Carbon Dioxide as an Indicator of Fruit Impact Damage

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Additional index words. blueberry, Vaccinium corymbosum, sweet cherry, Prunus avium, tart cherry, Prunus cerasus, mechanical harvesting, CO₂ analysis

Abstract. An infrared CO₂ analyzer system was used as a nondestructive and rapid means of monitoring the CO₂ evolution of blueberries (Vaccinium corymbosum L.), sweet cherries (Prunus avium L.), and tart cherries (P. cerasus L.). An increase in the CO₂ evolution of blueberries and cherries caused by impact-induced bruising was correlated with percent product decay. This technique may be useful in evaluating bruise damage caused by harvesting and handling systems.

The physical and physiological effects of mechanical harvesting on quality of blueberries and sweet and tart cherries are difficult to identify and quantify. Locating the points at which mechanical damage occurs throughout the different stages of the harvesting and handling operations usually is done by collecting large numbers of random samples of fruit and evaluating them for decay after a holding period of several days. A rapid, reproducible, and nondestructive method to identify and quantify those factors that contribute to fruit damage would be very desirable. Such a system would allow expedition of modifications in experimental equipment and procedures, as well as development recommendations for changes in existing commercial equipment and procedures.

Although CO₂ evolution has been recognized as an indicator of bruise damage to fruit, its application has not been widespread. When impacted, fruit such as citrus, cranberries, tomatoes, cherries, and apples show an immediate increase in the evolution of CO₂ (1, 3–6, 8), and, in some instances, the amount of bruise damage can be proportional to the CO₂ produced (2, 5, 6). This increase in CO₂ evolution is not due to enhanced normal respiratory activity, but to the decarboxylation of malic acid spilled from damaged cells at the site of the bruise (2, 4, 7).

The purposes of this study were to a) examine the effects of bruising on CO₂ evolution of blueberry and sweet and tart cherry fruit and b) determine if there is a correlation between the number of degree of impacts, CO₂ production, and subsequent decay development.

Blueberries ('Jersey'), sweet cherries ('Napoleon' and 'Schmidt'), and tart cherries ('Montmorency') were handpicked carefully in the morning at a stage when the fruit normally would have been mechanically harvested. Most cherries were picked without stems, but an additional control with stems was included for the tart and sweet cherry trials. After picking, the fruit were transported quickly and carefully to the laboratory, where the cherries were divided into lots of 250 g, while the blueberries were divided into 500-g lots. To simulate the bruising likely to occur to fruit during mechanical harvesting operations, we dropped the individual blueberries or cherries from a standard height of 1 m onto a hard, plastic surface from one up to five times. One lot was dropped 50 cm and another lot (the control) was not dropped.

Previous work showed that two 1-m drops created nearly the same bruise response as the commercial mechanical harvesting practices for cherry fruit (9).

Following each treatment, the samples were placed in plastic freezer containers of 2550 ml capacity and sealed with airtight, snap-on lids. Each treatment was replicated five times. Typically, <2 hr elapsed between fruit harvest and the sealing of the containers. In initial trials, we determined the amount of fruit needed in each container and the closure time required to obtain a minimum variation in CO₂ evolution between replications at 22°C. We also noted that the CO₂ evolution was essentially at maximum within 1 hr after the bruise treatment and generally remained at this level for 6 hr. The amount of CO₂ production in the container's headspace was sampled three times after a 1- or 2-hr interval, following sealing. After each 2-hr reading, the containers of fruit were opened and thoroughly aerated (using pressurized air) before resampling.

After completion of gas sampling, the fruit from each container were carefully transferred onto wet paper towels, one layer deep, in a plastic box with a lid. The fruit were held for 4 days at 23°C for decay development. An individual fruit was considered decayed if it showed a visible infection. The percent decay was determined by dividing the weight of decayed fruit by the total weight.

Carbon dioxide determinations for all fruit samples were taken by inserting needles attached to the intake and exhaust lines of an infrared gas analyzer (A.D.C. Carbon Dioxide Analyzer, The Analytical Development Co. Herts, U.K.), into the containers through vinyl tape covering two 1-cm-diameter holes in each lid. The holes were 8 cm apart and the needles were 2 and 8 cm in length to assure a good mix of the headspace atmosphere. This atmosphere was recirculated.

Received for publication 9 Apr. 1986. A joint contribution of the ARS/USDA and the Michigan Agr. Exp. Sta. Mention of a trade name or company name is used for specific information only and does not imply approval or recommendation of the product by the U.S. Department of Agriculture or Michigan State Univ. to the exclusion of others not mentioned. 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.

