Orchard Factors Affecting Postharvest Stone Fruit Quality

Carlos H. Crisosto[1], R. Scott Johnson[2], and Ted DeJong[4]

Pomology Department, University of California, Davis, at Kearney Agricultural Center, 9240 South Riverbend Avenue, Parlier, CA 93648

Kevin R. Day[3]

University of California Cooperative Extension, Tulare County Agricultural Building, County Civic Center, Visalia, CA 93291

Although stone fruit quality cannot be improved, only maintained, after harvest, little research has been conducted on the influence of preharvest factors on stone fruit postharvest quality and potential postharvest life. We believe that the maximum fruit quality for each cultivar can be achieved only by understanding the roles of preharvest factors in fruit quality. This article reviews the influences of orchard factors, such as mineral nutrition, irrigation, crop load, and fruit canopy position on fruit quality, market life potential, and internal breakdown (IB). The literature indicates that quality, market life, and IB are related to preharvest factors. Thus, there is a need to continue studying these factors to deliver high quality fruit to the consumer.

In recent years the production of stone fruits has increased rapidly, but consumption has remained low at ≈2.7 kg•year^{-1} per capita for nectarines and peaches and ≈0.6 kg•year^{-1} per capita for plums and fresh prunes (U.S. Dept. of Agr., 1994). Surveys conducted to explain the low rate of consumption of stone fruits found that consumers were bothered mainly by lack of flavor and IB problems (Bruhn et al., 1991). Since production is still increasing, more attention must be given to the production and delivery of high-quality stone fruits to increase consumer demand.

Studies have associated high consumer acceptance with high soluble solids concentration (SSC) in many commodities (Kader, 1994; Parker et al., 1991), but there are more factors involved, such as acidity (Kader, 1994; Peterson and Ivans, 1988), SSC/acidity ratio (Kader, 1994; Nelson, 1985; Rodan, 1988), phenolics (Robertson and Meredith, 1989), and volatiles (Romani, 1971). In peach [*Prunus persica* (L.) Batsch], plum (*Prunus salicina* Lindel.), and nectarine [*Prunus persica* var. nectarine (L.) Batsch], there is limited information on the relationship between consumer acceptance and ripe fruit chemical composition (Claypool, 1977; Kader, 1994; Mitchell et al., 1990). Since we do not have enough information on this subject, we are not able to propose any quality standards without detailed studies to support them (Crisosto, 1994a).

One important complex cause of quality deterioration and consumer complaints in apricots (*Prunus armeniaca* L.), peaches, nectarines, plums, and prunes (*Prunus domestica* L.) is the presence of flesh browning, flesh mealiness, darkened pit cavity, flesh translucence, red pigment accumulation (bleeding), and loss of flavor (Crisosto et al., 1995a, 1995b; Mitchell and Kader, 1989). These symptoms result from IB, which is also called chilling injury, dry fruit, or woolliness. IB normally appears during prolonged cold storage and/or after ripening at room temperature following cold storage. This disorder is the main limitation to long-term storage and shipping to distant markets for IB-susceptible cultivars. There is little published information on the possible influence of preharvest factors on IB incidence (Claypool, 1977; Saenz, 1991).

During the past 10 years, increased research emphasis has been placed on harvest maturity (Kader and Mitchell, 1989) and postharvest temperature management (Mitchell, 1987, 1989). However, little attention has been given to the influence of preharvest cultural practices on stone fruit quality and IB (Kader, 1988). The first step to assure high quality produce for the consumer is to maximize "orchard quality." We believe that, to maximize "orchard quality," all of the preharvest factors influencing fruit quality must be investigated and understood. This review describes the current information on the influence of preharvest factors, such as mineral nutrition, foliar nutrient sprays, irrigation regimes, girdling, crop load, and fruit canopy position on peach, nectarine, and plum fruit quality and IB incidence.

