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Relationship between Fruit Respiration, Bruising Susceptibility, and Temperature in Sweet Cherries

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Abstract. **Respiration rate and bruising incidence were assessed in new cherry (*Prunus avium* L.) cultivars adapted to high temperatures. 'Bing', 'Brooks', 'Tulare', and 'King' respiration rates were evaluated at 0, 5, 10, and 20C, and bruising susceptibilities at 0, 10, 20, and 30C. 'Bing' was the least susceptible to bruising and had the lowest respiration rate at all temperatures. Respiration rate increased with temperature in all cultivars. Impact bruising damage was greatest in all cultivars when fruit flesh was below 10C. Vibration damage was not influenced by fruit temperature. Our results suggest that the cherry cultivars assessed should be handled at temperatures between 10 and 20C during packing to minimize bruising damage. Due to increased respiration rates at higher temperatures, however, fruit should be cooled to 0C within 4 to 6 hours after harvest.**

Commercial cherry production has been restricted to areas with mild temperatures during the growing season. High temperatures during maturation induce rapid fruit deterioration (Ryugo, 1988). High temperatures late in the summer have also been associated with an increased frequency of double or spur fruit the following season. For this reason, commercial cherry production in warm areas, such as the southern San Joaquin Valley, Calif., has not been successful. In the last 10 years, however, new cherry cultivars that produce low amounts of double fruit have been bred for these high-temperature areas. These new cultivars are currently growing in commercial orchards in the southern San Joaquin Valley.

There is no information on physiological characteristics that affect postharvest performance of these new cultivars. Bruising and high respiration rates limit shelf life in cherries by inducing rapid fruit deterioration, softening, and decay (Kupferman and Ebel, 1989; Ogawa et al., 1972; Sommer et al., 1960). During respiration, sugar and other storage products in detached fruit are depleted and contribute to a loss of food value and reserves. Consequently, sensory quality suffers.

Bruising damage is caused either by dropping the fruit onto a surface or by dropping an object onto the fruit (impact bruising), by rubbing the fruit against other fruit or some other surface (vibration or abrasion bruising), or by pressing fruit against each other or a hard surface (compression bruising). This physical damage can occur during harvesting, hauling, and packing operations, and as a result of fruit movement in the package during transit to market (Sommer et al., 1960). A warehouse survey carried out in Washington state (Kupferman and Ebel, 1989) reported that 41% of the fruit that arrived at the packinghouse during the 1988 season was bruised and pitted. On their arrival in the New York market, bruising, pitting, and decay were the main causes of cherry fruit loss (Ceponis et al., 1987).

During the 1991 season, we compared two types of fruit-handling systems on 'King' and 'Tulare' postharvest performance. After storage at 0C for 5 days, about half of the fruit collected from the standard packing operation had softened. Field-packed fruit, however, started to soften after only 12 days of storage at 0C (Crisosto et al., 1992). These preliminary data suggested that the cultivars were susceptible to fruit softening and deterioration, and that softening was accelerated by rough handling during harvesting, hauling, and postharvest packing operations.

Understanding temperature's influence on bruising susceptibility and fruit respiration is necessary to prolong postharvest life. The incidence of impact bruising in 'Van' cherries was higher when flesh temperature was low (Lidster and Tung, 1980). As fruit temperature increased, the incidence of impact-induced surface pitting damage on 'Bing' and 'Van' cherries decreased linearly; but this response also depended on the cultivar, contact surface, and drop height (Patten and Patterson, 1985). 'Bing' cherry resistance to compression damage, however, decreased linearly with increasing temperature.

