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Development and Evaluation of a Portable, Handheld Mechanical Shaker to Study Fruit Detachment in Blueberry

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Abstract. **A portable, handheld, mechanical shaking device was developed and its effects on fruit detachment in rabbiteye bluebbery (*Vaccinium ashei* Reade) and southern highbush blueberry (hybrids of mostly *Vaccinium corymbosum* L. and *Vaccinium darrowi* Camp.) were evaluated. The instrument facilitated effective detachment of fruit within a branch, especially in rabbiteye blueberry (greater than 75%). Approximately 3 to 4 seconds of shaking was sufficient to detach the majority of the fruit. Differences in the extent of fruit detachment were observed across the genotypes, especially among southern highbush blueberry genotypes. The majority of fruit detachment in rabbiteye blueberry and most of the southern highbush blueberry genotypes occurred at the point of attachment of the pedicel to the berry, although a significant portion detached with the stem intact, resulting in stemmy fruit. Although only a small proportion of the detached fruit was immature in the rabbiteye blueberry genotypes, up to 23% of the detached fruit was immature in the southern highbush blueberry genotypes. Application of the abscission agents methyl jasmonate (MeJa; 20 mM) and ethephon (1000 mg·L^{-1}) reduced the time required for fruit detachment on mechanical shaking by up to 5-fold. Together, these data indicate that the mechanical shaking device developed here is an effective tool for studying fruit detachment in blueberry. This instrument has potential applications in blueberry research programs evaluating fruit production. It can be used in breeding programs to aid in the selection of genotypes with fruit detachment characteristics that are potentially better suited for mechanical harvesting, and also in programs involving the screening and evaluation of abscission agents in blueberry.**

Blueberry (*Vaccinium* spp.) production has increased greatly over the last decade, especially in the southeastern United States. It is currently valued at over $780 million in the United States [U.S. Department of Agriculture (USDA), 2012]. Sustaining the profitability of the blueberry industry requires a better understanding and the mitigation of problems associated with its production. Harvesting is generally one of the most expensive and labor-intensive aspects of blueberry production, especially when fruit are hand-picked. Mechanical harvesting can greatly reduce the costs associated with harvesting. Owing to the growing interest in the use of mechanical harvesting in blueberry, especially for fruit intended for the fresh market, there are considerable research efforts underway to enhance the efficiency of this process. In fact, a current area of focus of several blueberry breeding programs is the development of genotypes better suited for mechanical harvesting (NeSmith, 2009; Jim Olmstead, Steve Stringer, and Jim Ballington, personal communications). An additional area of research is the development of abscission agents that can facilitate fruit detachment and enhance the efficiency of mechanical harvesting (Malladi et al., 2012; Takeda et al., 2008; van Dalfsen and Gaye, 1999).

Better knowledge of fruit detachment properties is valuable in blueberry breeding because it is closely associated with suitability of a genotype for mechanical harvesting. Performing trials using commercial mechanical harvesters may be the most conclusive method to determine the suitability of a genotype for mechanical harvesting. However, such evaluations cannot be performed during the selection process in breeding programs as a result of factors such as the scale at which the plants are grown and the cost associated with such trials for multiple genotypes. Hence, much of the current evaluation of fruit detachment characteristics of genotypes during breeding and selection is performed through hand-harvesting. Evaluation of potential abscission agents to determine their effect on fruit detachment is essential to develop harvest aids that can enhance the efficiency of mechanical harvesting (Burns, 2002; Burns et al., 2005; Malladi et al., 2012). Such screening may not always be feasible using commercial-scale mechanical harvesters. A portable, handheld instrument that can allow for the mechanical shaking of a branch may provide an effective alternative and can greatly aid in blueberry breeding and abscission agent research efforts. The main objectives of this study were to develop a portable, handheld mechanical shaker and to evaluate its effects on fruit detachment in blueberry. To achieve the objectives, a reciprocating saw was modified to enable controlled mechanical shaking of blueberry branches. This instrument was evaluated across multiple rabbiteye and southern highbush blueberry genotypes. Additionally, mechanical shaking studies were performed using this instrument after treatment with abscission agents.