Mineral Nutrition. The nutrient with the single greatest effect on fruit quality is nitrogen (N). Research performed over the last 10 years at the Kearney Agricultural Center (Daane et al., 1995) has established that peaches and nectarines, grown under California conditions, should be kept between 2.6% and 3.0% leaf N for best fruit quality. Response of peach and nectarine trees to N fertilization is dramatic; high N levels stimulate vigorous vegetative growth, causing shading out of lower fruiting wood and its death (Crisosto et al., 1995b). Although high N trees may look healthy and lush, excess N does not increase fruit size, production, or SSC.

Furthermore, excessive N delays stone fruit maturity, induces poor visual red color development (Table 1), and inhibits ground color change from green to yellow. However, N deficiency leads to small fruit with poor flavor and unproductive trees (Daane et al., 1995).

In a 3-year study on 'Fantasia' nectarine (Daane et al., 1995), varying N fertilization did not affect quality measured at harvest and after various storage periods for fruit harvested at the same maturity, as based on firmness. Nitrogen fertilization rates from 0 to 364 kg•ha^{-1}•year^{-1} did not affect the rate of fruit ripening or susceptibility to physical damage (abrasion, vibration, and impact). The N treatments, which produced leaf N concentrations that varied from 2.6% to 3.6% did not affect the incidence of IB in 'Fantasia' nectarines during 6 weeks of storage at 0 °C or 5 °C (32 °F or 41 °F) (Crisosto et al., 1995b). Water loss from fruit from the highest N rate (3.6% leaf N) was greater than that from the lowest rate (2.6% leaf N). Fruit gas exchange (permeability to CO_2 and C_2H_4) and cuticle thickness also varied with N rates. Resistance to CO_2 and C_2H_4 was low in fruit from the higher N rates (Table 2).

The relationship between fruit N concentration and fruit susceptibility to brown rot [*Monolinia fructicola* (Wint.) Honey] has been extensively studied on stored nectarine fruit (Michailides et al., 1993). Wounded and brown-rot inoculated fruit from 'Fantasia' and 'Flavortop' trees having more than 2.6% leaf N were more susceptible to brown rot than fruit from trees with 2.6% or less leaf N. Fruit anatomical observations and cuticle density measurements indicated

Table 1. Relationship between leaf nitrogen and percent of fruit surface that is red, yield and fruit size (mean for 3 years) on 'Fantasia' nectarine.

N-Fertilization treatment (kg N/ha)	Leaf N (%)	Visual redness (%)	Yield (kg/tree)	Fruit weight (g)
0	2.7 a[z]	92 a	132 a	131 a
112	3.0 b	80 b	207 b	166 b
196	3.1 c	72 c	193 b	168 b
280	3.5 d	69 c	222 b	169 b
364	3.5 d	70 c	197 b	167 b

[z]Mean separation within columns by LSD test at $P \geq 0.05$.
Adapted from Daane et al., 1995.

Received for publication 5 Feb. 1996. Accepted for publication 8 June 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. Research conducted at Kearney Agricultural Center, Parlier, Calif. Use of trade names does not imply endorsement of the products named nor criticism of similar ones not named.
[1]Extension Postharvest Physiologist.
[2]Extension Pomologist.
[3]Pomology Farm Advisor.
[4]Pomologist.

differences in cuticle thickness among 'Fantasia' fruit from the low, middle, and high N treatments, but this can only partially explain the differences in fruit susceptibility to this disease (Michailides et al., 1995).

Foliar nutrient sprays. Little research has been done on the effect of foliar nutrient sprays, which supply small amounts of mineral nutrients, on fruit quality. Our observations and reports in the literature suggest that these sprays have little effect on fruit quality.

Our work with three commercial calcium foliar sprays on peach and nectarine (applied every 14 days, starting 2 weeks after full bloom and continuing until 1 week before harvest) showed no effect on fruit quality of mid- or late-season cultivars (Crisosto et al., 1993b, 1995a). These foliar sprays did not affect fruit SSC, firmness, decay incidence, or fruit flesh calcium concentration. Fruit flesh calcium concentration measured at harvest varied among cultivars from 200–300 $\mu g \cdot g^{-1}$, dry weight basis (Crisosto et al., 1993b). A lack of decay control was reported on 'Jerseyland' peaches grown in Pennsylvania, treated with 10 weekly preharvest calcium sprays of $CaCl_2$ at 0, 34, 67, or 101 $kg \cdot ha^{-1}$ (Conway et al., 1987). Even fruit treated at a rate of 101 $kg \cdot ha^{-1}$ which had 70% more flesh calcium (490 vs. 287 $\mu g \cdot g^{-1}$, dry weight basis) than untreated fruit showed no reduction in decay severity.