Since most of the bruising damage that

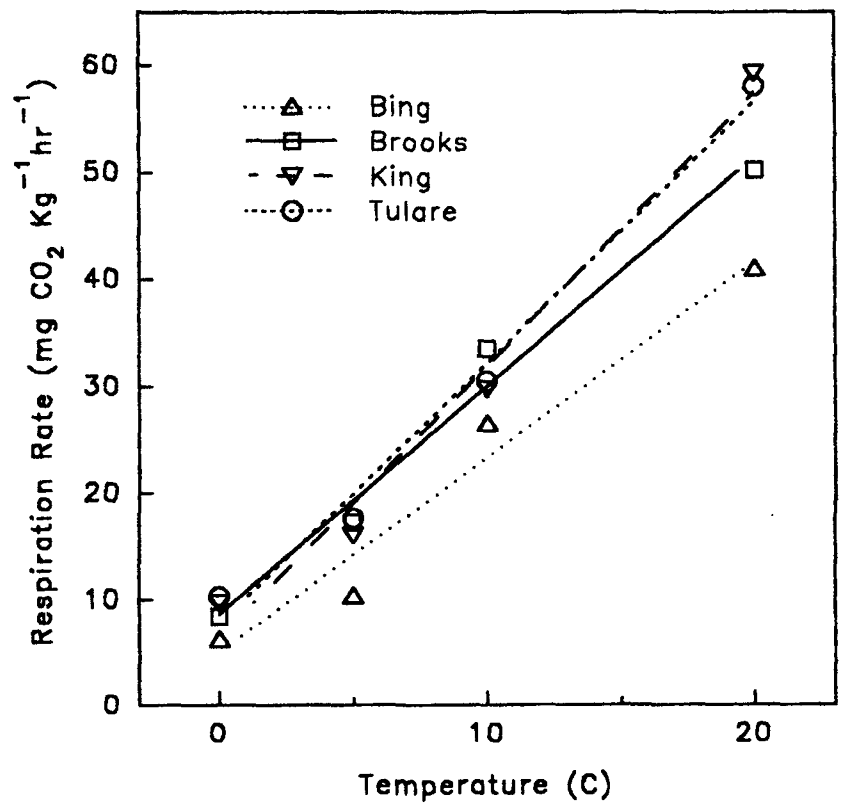

Fig. 1. Respiration rates of four cherry cultivars measured at four temperatures (t). Regression equations: 'Bing' rate = 5.94 + 1.78t, R^2 = 0.98; 'Brooks' rate = 8.35 + 2.15t, R^2 = 0.97; 'Tulare' rate = 7.44 + 2.46t, R^2 = 0.98; 'King' rate = 5.95 + 2.57t, R^2 = 0.97.

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occurs during harvest, hauling, and packing is due to impact and vibration, an investigation of the relationship between temperature and fruit bruising incidence (impact and vibration), and temperature and respiration rate was carried out for four cherry cultivars grown in the San Joaquin Valley.

During the 1991 season, 'Brooks' (harvested 20 May), 'Tulare' (harvested 22 May), 'King' (harvested 29 May), and 'Bing' (harvested 5 June) cherries growing in the Fresno, Calif., area were harvested when they reached commercial maturity, as determined by skin color (solid bright red). Within 2 h of harvest, fruit were gently transported to the Kearney Agricultural Center, Univ. of California, postharvest facilities and hydrocooled until flesh temperature reached 0C. Fruit were stored at 0C for 24 h before bruising treatments were applied and respiration was measured.

The SAS program (SAS, 1988) was used for analysis of variance and regression analysis (Neter et al., 1983). Mean comparisons were made using the *t* test and the Ryan–Einot–Gabriel–Welsch (REGWF test) multiple F test comparison (Ramsey, 1978; SAS, 1988) at $P = 0.05$.

Respiration rate

Carbon dioxide production in 'Brooks', 'Bing', 'King', and 'Tulare' cherries was measured at 0, 5, 10, and 20C. Fruit with pedicels (770, 280, 175, and 100 g/replication at 0, 5, 10, and 20C, respectively) from each cultivar were enclosed in glass respiration jars attached to a flow board in the appropriate temperature-controlled room. Air flow through the sample jars was adjusted using the flow board so that the internal atmosphere contained no more than 0.3% CO_2 (Nanos and Mitchell, 1991). Samples were allowed to equilibrate for 24 h, and the generated CO_2 was then measured with a Horiba PIR-2000R (Horiba Instruments, Irvine, Calif.) infrared gas analyzer using a 10-ml gas sample withdrawn from the glass jar.

Bruising susceptibility tests

The relationship between temperature (0, 10, 20, and 30C) and bruising (impact and vibration) in 'Brooks', 'Bing', 'Tulare', and 'King' cherries was studied using 21.4-mm-diameter fruit (size 12) at the solid-bright-red maturity stage. After the initial 24 h at 0C, fruit from each cultivar were transferred to the appropriate controlled-temperature chamber. Fruit were subjected to impact and vibration damage when their flesh temperature equaled the desired storage temperature. After bruising, fruit were placed in an open plastic bag and stored at room temperature (20C) for 48 h before being evaluated. Bruising damage was measured as the percentage of fruit showing visible injury. Visible bruising injury was determined by color and texture changes. In both experiments, bruising damage was evaluated externally (skin) and internally (flesh).