Materials and Methods

Development of the portable, handheld mechanical shaker. The portable, handheld mechanical shaker was developed at the Instrument Design and Fabrication Shop, University of Georgia. A variable-speed reciprocating saw (DeWalt Model no. DC385; DeWalt Industrial Tool Co., Baltimore, MD) driven by an 18-V lithium ion battery (DeWalt Model no. DC9181) was modified for this purpose (Fig. 1). An external resistor (5 ohm, 300 W, variable resistor, Part # E300K5R0E; Ohmite Manufacturing Co., Arlington Heights, IL) was fitted to the reciprocating saw to control the number of strokes per minute. A stainless steel adapter was developed and fitted to the instrument to function as an arm that could be clamped to a branch to enable mechanical shaking. The adapter was 30 cm in length, 1.5 mm in thickness, and 6.3 cm at its widest point. A V-shaped notch (4.5 cm wide and 2.3 cm deep) was designed at the end of this adapter and was padded with rubber strips. For mechanical shaking of the blueberry branches, the branches were placed within the V-shaped notch and a rubber band was used to attach the branch to the adapter through grooves designed on the adapter. Preliminary trials were performed to determine the number of strokes per minute required for fruit detachment from the branch. A setting on the resistor (2 to 2.4 ohm) that allowed for ≈900 strokes per minute was found to result in effective fruit removal in these trials and was used in all subsequent studies.

Evaluation of the mechanical shaker across blueberry genotypes. Fruit detachment using

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the mechanical shaker was studied in rabbiteye blueberry plants in 2011 and 2012 and in southern highbush blueberry in 2012. In 2011, five- to six-year-old rabbiteye blueberry plants grown at the Horticulture Farm, University of Georgia, Watkinsville, GA, were used to evaluate the mechanical shaker. Three cultivars were used in this study: 'Premier', 'Climax', and 'Briteblue', with four replicates (individual plants). Mechanical shaking was performed on 17 July for the three cultivars. A branch with ≈50 fruit was selected on each plant. The adapter of the mechanical shaker was attached to the branch several inches below the fruiting wood, and the branch was shaken for 5 s. The number of fruit on the branch segment was determined before and after mechanical shaking, and the data were used to calculate the percent fruit detachment. Occasionally, shaking of a single branch resulted in fruit detachment from branches in close proximity. The detached fruit were collected in a catch frame [rectangular metal basket lined with laminated paper (45.5 cm × 40.5 cm × 10 cm)] placed below the plant. From the collected fruit, the proportion of immature fruit (green and pink fruit) and the proportion of fruit with the pedicel attached (stemmy fruit) were determined.

In 2012, fruit detachment in response to mechanical shaking was studied using seven-year-old 'Premier' and 'Climax' rabbiteye blueberry plants grown at the Horticulture Farm, University of Georgia, Watkinsville, GA (n = 4). Fruit detachment in response to mechanical shaking was studied in these plants as described previously. Mechanical shaking was performed on 22 June for 'Premier' and on 3 July for 'Climax'. In addition, the time taken for the majority of the fruit on the sample branch to detach was also determined in this study using two branches per plant. To determine the time taken for fruit detachment, shaking was performed as described previously, and the time taken for the detachment of most of the fruit was recorded.

In 2012, the fruit detachment responses to mechanical shaking were also studied in southern highbush blueberry. The three genotypes used in this study were: TH907, 'Camellia', and TH1129. Five-year-old plants grown at the Georgia Station, Griffin, GA, were used. Four replicates (individual plants) were used for each of the genotypes. Mechanical shaking was performed for all the three genotypes on 23 May. At least two branches per plant were used for mechanical shaking in TH907 and 'Camellia', whereas one branch per plant was used in TH1129. Mechanical shaking was performed and the data collected as described previously.

Fruit detachment in response to abscission agent application and mechanical shaking. The effects of abscission agent application followed by mechanical shaking on fruit detachment were studied in 2011 in the rabbiteye blueberry cultivar, Briteblue. Five-year-old plants were used in this study (n = 3). Methyl jasmonate (Sigma-Aldrich, St. Louis, MO) at 20 mM and ethephon (2-chloroethylphosphonic acid; Bayer CropScience, Kansas City, MO) at 1000 mg·L^{-1} were applied along with an adjuvant (0.15% of Latron B-1956; Rohm and Haas, Philadelphia, PA) on 21 July. The control plants were treated only with the adjuvant. Abscission agent applications were performed using a hand-pump sprayer until runoff at 0830 HR. The average temperature on the day of application was 27 °C. At 24 h after application, branches with ≈50 fruit each were selected and the immature fruit (green and pink fruit) on these branches were removed to study the effects specifically on mature fruit. Mechanical shaking was performed on each of these individually, as described previously. Two branches per replicate were used in this study. The time taken for the removal of all fruit from the branch was recorded. The data were analyzed using analysis of variance and mean separation was performed using Fisher's least significant difference (α = 0.05). Data analyses were performed using SigmaPlot 11 (Systat Software Inc., San Jose, CA).