Postharvest vacuum infiltration of 1%, 2%, and 4% $CaCl_2$ solutions into mature peaches has been tested (Conway et al., 1987; Wills and Mahendra, 1989). This infiltration treatment increased flesh calcium concentration (Ca at 287 vs. 1088 $\mu g \cdot g^{-1}$, dry weight basis) and fruit maintained higher flesh firmness during cold storage but did not show a reduction in decay incidence. Other potential benefits were negated by skin injury (Wills and Mahendra, 1989).

Recent research (Cheng and Crisosto, 1994; Crisosto et al., 1993a) suggests that these sprays on peaches and nectarines should be treated with caution because their heavy metal content (Fe, Al, Cu, etc.) may contribute to fruit skin discoloration.

Irrigation. Despite the important role of water in fruit growth and development, few specific studies have been done on the influence of the amount and the timing of water applications on peach quality at harvest and postharvest performance (Claypool, 1977; Crisosto et al., 1994b; Johnson et al., 1992; Johnson et al., 1994; Kader, 1988; Uriu et al., 1964; Veihmeyer and Hendrickson, 1949). An early report (Veihmeyer and Hendrickson, 1949) indicated a reduction in yield and fruit size, an increase in SSC, and a high incidence of IB of peaches when trees were allowed to grow without irrigation during the growing season on a shallow soil under California conditions. Water stress induced by allowing the soil water potential of a peach orchard to dry down to 0.5 MPa between irrigations resulted in increased fruit SSC compared to the normally irrigated optimum treatment (Uriu et al., 1964).

Reducing the amount of applied water after harvest of early-season peaches and plums has shown no negative effects on yield in California (Johnson et al., 1992; Larson et al., 1988); however, timing of the water deficit interval is important. An increase in fruit defects, such as deep suture and double-fruit formation, has been reported for early-season 'Regina' peaches as a consequence of imposing a postharvest water stress (50% ET) in mid and late summer during the previous season (Johnson et al., 1992). These defects will reduce the final packout. A similar regulated water stress regime applied to early-season plums did not affect the number of double and deep-sutured fruit of Red Beaut, Ambra, and Durado cultivars (Johnson et al., 1994).

During the 1990 and 1991 seasons, we evaluated the influence of the following irrigation regimes applied 4 weeks before harvest on peach quality and postharvest performance (Crisosto et al., 1994): normal irrigation (100% evapotranspiration; ET); over-irrigation (150% ET), and deficit irrigation (50% ET). Yield, flesh firmness, percent red surface, acidity, and pH were not altered at harvest by any of these irrigation regimes in either 1990 or 1991. Average fruit size, measured as fruit weight, was lower, but SSC was higher for fruit from 50% ET than from the other treatments (Table 3).

Peaches and nectarines with 11% SSC or higher are highly acceptable to consumers (Claypool, 1977). Although fruit from the 50% ET treatment were smaller, they probably would be preferred by consumers over fruit from the other treatments. An economic study by Parker et al. (1991) showed that peaches with a higher SSC may have a higher retail value.

The irrigation regimes (100%, 50%, and 150% ET applied 4 weeks before harvest) did not affect 'O'Henry' peach IB during 2, 4, and 6 weeks in cold storage at 0 °C or 5 °C. Fruit from 50% ET had a lower water loss rate than fruit from 150% ET or 100% ET. Fruit from 150% ET had lost nearly 35% more water than fruit from 50% ET or 100% ET after 24 h. Light microscopy studies indicated that fruits from 50% ET and 100% ET had a continuous and much thicker cuticle and a higher density of trichomes than fruits from the 150% ET. These differences in exodermis structure may explain the higher percentage of water loss from fruit from 150% ET compared to the others.