Impact bruising. Fruit with pedicels were dropped, stem-end up, from a height of 45 cm through a vertical polyvinylchloride (PVC) pipe (2.6-cm i.d.) onto a slanted metal plate. Each fruit hit only once on its bottom end, then bounced off the metal plate onto a padded surface. When dropped through the PVC pipe, fruit with pedicels did not tumble and always hit bottom-end down, thus standardizing impact location and facilitating bruising damage evaluation. For each cultivar, five replications of 15 fruit were used at each temperature (0, 10, 20, and 30C).

Vibration bruising. Transit injury was

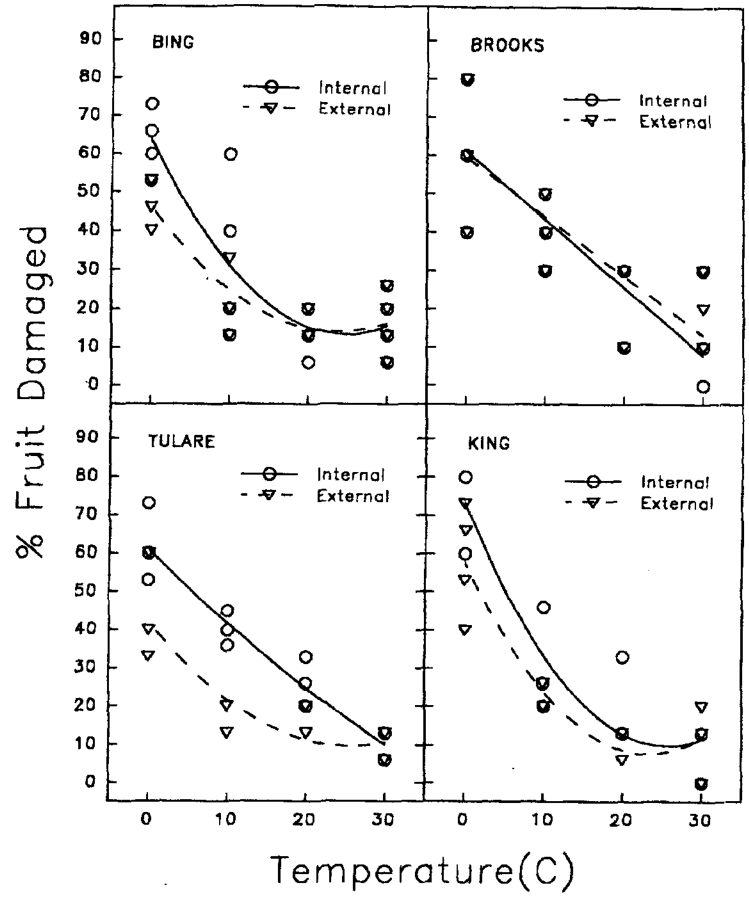

Fig. 2. Relationship between fruit flesh temperature (t) and impact bruising susceptibility (percent fruit damaged) for four cherry cultivars. 'Bing': internal = $112.8 - 57.3t + 8.3t^2$, $R^2 = 0.764^*$; external = $79.3 - 38.8t + 5.8t^2$, $R^2 = 0.797^*$. 'Brooks': internal = $76.3 - 16.3t$, $R^2 = 0.764^*$; external = $75.0 - 15.5t$, $R^2 = 0.652^*$. 'Tulare': internal = $67.5 - 14.1t$, $R^2 = 0.630^*$; external = $83.6 - 42.9t + 6.2t^2$, $R^2 = 0.800^*$. 'King': internal = $134.5 - 71.4t + 10.3t^2$, $R^2 = 0.882^*$; external = $111.9 - 63.9t + 9.9t^2$, $R^2 = 0.881^*$. *Regression equations significant at $P \geq 0.001$.

Table 1. Coefficient estimates and significance levels $P = (F) \geq \alpha$ for the fitted equations. Percentage of bruised fruit as measured on the skin (external) or in the flesh (internal) = $b0 + b1(t) + b2(t^2) + b3(t^3)$ for 'Bing', 'Brooks', 'Tulare', and 'King' cherries.

