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Fruit Temperature Effects on Mechanical Damage of Sweet Cherries

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Additional index words. fruit firmness, surface pitting, *Prunus avium*

Abstract. **The resistance of sweet cherries to compression damage as measured by the fruit firmness variables, [force to bioyield (FBY), slope of a compression curve, and maximum and residual forces of a compression-relaxation curve] decreased linearly with increasing fruit temperture. The incidence of impact-induced surface pitting decreased linearly as fruit temperature increased. The rate of decrease in impact damage per degree increase in fruit temperature was a function of the cultivar, contact surface, and drop height.**

The firmness and response to mechanical stress of a fleshy fruit is affected by temperature (1, 11). Further, whether the physical forces are applied instantaneously (impact) or gradually (compression) determines how temperature will affect the mechanical properties of the fruit.

Bourne (1) recently has established firmness-temperature coefficients (FT) for several commodities using quasi-static firmness measurements. Firmness-temperature coefficient is defined as the "percentage change in firmness per degree temperature increase." Most commodities showed a slight linear softening (negative FT) with increasing temperature. The FT coefficient, however, was highly variable within cultivar, among cultivars and species, and with stage of maturity.

This same negative relationship between temperature and

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firmness has been characterized for sweet and/or sour cherries, using a mechanical cherry pitter (19), compression (20), or puncture (6, 7). However, there was no difference in firmness between warm and cold sweet cherries as measured with a durometer (3). The FT coefficient also may vary from negative to positive based on the method of firmness measurement. For example, with strawberries, FT's of −0.67 to −3.21 were found for puncture (7, 14), compared to FT's of 0 to +3.48 for deformation to 1 N (1).

In general, under dynamic tests (impact), a converse relationship exists with warm fruit being more resistant to damage than cold fruit. This relationship exists for potatoes (8), pears (10), peaches, plums and apricots (17), and cherries (3, 9). Lower temperture produced increased resistance (13), decreased resistance (11), or had no effect (16) on the susceptibility of apples to impact damage.

In the sweet cherry industry, fruit are subjected to both compression and impact forces. Because of the dramatic influence temperature can have on both types of mechanical damage as well as on shelf life, it is important to investigate the relationships among temperature, firmness, and mechanical damage. This study examined the effect of fruit temperature on the compression-relaxation behavior, resistance to compression, and susceptibility to impact damage for sweet cherries.

Materials and Methods

An Instron model 1350 Servohydraulic Testing Machine (Instron Corp., Canton, Mass.) equipped with an 8-cm diameter flat plate was used to measure the compression-relaxation behavior and compression resistance of sweet cherries.

Expt. 1. For force-relaxation studies, approximately equal diameter and weight 'Bing' cherries at dark red color maturity (Techwest Color Comparator No. 6, Techwest Enterprises Ltd., Vancouver, B.C.) equilibrated in plastic bags to 0°, 5°, 10°, 20°, and 30°C were used. There were 30 fruit per temperture. Each fruit was placed on its cheek, preloaded to 0.2 N, and then compressed 2.5 mm (about 10% of diameter and less than required to cause failure) at a crosshead speed of 0.75 mm/sec. Deformation was maintained for 14 sec. Because actual surface area under force continually changes with compression of intact fruit, true stress values are not known. Initial maximum force and residual force after 14 sec. (Fig. 1A) therefore were measured, instead of a true stress relaxation evaluation (11).

Expt. 2. For compression tests, fruit temperature, size, maturity, placement, preload force, and crosshead speed conditions were as before. Fifty 'Bing' cherries were tested individually for each temperture. Fruit were compressed 5 mm in 6.7 sec. The force required to cause compression failure (force to bioyield) and the minimum and maximum slope of the compression curve (Fig. 1B) were measured.

