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Towards precision spray applications to prevent rain-induced sweet cherry cracking: Understanding calcium washout due to rain and fruit cracking susceptibility

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ABSTRACT

Cracking of sweet cherries (*Prunus avium* L.) due to rain leads to serious economic loss to fresh market sweet cherry growers. Previous studies have proven that calcium (Ca)-based spray applications prior to rain events reduce rain-induced cracks in sweet cherries. The Ca-based chemicals on the surface of fruit get diluted or washed out due to rain and understanding such washout rates is critical to decide upon re-application rates to prevent fruit cracking. Therefore, the main purpose of this study was to quantify the potential washout of sprayed Ca-based chemicals from cherry fruit surface and leaf samples at different rain levels (2.5, 5.0 and 10.0 mm) under field condition. Prior to the field Ca washout experiment, cracking susceptibility, represented as cracking index (CI) of three different sweet cherry varieties (Selah, Skeena and Rainier) with different concentrations of calcium chloride ($CaCl_2$) and calcium nitrate ($Ca(NO_3)_2$) (T1 = 0.5% $CaCl_2$, T2 = 1.0% $CaCl_2$, T3 = 0.5% $Ca(NO_3)_2$, T4 = 1.0% $Ca(NO_3)_2$) was measured under laboratory condition. Similarly, the CI of fruits sampled from 'Selah' cherry trees sprayed with T1, T2, T3 and T4 after 10 mm of rain was also measured. The laboratory experiment data revealed that CI for non-treated fruits was in the range of 55–85 and susceptibility reduced significantly (4–37) when fruits were treated with Ca-based chemicals. The field experiments revealed that the Ca washout from both fruit and leaf linearly ($R^2 > 0.750$) increased with rain levels. Maximum washout was up to 72% at 10.0 mm rain. Results also suggest that for 5.0 mm or less rain, the Ca washout from cherry fruit surface was generally below 50%. Findings of this study could serve as a basis for determining suitable Ca-based chemical re-application rates and concentration on sweet cherries to minimize the fruit cracking without affecting produce quality.

1. Introduction

Cracking of sweet cherries (*Prunus avium* L.) is the greatest challenge to the cherry growers all over the world. Severe fruit injury, unpleasant appearance, poor taste and increased susceptibility to pathogenic infection render such produce unmarketable in the fresh market (Ono et al., 1954). Similarly, cracked cherries are prone to different storage diseases and have shorter shelf-life. Sweet cherries are liable to crack if it rains when fruits are nearing harvest or maturity (Ono et al., 1954). Cracking is also affected by fruit characteristics (size, firmness, osmotic concentration and growth stage, etc.), rainfall duration, ambient temperature and other environmental conditions (Rupert et al., 1997; Simon, 2006; Erogul, 2014).

Two major causes of sweet cherry cracking reported in literatures are (1) as a result of direct rain water absorption through the fruit skin or cuticle, and (2) as a result of water supplied to the fruit through trees' vascular system (Schrader and Sun, 2005; Simon, 2006). Generally, crop is assumed unprofitable to harvest if cracked fruits are greater than 20–30% of yield; because under such condition labor costs for sorting out cracked cherries exceed the crop value (Hanson and Proebsting, 1996). In certain years, fruit cracking in some sweet cherry varieties can be up to 90% of harvestable yield (Cline et al., 1995; Christensen, 1996). Therefore, there is great interest in the effective management of crop to avoid rain-induced sweet cherry cracking.

Current available solutions include calcium (Ca)-based chemical applications prior to rain events to reduce water uptake through

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fruit cuticle. Several previous studies have reported that Ca sprays reduce rain induced cracking in sweet cherries (Yamamoto et al., 1992; Wojcik et al., 2013). Glenn and Poovaiah (1989) reported that Ca in the ionic form (Ca^{2+}) strengths the cell wall and helps in preventing fruit cracking. In addition to cracking minimization in orchard conditions, the post-harvest disorders such as fruit decay and pitting can also be minimized and the fruit quality can be maintained by Ca application on cherries (Rupert et al., 1997; Wang and Long, 2015).

Cherry cracking susceptibility to rain starts 10–25 days before harvest when there is a rapid growth of fruit and formation of sugar from starch (Christensen, 1973). Previous studies have recommended repeated sprays (3–4 times starting 4 weeks before harvest) of Ca containing chemicals such as calcium chloride ($CaCl_2$), calcium nitrate ($Ca(NO_3)_2$), calcium hydroxide ($Ca(OH)_2$), calcium acetate and calcium caseinate to prevent sweet cherry cracking (Ono et al., 1954; Fernandez and Flore, 1998; Wojcik et al., 2013; Erogul, 2014). Amongst these chemicals, $CaCl_2$ and $Ca(NO_3)_2$ are commonly used in different parts of the world (Wojcik et al., 2013). According to Rupert et al. (1997), it will be more effective to apply Ca directly to the fruit surface because Ca translocation to the fruits is minimal from canopy and leaves. In the orchard where Ca-based chemical has been sprayed, Ca present on the fruit surface will be diluted if rain occurs. Chemical washout from the fruits can vary depending on the rain intensity and duration. The residual concentrations on the fruit surface may or may not be sufficient to protect fruits from cracking due to future rain events. On the other hand, chemical overdose might cause fruit skin burn adversely affecting quality. Measurement of Ca chemical concentration in the cherry leaf surface will also be useful in determining the potential side effects on leaves.

