

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 (Galletta, 1981; Morris and Sistrunk, 1991). *Botrytis* resistance in strawberry is moderately heritable but seasonal variation is high (Galletta, 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 (Kliwer, 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,

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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 shearpres 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