Expt. 3. Resistance to impact damage was determined by dropping fruit onto 1 of 2 surfaces: the side opposite the suture onto a rubber traction belt, or the cheek side onto a smooth concrete surface. In each instance, rebound height was less than 5% and not significant enough to cause damage with the 2nd impact. The traction belt had small rectangular points and was found on a commercial fresh market cherry packing line. Each point had a height of 1 mm and apex area of 1 mm^2. The points were 4 mm apart (center to center). After 2 weeks storage at 10°C, damage was assessed visually as distinctly shaped pits (traction belt) or as large sunken depressions (concrete surface). In the 1st experiment, 'Bing' cherries at the same temperatures and maturities were used as before. 'Bing' fruit were dropped 15 cm onto the belt or 30 cm onto the concrete. There were 2 replications of 100 fruit for each temperature and surface.

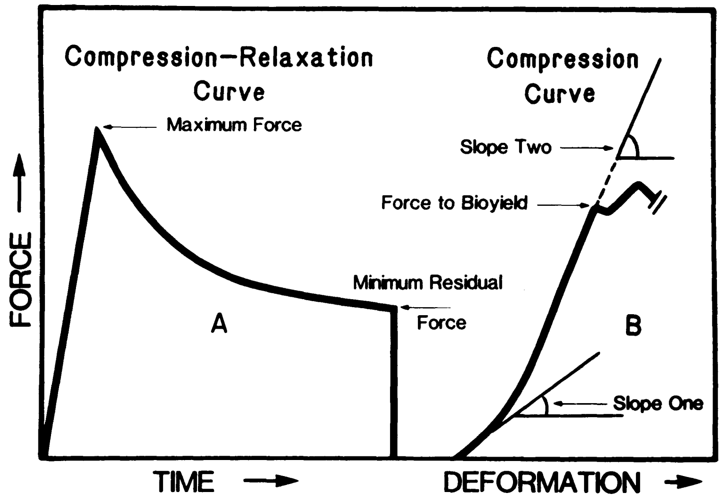

Fig. 1. Tracing from: **A**. a typical compression-relaxation, and **B**. a compression curve of sweet cherries.

Table 1. Effect of impact surface, drop height, and fruit temperature on the percentage of surface pitting of 'Bing' and 'Van' sweet cherries.[z]

Source of variation	Significance[y]
	Traction belt — 'Bing' and 'Van'
Cultivar	**
Height	**
Linear of ht	**
Quadratic of ht	*
Temperature	**
Linear of temp	**
Quadratic of temp	NS
Height × temp	*
Cultivar × ht	NS
Cultivar × temp	*
Cultivar × ht × temp	*
CV 17%	
	Concrete surface — 'Van'
Height	**
Linear of ht	**
Quadratic of ht	*
Temperature	**
Linear of temp	**
Quadratic of temp	NS
Height × temp	NS
CV 11%	

[z]Analysis of data performed on arcsin square-root transformations of percentage of damage.
[y]Nonsignificant (NS), or significant at 5% (*), or 1% (**) level.

Expt. 4. To better define impact damage sensitivity for different temperatures and drop heights, additional red (Techwest Color Comporator No. 3) 'Bing' and 'Van' cherries that had been stored 2.5 weeks at 0°C were warmed to 6°, 9°, or 15° and dropped 2.5, 5 or 10 cm onto the traction belt. There were 3 replications of 30 fruit for each temperature, drop height, and cultivar. 'Van' cherries also were dropped onto the concrete surface from 10, 20, or 30 cm at 6°, 9°, or 15°. There were 5 replications of 25 fruit for each height and temperature.