Girdling. Girdling 4–6 weeks before harvest is performed to increase peach and nectarine fruit size and advance and synchronize maturity (Day and DeJong, 1990; Johnson and LaRue, 1989). In some cases, girdling increases fruit SSC (Day et al., 1995; Marini et al., 1985), but also increases fruit acidity so that the taste resulting from the additional sugars may be masked.

Girdling can also cause the pits of peach and nectarine fruits to split, especially if it is done too early during pit hardening (Johnson and LaRue, 1989). Fruit with split-pits soften more quickly than intact fruits. Split-pits, as a consequence of girdling, have not been observed in Black Amber, Santa Rosa, Friar, and Royal Diamond plum cultivars; however, rapid fruit softening and severe tree weakening has been noted (Day et al., 1990).

Crop Load. Fruitlet thinning increases fruit size while also reducing total yield; thus, a balance between yield and fruit size must be achieved (Day et al., 1993). Generally, maximum profit does not occur at maximum marketable yield, since larger fruit bring a higher market price (Parker et al.,1991). Leaving too many fruit on a tree reduces fruit size and SSC (Crisosto et al., 1995a) in the early ripening 'May Glo' nectarine and late ripening 'O'Henry' peach (Fig. 1A&B).

Crop load on 'O'Henry' peach trees affected the incidence of IB measured after 1, 2, and 3 weeks at 5 °C (Crisosto et al., 1995a). Despite a large amount of mealy fruit for all lots, the overall incidence of mealiness and flesh browning in fruit from the high-crop load was low, intermediate in fruit from the commercial crop load, and the highest in fruit from the low-crop load. Bleeding was not affected by crop load.

Fruit Canopy Position. Initial fruit quality of several peach, nectarine, and plum cultivars according to fruit canopy position has been evaluated in differing production areas (Marini, 1991; Saenz, 1991).

Table 2. Effect of three nitrogen fertilization levels on fruit gas exchange and cuticle thickness of 'Fantasia' nectarine (± SD).

N Rate ($Kg \cdot ha^{-1}$)	Leaf N concentration (%)	Gas exchange[z] rCO_2	Gas exchange[z] rC_2H_4	Cuticle density ($mg \cdot mm^{-2}$)
0	2.7	0.04 (±0.02)	0.92 (±0.27)	13.5 (±2.6)a[y]
196	3.1	0.04 (±0.01)	0.83 (±0.08)	10.7 (±1.6)b
364	3.5	0.06 (±0.01)	0.79 (±0.16)	9.5 (±1.2)c

[z]Resistance.
[y]Mean separation within columns by LSD at $P \leq 0.05$.
Data from Crisosto et al., 1995a.

Table 3. Effect of three irrigation regimes on fruit weight and soluble solids concentration (SSC) of 'O'Henry' peach at harvest.

Irrigation amount (% of ET[z])	Fruit weight (g)	SSC (%)
1990		
100%	218 a[y]	11.7 a
150%	221 a	10.8 a
50%	192 b	13.3 b
1991		
100%	291 a	10.7 a
150%	304 a	10.9 a
50%	244 b	11.2 b

[z]ET = evapotranspiration.
[y]Mean separation within columns and year by LSD test at $P \geq 0.05$.
Adapted from Crisosto et al., 1994b.

Large differences in SSC, acidity, and fruit size were detected between fruit obtained from the outside and inside canopy positions of open-vase trained trees (Marini, 1991; Saenz, 1991). During the last five seasons, we have observed that fruit grown under a high-light environment (outside canopy) has a longer shelf life (storage and market) than fruit grown under a low-light environment (inside canopy). Summer pruning and leaf pulling around the fruit increases fruit light exposure and, when performed properly, can increase fruit color without affecting fruit size and SSC. Excessive leaf pulling or leaf pulling done too close to harvest, however, can reduce both fruit size and SSC in peaches and nectarines (Day et al., 1995).

