Firmness, Respiration, and Weight Loss of ‘Bing’, ‘Lapins’ and ‘Sweetheart’ Cherries in Relation to Fruit Maturity and Susceptibility to Surface Pitting

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Abstract. A convenient and reliable method that used a specially designed tool to apply a uniform bruising force in situ was developed to assess the relative susceptibility to fruit surface pitting in sweet cherry. Assessment of pitting with a visual scale after 2 weeks of 1°C storage was found to be in close agreement with measurements of pit diameter. Using this method ‘Bing’, ‘Lapins’, and ‘Sweetheart’ cherries showed a decline in susceptibility as fruit matured. The predictive value of fruit firmness at harvest, fruit respiration at harvest, and weight loss in storage was assessed in relation to the severity of pitting. The model to best describe pitting was found to include all three physiological variables (firmness, respiration, and weight loss). While an acceptable model was obtained when combining all three cultivars, the best models were achieved when each cultivar was considered separately. It was concluded that there are likely unmeasured variables involved in determining susceptibility to pitting. Hence the best approach to predicting pitting susceptibility is the application of the pit-induction method described in this work.

Surface pitting is a serious post-harvest quality problem in sweet cherries (Porritt et al., 1971), with some cultivars showing greater susceptibility than others. The pitting symptom appears some days or even weeks after bruising. Previous work has shown that fruit are more susceptible to injury leading to pitting if handled at lower temperatures (Lidster and Tung, 1980) and Patten et al. (1983) recommended that fruit be sorted prior to cooling, since much of the injury occurs during movement on the sorting line and at the cluster cutting stage in the line.

Previous work in simulating pitting involved dropping fruit a known distance onto a dimpled belt, similar to the belts used in cherry packing lines at the time (Crisosto et al., 1971). For instance, the mechanical injury that leads to pitting. While pitting susceptibility is influenced by maturity in ‘Van’ (Lidster et al., 1980) and ‘Lambert’ (Couey and Wright, 1974), there has been no examination of this relationship with either ‘Bing’ or any of the newer cultivars of sweet cherry now widely planted in North America. Firmness has been implicated as being an important factor in the determination of pitting susceptibility (Facteau, 1982; Facteau and Rowe, 1979; Looney and Lidster, 1980). Firmness is also an indicator of cell wall structure and is considered to be important in describing tissue response to mechanical forces (Facteau, 1982). Therefore, firmness was considered to be a physiological factor with potential to be a good predictor of pitting susceptibility.

While much has been done to evaluate the potential influences of cell wall structure on pitting susceptibility, questions have arisen as to whether there are other factors that might influence severity of pitting (Blachovec and Pato_ka, 1996; Choi et al., 2002a). Therefore, it was decided that other physiological characteristics should be examined. Water loss has been implicated as an important factor in the development of pits after mechanical injuries have been incurred (Toivonen, unpublished data; Lidster and Tung, 1980). Cultivar and/or maturity differences in susceptibility to pitting injury could potentially be influenced by water loss potential. Respiratory activity (or metabolic rate) might be expected to show some relation to pit development since glycolysis and respiration are important processes required for production of ATP and intermediates required in numerous biosynthetic pathways (Plaxton, 1996) and may hence be important in repairing the mechanical injury that leads to pitting.

The first goal of this work was to develop a rapid and reliable method to artificially induce pitting and to confirm that visual ratings could be used in place of actual measurement of pits. The second goal was to evaluate relative susceptibility to surface pitting of three important cultivars in two growing seasons and at different maturities. Finally, we have attempted to relate differences in pitting susceptibility to three physiological measures: fruit firmness at harvest, fruit respiration at harvest, and water loss during storage.

Materials and Methods

Fig. 1. Photograph of device designed to induce a controlled, repeatable bruising force to individual cherry fruit. The bottom tip of the device is carefully placed on the surface of the cherry and the rod is lifted to the highest level which the collar will allow and is simply let go to induce the injury on the surface of the fruit.