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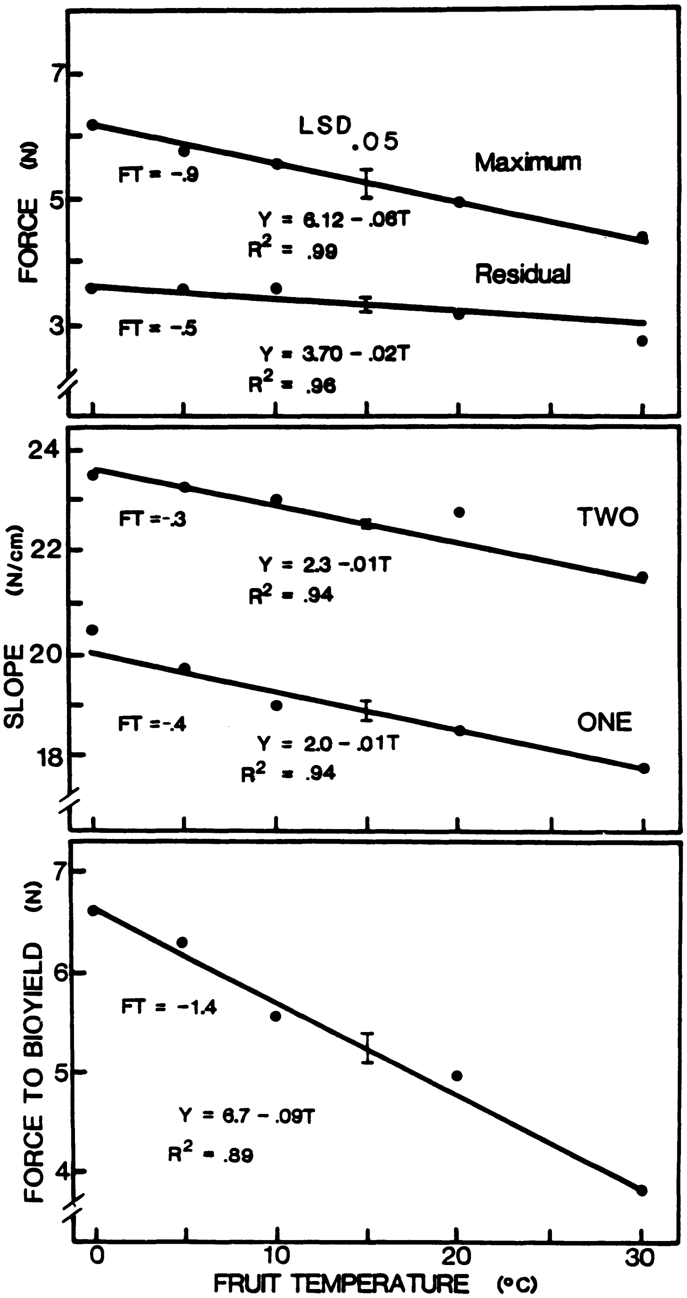

Fig. 2. Effect of fruit temperature on the maximum and residual force from compression-relaxation curves, and slope one and two and force to bioyield from compression curves of 'Bing' sweet cherries. (FT = firmness – temperature coefficient.)

Results

Compression damage. The resistance to compression damage, as measured by the maximum and residual force from compression-relaxation curves (Expt. 1; Fig 2), the force to bioyield, and slope 1 and 2 of a force-deformation curve (Expt. 2; Fig. 2) decreased linearly with an increase in fruit temperature of 'Bing' cherries. The greatest change in FT coefficient occurred with FBY; the least change occurred with slope 1 and 2 of a compression curve.

Impact damage. The incidence of surface pitting of 'Bing' cherries induced by impact decreased linearly with an increase in fruit temperature for both impact surfaces (Expt. 3; Fig. 3). This relationship also was evident when the temperature range