Cultivar	Injury location	Coefficient estimates b0[z]	b1	b2	b3	R^2
Bing	Internal[y]	112.8	–57.3	8.3	2.3	0.764
		(0.0001)[x]	(0.0026)	(0.0178)	(0.63)	
	External	79.3	–38.8	5.8	0	0.797
		(0.0001)	(0.0008)	(0.0061)	(1.0)	
Brooks	Internal	76.3	–16.3	5.6	---	0.678
		(0.0001)	(0.0147)	(0.093)	---	
	External	75.0	–15.5	6.3	---	0.652
		(0.0001)	(0.010)	(0.062)	---	
Tulare	Internal	67.5	–14.1	–1.7	---	0.630
		(0.0001)	(0.0002)	(0.617)	---	
	External	83.6	–42.9	6.2	4.71	0.800
		(0.0001)	(0.0011)	(0.0094)	(0.123)	
King	Internal	134.5	–71.4	10.3	–5.5	0.882
		(0.0001)	(0.0001)	(0.0011)	(0.146)	
	External	111.9	–63.9	9.9	0.6	0.881
		(0.0001)	(0.0001)	(0.0002)	(0.849)	

[z]Interception coefficient (b0) used applies to best-fit model; t = temperature.
[y]Internal damage evaluated in the flesh, external damage evaluated in the skin.
[x]*P* values are in parentheses.

Table 2. Susceptibility of four cherry cultivars to vibration injury after subjecting them to 1.1× g force for 10 or 20 min at 20C.

Time	Fruit with internal bruising damage[z] (%)			
(min)	Brooks	King	Tulare	Bing
10	45.0 a	40.0 a	41.0 a	43.4 a
20	85.0 b	80.0 b	80.0 b	96.5 b

[z]Mean separation done by t test at $P = 0.05$. Each mean represents an average of four replications (15 fruit each). Similar letters within a column indicate no significant difference.

simulated by allowing fruit to roll loosely in a container that was subjected to vibration of 1.1× g acceleration at 550 cycles/min and 6.4-mm stroke at 0, 10, 20, and 30C. The effect of 10- and 20-min vibration on bruising incidence of the four cherry cultivars was compared when the flesh temperature reached 20C. For each cultivar, four replications of 15 fruit were used at each temperature.

Respiration. Carbon dioxide production rate (milligrams CO_2/kilogram fruit per hour) increased with temperature in all cultivars tested. 'Bing' cherries generated less CO_2 than 'Brooks', 'Tulare', and 'King' at each temperature. Linear regression models indicated that there was a significant relationship between fruit flesh temperature and respiration rate for all cultivars (Fig. 1). Polynomial regression models did not significantly improve the correlation between temperature and respiration rate. Slope comparison analysis indicated that 'King' and 'Tulare' had significantly (P = 0.001) higher slopes than 'Brooks'; 'Bing' had the lowest. Similar respiration rates for 'Bing' cherries growing under mild temperatures were reported by others (Gerhardt et al., 1942, Micke et al., 1965). Respiration rates were similar for 'Brooks', 'Tulare', and 'King' at 0, 5, and 10C. At 20C, 'Brooks' had a lower respiration rate than either 'Tulare' or 'King'. Carbon dioxide production was 45 to 55 mg CO_2/kg fruit per hour at 20C for 'Brooks', 'Tulare', and 'King'. These results suggest that these cultivars may be more susceptible to rapid fruit deterioration than 'Bing' (35 mg CO_2/kg fruit per hour at 20C).

Impact damage. Flesh temperature at the time of impact significantly affected bruising incidence. Surface pitting was not observed during evaluation. Internal and external bruising damage decreased as temperature increased for all cherry cultivars (Fig. 2). Regression analysis using temperature as a predictor of percentage of fruit bruised showed a significant relationship for all cultivars (Table 1). A linear or quadratic regression model significantly correlated the temperature–bruising relationship. The cubic component did not significantly improve the relationship between temperature and bruising susceptibility over a quadratic model determined by a t test comparing coefficients (Table 1) and a stepwise analysis using "all, each, and all combinations of" potential independent variables (data not shown).

In 'Brooks', there was no difference between the internal and external bruising damage incidence. This result suggests that skin and flesh tissues are equally susceptible to bruising damage or that damage is easily detected in this white-flesh, red-skinned cherry. For 'Bing', 'Tulare', and 'King', especially at low temperatures, internal bruising damage levels were higher than external ones. A similar situation has been reported for peaches and nectarines [*Prunus persica* (L.) Batsch.] (Sommer et al., 1960), where impact damage almost exclusively affected the flesh.

A linear regression model best described the relationship between temperature and internal and external bruising damage for 'Brooks' and temperature and internal bruising damage for 'Tulare'. A quadratic model defined the relationship between temperature and bruising for 'Bing', 'King' (internal and external), and 'Tulare' (external) (Fig. 2). This quadratic model showed a plateau in bruising damage to >20C. These results suggested that temperatures higher than this will not significantly reduce the incidence of impact bruising damage for these three dark-colored cherry cultivars, while it will reduce the incidence of internal damage of 'Brooks' and 'Tulare'.

