness of grapes, since it can reduce the number of berries per cluster (Pearson and Goheen, 1988). A looser cluster can reduce the spread of fungal infection.

Some pesticides can have bioregulator effects that affect postharvest quality. Anthocyanin content of cranberry, which is a desirable postharvest attribute, can be increased by malathion (O,O-dimethyl phosphorodithioate of dimethylmercaptosuccinate or diethyl

mercaptosuccinate, S-ester with O,O-dimethyl phosphorodithioate; insecticide), dichlobenil (2,6-dichlorobenzonitrile; herbicide), or ferbam (ferric dimethyldithiocarbamate; fungicide), whereas the fungicides zineb (zinc ethylenebisdithiocarbamate), phaltan (N-[(Trichloromethyl)thio]phthalimide), and maneb (manganese ethylenebisdithiocarbamate) may reduce anthocyanin production (Eck, 1986, 1990). Highbush blueberry fruit sprayed with malathion mature earlier and have lower acidity and higher SSC than untreated fruit (Hall and Forsyth, 1969). Furthermore, the malathion-treated highbush blueberry fruit produce less methyl acetate and ethyl alcohol volatiles, compared to untreated fruit.

However, various chemical pesticides can reduce postharvest fruit quality because of their toxicity. Examples are misshapen strawberry fruit caused by 2,4-D (2,4-dichlorophenoxyacetic acid) (Maas, 1984), injured cranberry fruit caused by chlorpyrifos ((O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate) and chlorothalonil (tetrachloroisophthalonitrile) (Caruso and Ramsdell, 1995), and dam-

aged grapes caused by sulfur and copper fungicides, dinocap (2,4-dinitro-6-octyl-phenyl-crotonate, 2,6-dinitro-4-octyl-phenyl crotonate and nitrooctyl-phenols), and phosalone (S-[(6-chloro-2-oxo-3(2H)-benzoxazolyl)methyl]O,O-diethyl phosphorodithioate) (Pearson and Goheen, 1988). Purple berry, a postharvest storage disorder in cranberry, tends to be promoted by applications of fungicide (Caruso and Ramsdell, 1995).

Some fungicides can affect flavor. The fungicides captan (N-trichloromethylthio-4-cyclohexene-1,2-dicarboximide), thiram (tetramethylthiuram disulfide), and prochloraz (1-N-propyl-N-[2-(2,4,6-trichlorophenoxy)ethyl]carbamoyl)imidazole) are reported to induce taints in strawberries (Given, 1985). The sugar content of strawberries decreases and the acid content increases when the fruit are sprayed with vinclozolin (3-(3,5-dichlorophenyl)-5-methyl-5-vinyl-1,3-oxazolidine-2,4-dione) or dichlofluanid (1,1-dichloro-N-[(dimethylamino)sulfonyl]-1-fluoro-N-phenylmethanesulfenamide), and consumers prefer unsprayed fruit (Given, 1985).

Table 1. Postharvest fungal diseases, in addition to *Botrytis cinerea*, known to occur in more than one berry crop (Brook, 1990; Caruso and Ramsdell, 1995; Dennis, 1983; Ellis et al., 1991; Lambert, 1990b; Maas, 1984; Pearson and Goheen, 1988).

Disease	Scientific name(s)	Affected crop(s)
Anthraxnose or bitter rot	<i>Colletotrichum gloeosporioides</i> (Penz.) Penz. & Sacc. in Penz. [= <i>Glomerella cingulata</i> (Ston.) Spauld. & Schrenk]	strawberry, <i>Rubus</i> spp., grape, blueberry (highbush, rabbiteye, lowbush)
Gloeosporium stem and leaf spot	<i>Gloeosporium minus</i> Shear	blueberry (highbush, rabbiteye, lowbush), cranberry
Soft rot (Leak disease)	<i>Rhizopus</i> spp., <i>Mucor</i> spp.	strawberry, <i>Rubus</i> spp., gooseberry, grape, blueberry (lowbush)
Alternaria rot	<i>Alternaria</i> spp.	strawberry, <i>Rubus</i> spp., blueberry (highbush, rabbiteye, lowbush), gooseberry, grape, kiwifruit
Cladosporium rot	<i>Cladosporium</i> spp.	strawberry, <i>Rubus</i> spp., grape, cranberry
Sclerotinia rot	<i>Sclerotinia sclerotiorum</i> (Lib.) de Bary	strawberry, grape, kiwifruit
Macrophoma, Phyllosticta, Botryosphaeria or early rot	<i>Botryosphaeria</i> spp., <i>Phyllosticta</i> spp.	grape, kiwifruit, blueberry (highbush, rabbiteye), cranberry
Phomopsis or viscid rot	<i>Phomopsis</i> spp.	strawberry, grape, kiwifruit, blueberry (highbush, rabbiteye), cranberry
Penicillium rot	<i>Penicillium</i> spp.	strawberry, <i>Rubus</i> spp., grape, kiwifruit, blueberry (lowbush), cranberry
Aspergillus rot	<i>Aspergillus</i> spp.	strawberry, grape, blueberry (lowbush), cranberry