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Fig. 2. Regression of three measures of surface pits against a visual pitting rating. Note pit cross-sectional area was calculated from pit diameter and depth assuming a triangular pit. The visual rating scale was as follows: 1 = no pitting; 2 = superficial pitting, i.e., very shallow depression in the skin with edges being diffuse; 3 = moderate pitting, i.e., the pit was deeper and wider and had clearly distinct edges; 4 = severe pitting, i.e., the pit was very deep and edges of the pit had sunken into the pulp tissue.

fruit of each cultivar were randomly placed into clear polystyrene clamshell containers (1.5 dry pint (775 mL); Berigard Hinged Basket, Packaging Corporation of America, Northbrook, Ill.). Each clamshell contained 25 fruit. Once the clamshells were filled, they were placed into a 4 °C room. A 25-fruit sample of fruit not placed into induction treatment, these fruit were returned to the polystyrene clamshell containers and held at 1 °C for 2 weeks. To assess water loss, five replications, each consisting of 25 fruit, were weighed at harvest and again after 2 weeks of storage.

The pits were evaluated after 2 weeks, using both a visual rating and also a dental impression compound to produce an exact negative that could be measured under a microscope. The visual rating used the following scale: 1 = no pitting; 2 = superficial pitting, i.e., very shallow depression in the skin with edges being diffuse; 3 = medium pitting, i.e., the pit was deeper and wider and had clearly distinct edges; 4 = severe pitting, i.e., the pit was very deep and edges of the pit had sunken into the pulp tissue. The impressions of the pits were taken after storage, using Type 1 (low viscosity) Aquasil LV Smart Wetting Impression Material (Dentsply International Inc., Milford, Del.), which was applied with the Dentsply MixPac caulk dispenser. This two part dental impression compound was found to produce stable, detailed negative replicas of the pit area. Once cured (≈5 min) the pit impressions were stored in sealed 25-mL glass vials at room temperature after flushing the vials with N₂. This was done as a precaution to ensure that the impression dimensions remained stable until they could be measured. A 0.5-mm-thick cross-sectional slice was cut from the negative impression of each pit using a sharp razor blade. The pit diameter and depth were directly measured using a dissecting microscope (model M8; Wild Leitz Canada Ltd., Willowdale, Ont.) fitted with a digital video camera (Panasonic WV-D5000; Matsushita Commercial Industries Co., Ltd., Japan). Dimension measurement was accomplished with a video imaging program (Image Pro-Plus, version 3.0 for Windows, Media Cybernetics, Silver Spring, Md.), after calibration with a known standard rule. Assuming the pit area was triangular in shape, pit cross-sectional areas were calculated using the height and width measurements taken with the digital imaging system.

Respiration was measured as reported previously (Kappel et al., 2002). At harvest, fruit samples (15 to 30 g) were placed in 1-L plastic jars with tight-fitting lids and put into a 20 °C incubator (model 307; Fisher Scientific Canada, Nepean, Ont.). Jars were continuously flushed with air at a rate of 1.5 L·h⁻¹. The output of each jar was connected to an automated solenoid switching system. Every 5 min the sampler was advanced to the output from the next jar and the CO₂ detector was flushed with gas from a new sample. The level of CO₂ was detected with a P infrared instrument (Type DPIP-CD-1900-0; Analytical Development Co., Hoddesdon, England) and logged by computer. Samples were analyzed over a 24-h period. Rates of CO₂ production are expressed as mL CO₂/kg h⁻¹. All statistical analyses were performed using SAS software (SAS, Cary, N.C.). The relationship of visual pitting ratings to pit diameter, depth and calculated cross-sectional pit area was evaluated by regression analysis. All physiological parameter and pitting data were analyzed in a factorial design with cultivar, maturity, and year as main effects. Maturity level 7 was never achieved in ‘Sweetheart’, therefore those values for that cultivar were treated as missing data. For all measures, the three way interactions were found to be significant, so data are presented as graphs of simple effects with standard errors for each data point. The relationship of respiration at harvest, firmness at harvest and weight loss during storage to level of pitting was evaluated by regression analysis.