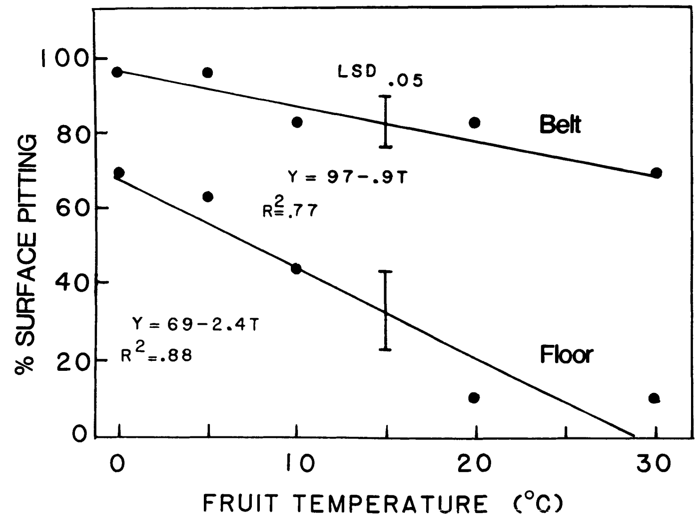

Fig. 3. Effect of fruit temperature on the percentage of surface pitting of 'Bing' sweet cherrries.

was narrowed and different drop heights were considered for both 'Bing' and 'Van' cherries (Table 1; Fig.4). Pitting increased with an increase in drop height. The slope of the regression line for the percentage of surface pitting (damage-temperature coefficient, DT) indicates the rate of change in percentage of pitting per degree increase in temperature. DT value decreased with a decrease in drop height (Fig. 4). For the same drop heights, the DT value always was greater for 'Van' than 'Bing'.

There was a quadratic relationship between surface pitting and drop height for both surfaces (Table 1). That is, at the highest drop height, the rate of increase in pitting with an increase in drop height declined. Height and cultivar interacted with temperature for fruit dropped on the traction belt (Table 1). These interactions mainly resulted from the lack of a temperature effect at the 2.5 cm drop height and the higher DT values for 'Van' than 'Bing' (Fig. 4). For any given drop height and temperature, 'Van' usually had about twice the damage determined for 'Bing'. The exception was for the 2.5 cm drop at 9° and 15°C. This exception and the lack of a significant regression line for 'Bing' at the 2.5 and 10 cm drops account for the 3-way interaction between height, temperature, and cultivar.

Overall, when impact surface area was small (traction belt points) and fruit temperatures were low, an extremely small drop height (2.5 cm) was required to cause considerable damage in a pitting-sensitive cultivar like 'Van' (Fig. 4).

Discussion

During gradual compression, there is a redistribution of liquid to equilibrate stresses between cells of an easily compressible commodity (12). Slower efflux of fluid through cells and intercellular spaces and higher initial cell water potential produce greater resistance to external compression forces (12). The flux of cellular fluid is inversely proportional to its viscosity (11). The reduction of firmness (slope) and greater dissipation of force with time (less residual force in a force-relaxation curve) associated with an increase in fruit temperature could, therefore, be explained on the basis of decreased fluid viscosity.

All other measured variables of firmness also were reduced for warm fruit. Since the exact relationship between these variables and actual resistance to compression force is not known,