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Fig. 1. The relationship of the number of impacts to CO₂ evolution and decay development of 'Schmidt' sweet cherries. This relationship is similar for all tender fruits. Mean separation by Duncan's multiple range test, 5% level.
through the analyzer and container until a constant reading was obtained, usually within 15 to 20 sec. The analyzer provided a CO₂ reading in hundreds of a percent, which was converted to CO₂ (µg·g⁻¹·hr⁻¹) after making adjustments for the headspace volume of the container. The amount of CO₂ evolution monitored in the first 2 hr following sealing was used for reporting the data in this study. This study was conducted over a 3-year period beginning in 1983 and involved several trials with each of the different fruits.

Changes in the CO₂ evolution of blueberries and cherries remained fairly consistent between tests performed during different harvest times in the same year and from one year to the next. In general, there was a close relationship between impacts and impact damage (thus degree of injury), so the number of impacts was used in the correlation between impact damage and decay and impact damage and CO₂ evolution. Carbon dioxide evolution of blueberry and ‘Schmidt’ sweet cherry increased significantly with one, two, and three impacts, but with no further effect of four and five impacts as illustrated in Fig. 1 for ‘Schmidt’ sweet cherry. For ‘Napoleon’ sweet cherry, CO₂ evolution increased significantly with increasing number of impacts (data not shown). In the tart cherry tests, CO₂ evolution increased slightly with the 1-m impact over that of the control, but with additional impacts there was a significant decrease in CO₂ evolution (data not shown). All fruits except tart cherry there was a close positive correlation between increased CO₂ evolution and impact damage, as represented by the number of impacts. With the tart cherries there was a close correlation, but it was negative, because, as indicated previously, CO₂ evolution decreased with increasing number of impacts.

With all of these fruit there was a highly significant correlation between the number of impacts (degree of injury) and subsequent decay development—more impacts result in more decay (Table 1). However, the amount of decay development found on blueberries and cherries varied with the level of inoculation and type of field-borne postharvest pathogens that contaminated the fruit at harvest time. As an example, a high incidence of fungi in fields at harvest resulted in a high level of decay developing on all treatments except the control. Thus, when the percent fruit decay is used as an index of damage, it can give a distorted evaluation when compared with tests conducted at different times or at different sites when there may be a low level of inoculum.

In the sweet (‘Napoleon’) and tart cherry experiments, the control fruit with stems showed significantly less CO₂ evolution and decay development than the control fruit without stems (Table 2). Part of the tissue surrounding the stem scar area was damaged when the stem was removed, thus increasing CO₂ evolution and creating a site for pathogen entry. In commercial operations, (2-chloroethyl)phosphonic acid (ethephon) usually is applied to the cherries several days before mechanical harvesting. An abscission layer forms between the stem and fruit, facilitating removal. The use of ethephon nearly eliminates any open-stem scarred fruit. The ‘Schmidt’ sweet cherries were treated in this manner and the controls were picked with and without stems. When the CO₂ evolution and decay development results were compared between the two picking methods, there was no significant difference (data not shown).

In summary, these data show that progressive bruising of blueberry and sweet cherry fruit resulted in increased CO₂ evolution (decrease for tart cherry) that was proportional to the amount of tissue damage and percent decay. This trend of increased CO₂ continued until cell damage was severe. We concluded that the CO₂ evolution technique using an infrared CO₂ gas analyzer is a more efficient means of determining impact injury than the standard percent decay method.

Table 1. Correlation between impact damage and percent decay, impact damage and CO₂ evolution, and percent decay and CO₂ evolution.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Impact damage (%) vs. decay (%)</th>
<th>Impact damage (%) vs. CO₂</th>
<th>Percent decay (%) vs. CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tart Cherry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Montmorency)</td>
<td>0.946**</td>
<td>-0.937**</td>
<td>-0.861**</td>
</tr>
<tr>
<td>Sweet Cherry</td>
<td>0.993**</td>
<td>0.969**</td>
<td>0.973**</td>
</tr>
<tr>
<td>Sweet Cherry</td>
<td>0.973**</td>
<td>0.982**</td>
<td>0.944**</td>
</tr>
<tr>
<td>Blueberry</td>
<td>0.984**</td>
<td>0.898**</td>
<td>0.882**</td>
</tr>
<tr>
<td>(Jersey)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. The effect of stem vs. stemless harvesting on CO₂ evolution and percent decay of cherries when ethephon is not applied before harvest.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Stem</th>
<th>Stemless</th>
<th>CO₂ (%)</th>
<th>Decay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montmorency</td>
<td>37.0**</td>
<td>44.9</td>
<td>4.0**</td>
<td>20.7</td>
</tr>
<tr>
<td>Napoleon</td>
<td>45.2**</td>
<td>54.7</td>
<td>4.0**</td>
<td>37.5</td>
</tr>
</tbody>
</table>

**Carbon dioxide (µg·g⁻¹·hr⁻¹) determined 2 hr after enclosing in airtight container.

#Literature Cited#