Results and Discussion

There was a strong linear correlation between visual pitting ratings and the measured...
suggested that greater firmness is associated with resistance to pitting (Facteau and Rowe, 1979; Facteau, 1982), but it is clear from the current work that this is not always the case. Firmness differences at the different maturities related to pitting susceptibility in ‘Bing’ and ‘Lapins’ ($R^2 = 0.51$, $P < 0.05$ and $R^2 = 0.61$, $P < 0.01$, respectively), however, this was not the case with ‘Sweetheart’ ($R^2 = 0.15$). Moreover, when data were combined for three cultivars, there was no significant relationship between firmness and pitting ($R^2 = 0.06$, ns). These results suggest that if fruit firmness is associated with pitting susceptibility, it may be only a partial determinant.

Water loss is also a potential factor in pitting susceptibility since the visual expression of the injury occurs only after water loss has been incurred by the fruit (P.M.A. Toivonen, unpublished data). This observation is supported by work showing that pitting developed faster, but not to a greater extent, at warmer storage temperatures (Lidster and Tung, 1980) where water loss is known to be much greater (Shibaaro et al., 2002). The data show that weight loss decline with advancing maturity was only dramatic in ‘Bing’ fruit (Fig. 5) and this was associated with decline in pitting severity in that cultivar (Fig. 3). In addition, ‘Lapins’ and ‘Sweetheart’ had lower rates of weight loss along with lower susceptibility to pitting as compared with ‘Bing’. However, since there was no trend between weight loss and pitting in ‘Lapins’ and ‘Sweetheart’, it cannot be concluded that weight loss is an overriding determinant of pitting susceptibility with advancing maturity in these three sweet cherry cultivars.

Changes in respiration rate (Fig. 6) were proportional to the pitting ratings (Fig. 3). Respiration rate was highest in ‘Bing’, intermediate in ‘Lapins’ and lowest in ‘Sweetheart’ over the different maturities of harvest and these differences were associated with the relative pitting susceptibility of these cultivars. This is similar to previous findings, which showed that cherry cultivars with greater basal respiration rates were generally more susceptible to bruising injury (Crisosto et al., 1993). However, a simple regression analysis failed to show a strong relationship between respiration rate and pitting susceptibility ($R^2 = 0.42$, $P < 0.05$).

The lack of a strong or consistent relationship between each of the three physiological measures and pitting susceptibility suggested that a model containing more than one of these measures was more likely to explain differences in pitting susceptibility. Multiple regression analysis, using a model which included all three physiological measures, demonstrated that all three factors were required in the model to best explain pitting susceptibility within a cultivar (Table 1). However, when data for all three cultivars were used in the model, the relationship was much weaker. This finding points to the likelihood that there are other physiological determinants which were not measured in this study. For instance, prior work suggests that cell wall composition and fruit calcium status may also be important determinants of pitting susceptibility (Facteau, 1982; Lidster et al., 1979) and at least one plant growth regulator, gibberellic acid, is known to reduce susceptibility to sweet cherry pitting (Looney and Lidster, 1980). Surface pitting in sweet cherries appears to be associated with several physiological factors. Some factors may be more important for one cultivar than another. For example, it appears that water loss in storage could be a good predictor of pitting susceptibility in ‘Bing’ but not in ‘Lapins’ or ‘Sweetheart’. However, the importance of firmness and respiration cannot be ruled out in ‘Bing’, since the prediction is improved by adding these other factors into the model. Obviously, other factors which were not measured may also be important in determining the severity of pitting. Since there was no single measure that could be useful in predicting pitting susceptibility, the only reliable approach to assessing the potential severity of pitting in sweet cherries was the controlled application of a known force combined with a
visual assessment of the injury symptom after it was given time to develop in cold storage. The results also show that the two Summerland cultivars—‘Lapins’ and ‘Sweetheart’—were less susceptible to pitting than ‘Bing’ when grown at the Summerland Research Centre site and confirm that as maturity advances in these three sweet cherry cultivars the susceptibility to surface pitting declines as it does in other cultivars.

The device and procedures developed in this work should prove useful to evaluate differences in pitting incidence due to handling or storage parameters or susceptibility of new cherry cultivars. The relatively quick visual rating of symptoms after 2 weeks of 1 °C storage appears to provide information as accurate as the more intensive physical measurement of pit dimensions and cross-sectional area.

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