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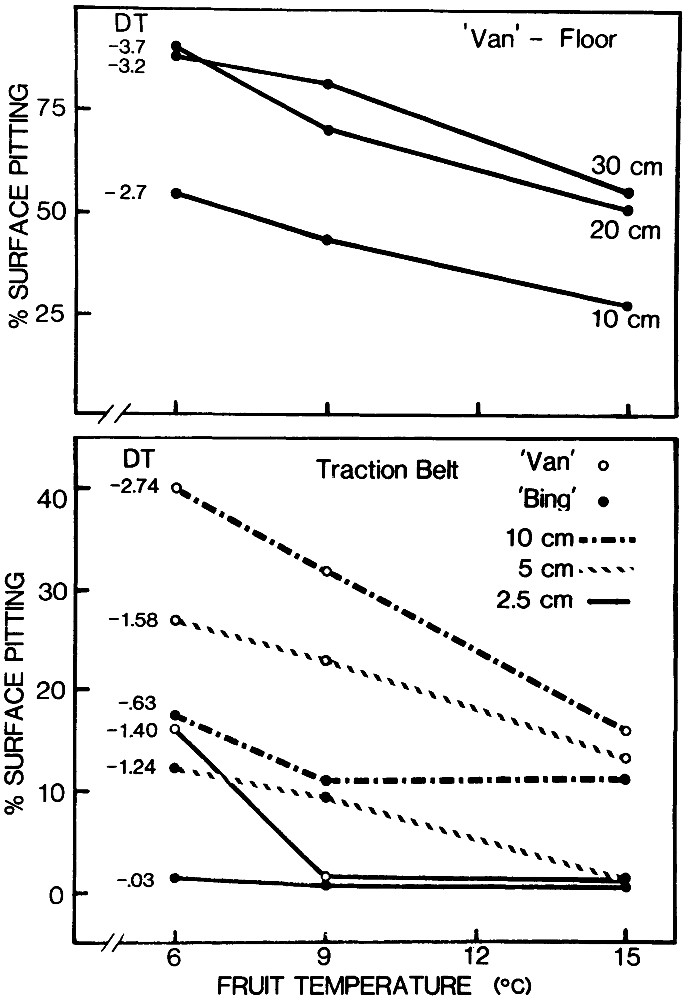

Fig. 4. Effect of fruit temperature, drop height, and drop surface on the percentage of surface pitting of sweet cherries. (DT = damage coefficient, which is the slope of the regression line.)

inferences on the effect of temperature on compression damage must be restricted to assumptions. With most commodities, an increased FBY implies that a greater compression force is required to cause initial tissue failure (11). Increased firmness (slope) values also are associated with reduced compression damage (5, 15). Therefore, the resistance to compression damage would likely decrease linearly with an increase in fruit temperature, concomitantly with all firmness variables. Whether the rate of this decrease is the same as for FT values is not known, especially considering that FT has been shown to be highly dependent on the firmness variables chosen for measurement and on the testing conditions (1). For example, the FT's previously reported for cherries range from −0.9 to −1.95 for puncture test (1), whereas our values range from −0.3 for slope 2 to −1.4 for FBY.

Although the exact relationships of FT values to compression damage resistance are not known, they are of fundamental importance in the assessment of fruit firmness. With an FT of −1.4 and a 10°C difference in temperature between identical fruit samples, a 14% difference in firmness would be expected to occur.

In contrast to compression damage, increased impact damage is associated with decreasing fruit temperature. The rate of this linear decline in impact damage resistance per degree temperature drop (DT) is dependent on the cultivar, drop height, and impact surface, ranging from a nonsignificant DT of −0.03 for 'Bing' dropped 2.5 cm onto a traction belt to −3.7 for 'Van' dropped 30 cm onto a concrete surface. Other DT values calculated from existing literature are −1.1 (3) and −0.68 (9) for cherries, −0.97 for pears (10), −2.5 for apricots (17), and −1.28 for peaches (17). These agree with the average DT of −1.7 for our data.

Firm fruit show reduced impact-induced surface pitting (4). A misleading relationship between cherry firmness and resistance to pitting might be assumed if temperature were not considered. Increased impact damage and decreased compression damage at cold temperature is not a phenomenon restricted to fruit. In general, all structural materials have an increased yield strength and stiffness when cold, but increased fracture and impact strength and reduced brittleness when warm (2, 18).

Determining the best handling temperature for cherries to reduce overall mechanical damage is confounded by the short postharvest life of cherries which requires rapidly reducing fruit temperature to 0°C. A multi-dimensional analysis considering postharvest liffe, impact and compression damage, relative amount and severity of each type of damage, and overall importance of damage and postharvest life to marketability is required to solve this problem. This analysis is beyond the scope of this paper, but some conclusions are apparent. Most compression damage to cherries occurs before the fruit is passed over the packing line (picking bruises and compression of fruit at the bottom of bins). Harvesting during cooler periods of the day and rapid cooling would be desirable to reduce compression damage and maximize storage life. If packed shortly after harvest, impact damage on the packing line could be reduced, without much loss of postharvest life, if fruit 1st were cooled and passed over the packing line at 7° to 13°C, followed by further rapid cooling to just above freezing.