During three seasons, we have found that fruit that developed in the more shaded inner canopy positions have a greater incidence of IB than fruit from the high-light, outer canopy positions (Crisosto et al., 1995a). Thus, fruit from the outer canopy have a longer potential market life, especially IB-susceptible cultivars (Table 4).

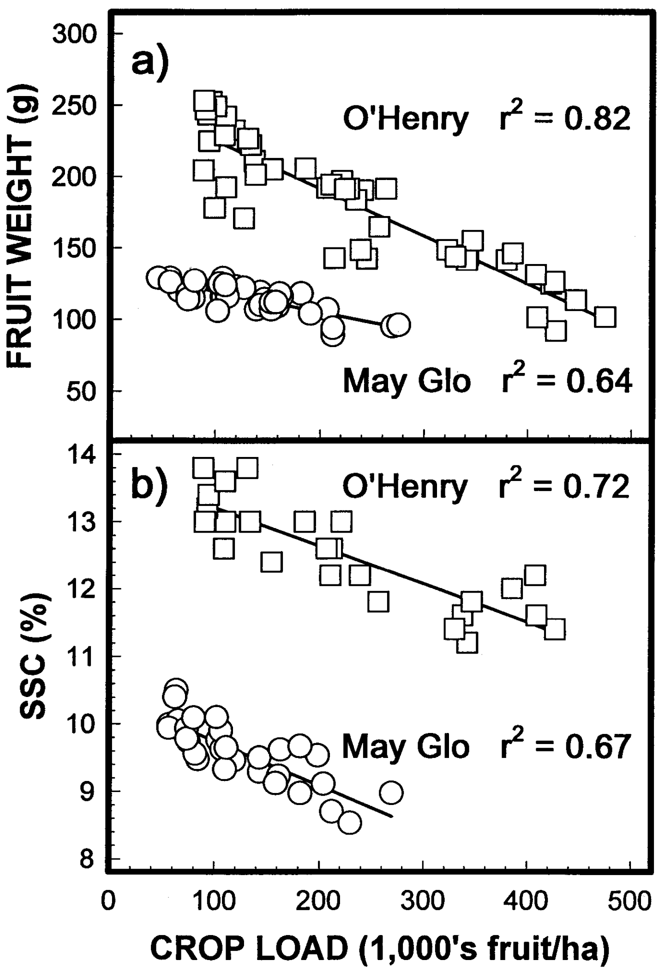

Fig. 1. Relationship between (**a**) crop load and soluble solids concentration (SSC) and (**b**) crop load and fruit weight for 'O'Henry' peach and 'Mayglo' nectarine. Adapted from Crisosto et al. 1995a.

Table 4. Influence of fruit canopy position on market life of peach and nectarine cultivars.

Fruit and cultivar	Market life at 0 °C (weeks) Canopy Outer	Inner
Peach		
Spring Lady	4	4
Springcrest	6	6
Flavorcrest	5	4
Redtop	3	2
O'Henry	5	2
Fairtime	3	2
Nectarine		
June Glo	6	6
Sparkling June	5	4
Fantasia	6	5
September Red	4	3
Fairlane	3	3

[z]The end of market life was determined when >25% of the fruit was mealy or 15% of the fruit had a score of 3 (25% of the flesh showing browning) or higher for internal browning.
Adapted from Crisosto et al., 1995a, 1995b.

CONCLUSIONS

Since stone fruit quality assessment has been limited to SSC, acidity, and fruit surface color measurements, we recommend adding sensory evaluation (taste panel and/or consumer acceptance) testing to future work on the relationship between orchard factors and fruit quality. Evaluation of the influence of preharvest factors on fruit quality needs to be conducted through to consumer acceptance and consumption. We recommend evaluating quality criteria at harvest and at different points during simulated shipping periods under various temperature regimes.

Additional fruit quality research is needed in relation to foliar calcium uptake, deficit irrigation near harvest, and the timing of nitrogen fertilization.

Current research indicates that flesh browning and mealiness symptoms are associated with canopy position of the fruit. However, studies are needed to develop a better understanding of this relationship to maximize the market life of IB-susceptible stone fruit cultivars.

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