Table 2. Additional examples of postharvest fungal diseases known to occur in only one berry crop (Brook, 1990; Caruso and Ramsdell, 1995; Dennis, 1983; Ellis et al., 1991; Maas, 1984; Pearson and Goheen, 1988).

Crop	Scientific name	Disease	Common name
Strawberry	<i>Discohainesia oenotherae</i> (Cke. & Ell.) Nannf.		Tan-brown rot
	<i>Phytophthora cactorum</i> (Leb. & Cohn) Schroet.		Leather rot
	<i>Sphaerotheca macularis</i> (Wallr. ex Fr.) Jacz.		Powdery mildew
	<i>Rhizoctonia solani</i> Kuehn		Rhizoctonia rot (hard rot)
	<i>Gnomonia comari</i> Karsten		Stem-end rot
	<i>Mycosphaerella fragariae</i> (Tul.) Lindau		Black seed disease
	<i>Pestalotia longisetula</i> Guba		Pestalotia rot
Grapes	<i>Elsinoë ampelina</i> (de Bary) Shear		Grape anthracnose
	<i>Pseudopezicula tracheiphila</i> (Müll-Thurg.) Korf & Zhuang		rotbrenner
	<i>Coniella diplodiella</i> (Speg.) Petrak & Sydow		white rot
	<i>Diplodia natalensis</i> Pole Evans		Diplodia bunch rot
Cranberry	<i>Allantophomopsis</i> spp.		black rot
	<i>Strasseria geniculata</i> (Berk. & Broome) Höhn		
	<i>Phyalospora vaccinii</i> (Shear) Arx & E. Müller		blotch rot
	<i>Monilinia oxycocci</i> (Woromin) Honey		cottonball
	<i>Godronia cassandra</i> Peck f. <i>vaccinii</i> Groves		end rot
	<i>Protoventuria myrtilli</i> (Cooke) Barr		Protoventuria berry speckle
	<i>Coleophoma empetri</i> (Rostr.) Petr.		ripe rot
	<i>Aureobasidium pullulans</i> (de Bary) G. Arnaud		
	<i>Pestalotia vaccinii</i> (Shear) Guba		
	<i>Sphaeropsis vaccinii</i> W.B. Cooke & C.G. Shaw		
	<i>Synchronoblastica crypta</i> Uecker & Caruso		
Kiwifruit	<i>Fusarium acuminatum</i> Ellis & Everh.		
	<i>Cryptosporiopsis</i> spp.		
	<i>Diaporthe</i> spp.		
	<i>Colletotrichum acutatum</i> J.H. Simmonds		
	<i>Botryosphaeria parva</i>		
	<i>Fusicoccum luteum</i>		
	<i>Cryptosporiopsis</i> sp.		

CONCLUSIONS

No preharvest factor is unique to berry crops. Furthermore, the range of berry crop responses to these preharvest factors is not dramatically different from those observed on other horticultural crops.

Although most postharvest quality characteristics are genetically based and choice of cultivar is important in determining many postharvest quality characteristics, genetic selection has not provided adequate resistance to fruit decay, the major cause of postharvest quality loss in many berry crops. Virtually all of the fruit decay is caused by fungal pathogens, especially by *Botrytis cinerea*.

It is very difficult to maximize fruit yield and quality. Preharvest factors that increase yield, especially the addition of N and water, tend to reduce postharvest quality and increase the likelihood of decay.

Improving the Ca content of the fruit improves postharvest quality. However, the application of other minerals and bioregulators produces inconsistent effects on postharvest quality of berry crops.

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