Vibration damage. All of the cultivars were sensitive to vibration, but there were no significant differences in susceptibility to vibration damage among them (data not shown). Flesh temperature did not significantly affect bruising incidence, and there were no differences between the incidence of internal and external bruising (data not shown). Only the duration of the vibration treatment, measured at 20C, significantly affected the percentage of fruit damaged (Table 2).

The incidence of impact bruising damage was higher when the flesh temperature was <20C, but vibration bruising, due to rolling, was not significantly influenced by temperature (Fig. 3). In peaches, nectarines, and plums (*Prunus salicina* Lindel.), bruising susceptibility was reported to be lowest when the fruit flesh was between 5 and 20C during packing (Mitchell, 1987).

Recommendations to reduce fruit deterioration in 'Bing' cherries state that fruit should be cooled to 0C within 4 to 6 h after harvest (Micke et al., 1965; Overholser, 1932). Cooling delays induce fast fruit deterioration, fruit shriveling, and stem browning, thereby shortening postharvest life. The new cherry cultivars ('Brooks', 'King', and 'Tulare') had almost double the respiration rate of 'Bing' at 20C. Consequently, they should be cooled to 0C in <4 to 6 h after harvest to reduce fruit deterioration and maximize postharvest life.

Based on our results, options for managing temperature during cherry packing to reduce bruising and maximize postharvest life are limited. For these cherry cultivars, fruit handled between 0 and 5C suffered more bruising damage than those handled at >10C. Thus, careful temperature management during fruit packing and fast cooling are important to reduce fruit bruising and deterioration. If packing is performed within 4 to 6 h of harvest, cooling can be postponed until just before package filling (in-line hydrocooler), or by forced-air cooling after packaging. If fruit packing and cooling are delayed more than 4 to 6 h, fruit should be cooled immediately to near 0C after picking.

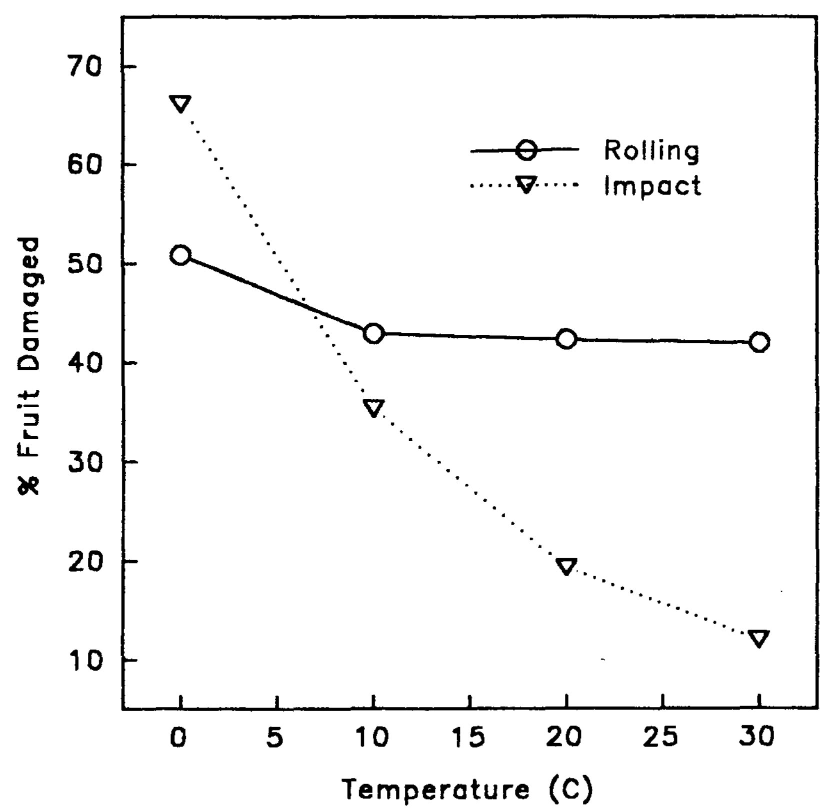

Fig. 3. Effect of fruit flesh temperature on internal bruising susceptibility of four cherry cultivars (average).

Differences in bruising and respiration rate could be helpful in managing packing operation temperature and attaining maximum postharvest life for these new cherry cultivars. A critical review of the actual harvesting, hauling, cooling, and packing operations should be done to identify when and how fruit damage occurs. After doing so, steps can be taken to reduce or eliminate these problems.

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