Therefore, it is very essential to have information of the Ca concentration on fruit and leaf surface to optimize the future application rate and concentration of Ca-based chemicals. Thus, aim of the present study was to quantify cracking susceptibility of sweet cherry varieties and in-field evaluation of the potential washout of sprayed Ca-based chemicals from the fruits and canopy (leaves) at the different rain levels (2.5, 5.0 and 10.0 mm).

2. Materials and methods

2.1. Study location and field conditions

Experiments were conducted in the Roza orchard (experimental orchard of Washington State University [WSU]) near Prosser, WA, USA. Two different tree architectures, including Y-trellised and vertical canopy, were used for the tests, as shown in Fig. 1. Cherry trees with Y-trellised canopy architecture (YCA) were seven years old and with vertical canopy architecture (VCA) were 10+ years old. Cherry tree branches for YCA were trained to grow in both sides as 55° to the ground and each side of a tree had three to five branches. Cherry trees of VCA were trained to grow vertically. The inter-row spacing, intra-row spacing, maximum canopy height and trunk height for YCA were 4.6, 0.9, 4.0 and 1.1 m, respectively. In case of VCA, the above mentioned parameters measured 3.0, 2.4, 4.2 and 1.1 m, respectively. The 'Selah', 'Skeena' and 'Rainier' sweet cherry varieties tested in this study were on Gisela®6 (Gi6), Gi6 and Gi5 rootstock, respectively. The management practices for the experimental orchard were similar to commercial orchards in the Washington State.

Field experiment was conducted on June 27–28, 2015 (one week before harvest). The micro-meteorological conditions recorded by nearby WSU AgWeathernet station including wind speed and direction, air temperature and humidity, were 3.9 ± 2.5 (mean ± std. dev.) $m\,s^{-1}$ SW, 29.7 ± 1.8 °C, and 27.8 ± 3.8%, respectively, during first day and were 4.4 ± 1.3 $m\,s^{-1}$SW, 22.2 ± 3.4 °C, and 42.7 ± 10.3%, respectively, during the second day of the experiment.

2.2. Rainfall simulation system

The rainfall simulation system used in this study is shown in Fig. 1c, which consists of (1) a 190 L capacity water tank; (2) a centrifugal pump (Model 1538, Hypro, New Brighton, MN, USA) which was powered using gas engine (Model GX 120, Honda Engines, Alpharetta, GA, USA); (3) a telescopic mast (maximum height of 10 m above ground); (4) the spraying system consisting of eight sets of full cone spray tips (nozzles) (Model FCX80, Hypro, New Brighton, MN, USA). Nozzle with 80° cone angle had flow rate of 1.3 $L\,min^{-1}$ at 275 kPa. The spacing between nozzles was maintained at 0.3 m. The PVC hose with sprayers was tied to an aluminum structure and then mounted on the telescopic mast.

The measured discharge rate of the developed rainfall simulation system was approximately 10.3 $L\,min^{-1}$ at the pressure of 200 kPa (30 psi) in field condition. The coverage area of the rainfall simulation system was measured approximately 13.7 m^2 when the height of nozzles was 5.0 m above the ground, which covered 3–5 trees based on tree canopy size. In the test, the nozzles height was maintained in the range of 0.5–1.5 m above tree canopy (4.5–5.5 m above ground) depending on the wind direction and velocity.

Three rain levels were determined as 2.5, 5.0 and 10.0 mm based on the maximum and average daily rainfall level of the experiment site in the month of June and July for last 7-year (2008–2014) rain data from WSU AgWeatherNet (http://weather.wsu.edu). The desired rain level was maintained by operating rainfall simulation system for designed interval of time (for example, 2 min for generating 2.5 mm of rain). Five manual rain gauges were also hanged in tested trees at different heights and positions to quantify the rain level (Fig. 1c).

2.3. Evaluation of fruit cracking susceptibility

To assess the cracking susceptibility of tested sweet cherry varieties to water with different concentrations of Ca chemicals, laboratory tests were conducted. CI experiment was divided into two sub-experiments (Experiment-1 and Experiment-2). Fruit samples were collected in plastic bags and transported in a cooler to laboratory. In Experiment-1, CI of different varieties of cherry fruits (Selah, Skeena and Rainier with weight of 11.2 ± 2.1, 10.8 ± 1.6, 10.3 ± 1.6 g, respectively) were evaluated by dipping fruits into pure deionized (DI) water (control group, C) and DI water containing Ca-based chemicals at different concentrations (T1 = 0.5% $CaCl_2$, T2 = 1.0% $CaCl_2$, T3 = 0.5% $Ca(NO_3)_2$, T4 = 1.0% $Ca(NO_3)_2$).

In Experiment-2, CI was evaluated for 'Selah' cherry fruits sampled after 10.0 mm of rain from VCA and YCA trees sprayed with different concentration of Ca-based chemicals by dipping the sampled fruits in pure DI water. Fruit samples analyzed were from VCA trees sprayed with T1, T2, T3 and T4 and YCA trees sprayed with T2 and T4.

Both the CI experiments were conducted with three replications with sample size of 20 uniform size fruits. Cracking rates after 2, 4 and 6 h evaluation were used to estimate CI (Eq. (1), (Stojanović et al., 2013; Erogul, 2014)).

$$CI = \frac{(5N_{2h} + 3N_{4h} + N_{6h})100}{5N_T} \tag{1}$$

where

CI = cracking index
$N_{2\,h}$ = number of cracked cherries in two hour
$N_{4\,h}$ = number of cracked cherries in four hour
$N_{6\,h}$ = number of cracked cherries in six hour
N_T = total number of cherries used for the experiment