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Pistillate Flower and Fruit Abortion in Pecan as a Function of Cultivar, Time, and Pollination

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Additional index words. *Carya illinoensis*, shoot length, alternate bearing, pollination

Abstract. **Abortion of pistillate flowers and fruit was determined in 'Cherokee', 'Success', 'Stuart', and 'Desirable' pecans [*Carya illinoensis* (Wang.) K. Koch]. Abortion occurred in 4 periods during the growth cycle of the fruit. The distinctness and magnitude of the drops varied greatly among cultivars. Total seasonal abortion was inversely related to the alternate bearing tendency of the cultivars. The 1st drop varied inversely with shoot length, the 2nd drop coincided with abortion of nonpollinated flowers and was increased by selfing, and the 3rd drop coincided with abortion induced by self-pollination. The majority of fruit loss during the 4th drop followed fruit split or discoloration. This drop correlated with high soil moisture and humidity. However, a lesser drop, from embryo abortion, also is proposed to occur at this time.**

Abortion of pistillate flowers and fruit in pecan generally is considered to occur within 3 distinct periods (8, 15, 23, 29) commonly referred to as drops. The 1st drop occurs almost immediately after full bloom and consists of weak and underdeveloped pistillate flowers (23, 29). This drop is inversely related to shoot vigor (6, 10, 23). The 2nd drop, originally referred to as the May (29) or fertilization drop (15), begins about 14 days after pollination and continues until up to about 40–45 days after pollination (18). This drop coincides with the abscission of nonpollinated controls (1, 8, 15, 17, 18). The 3rd drop, or summer drop (15, 29), is subtle and has not been well defined, but it has been proposed to be due to embryo abortion (29). The 3rd drop is accentuated by self-pollination (15). Historically, this drop has included abortion that occurs from the end of the 2nd drop until the fruit mature (8, 15, 23, 29). However, at least one additional drop can occur within this interval (4). This drop occurs about the time the water stage of fruit development is at its maximum, which also coincides with initial shell hardening. The abortion often follows a fruit split that presumably is due to excessive internal pressure resulting from high soil moisture and/or high humidity (4). Sometimes, however, the aborted fruit do not have a visible split. In this case, the shuck has black splotches or elongated areas on the shuck, and the internal portion of the fruit is discolored.

The degree of the 3rd drop usually is small (8, 15, 23, 27). However, the magnitude of the 1st (29) and 2nd (1, 8, 29) drop varies greatly among seasons within a cultivar and among cultivars within a season. Observations indicate that the drop following fruit split and/or fruit discoloration also varies widely among cultivars and seasons. In addition to the variation among the individual drops, data (8, 15, 23, 29) and observations indicate that the total seasonal abortion of pistillate flowers and fruit varies greatly among pecan cultivars. This variation in total abortion among cultivars has been proposed as a factor in their alternate bearing tendencies (21). For example, 'Success' (20) and 'Cherokee' are severe alternate bearers; whereas, 'Stuart' (22) and especially 'Desirable' are fairly consistent fruit producers. Observations indicate that pistillate flower and fruit abortion is higher in 'Stuart' and 'Desirable' than in 'Success' and 'Cherokee'. Abortion, like fruit thinning, should increase the leaf area per fruit and return bloom (3, 16). The objectives of this study were to a) establish the seasonal abortion patterns of 'Cherokee', 'Success', 'Stuart' and 'Desirable', b) examine the relationship of pistillate flowers produced and aborted to shoot length, and c) determine the relationship between abortion and the alternate bearing tendency of these 4 cultivars. In addition, the effect of self-, cross-, open-, and no pollination on pistillate flower and fruit abortion of 'Desirable' was determined.

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