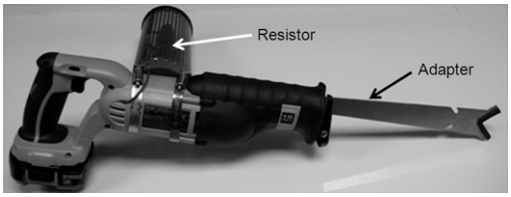

Fig. 1. Mechanical shaker for fruit detachment in blueberry. A reciprocating saw was modified by the addition of a resistor and an adapter (indicated by arrows) to enable mechanical shaking and fruit detachment in blueberry.

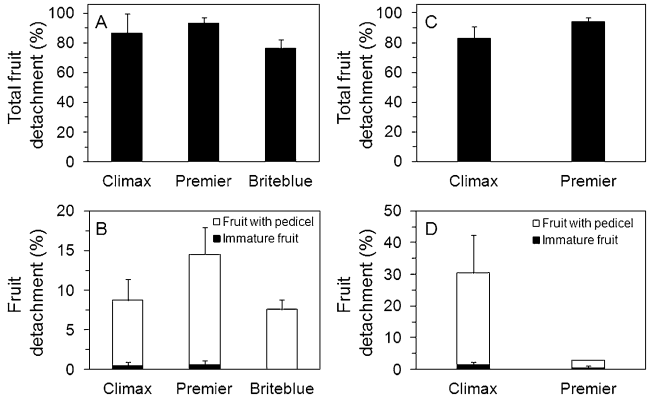

Fig. 2. Fruit detachment in response to mechanical shaking in rabbiteye blueberry cultivars. Individual branches with ≈50 fruit were shaken for 5 s using the mechanical shaker in 2011 (**A–B**) and in 2012 (**C–D**). (**A** and **C**) The fruit number on the branch was counted before and after shaking to determine the extent of total fruit detachment. (**B** and **D**) Fruit detached during shaking were collected in a catch frame and the proportion of fruit with the pedicel attached and the proportion of immature fruit were determined. Error bars indicate the SE of the mean (n = 4).

Results

Mechanical shaking for 5 s resulted in the removal of 87% and 93% of the fruit in 'Climax' and 'Premier', respectively, but only in 76% fruit detachment in 'Briteblue' (Fig. 2A). In all three cultivars, the majority of fruit detachment (greater than 85%) in response to mechanical shaking occurred at the point of attachment of the pedicel to the berry (Fig. 2B). A small proportion of fruit detachment (≈8% to 14%) occurred at the point of attachment of the pedicel to the branch, resulting in stemmy fruit. Among the detached fruit, only a small proportion (less than 1%) was constituted by immature fruit, whereas the vast majority was mature fruit (Fig. 2B).

The fruit detachment response of the rabbiteye blueberry cultivars, Climax and Premier, in the 2012 study was largely similar to that in the 2011 study. Mechanical shaking for 5 s resulted in 83% and 94% fruit detachment in 'Climax' and 'Premier', respectively (Fig. 2C). Approximately 3.4 s (± 0.4 s) of shaking was sufficient to cause the detachment of up to 93% of the fruit in 'Premier'. In 'Climax', ≈4.3 s (± 0.6 s) was required to achieve ≈85% fruit detachment. Only 2% of the fruit detachment occurred along with the pedicel in 'Premier', whereas up to 29% of the fruit was found to retain the pedicel in 'Climax' (Fig. 2D). Similar to the results from the previous year, the large majority of the detached fruit was mature and only a small proportion (less than 2%) was constituted by immature fruit in 2012 (Fig. 2D).

Fruit detachment responses of the southern highbush blueberry genotypes were more variable than that of the rabbiteye cultivars. In TH907, mechanical shaking for 5 s resulted in 88% fruit detachment (Fig. 3A). However, in 'Camellia' and TH1129, shaking for a similar duration resulted in only

69% and 49% fruit detachment, respectively. The majority of fruit detachment in TH907 (58%) occurred at the point of attachment of the pedicel to the branch, whereas 12% and 33% fruit detachment occurred at this location in 'Camellia' and TH1129, respectively (Fig. 3B). In the southern highbush blueberry genotype, TH907, as high as 23% of the detached fruit was immature, whereas ≈12% of the fruit was immature in the other two genotypes. In some instances, multiple fruit were found to detach together as a result of the breakage of the peduncle in response to mechanical shaking. The majority of these were immature fruit.

The effect of abscission agents on the time taken for fruit detachment on mechanical shaking was determined in the rabbiteye blueberry cultivar, Briteblue. In the control, mechanical shaking of ≈14.4 s was required to detach all the fruit for a sample branch (Fig. 4). The application of MeJa (20 mM) reduced the time taken for fruit detachment by almost 5-fold (3 s). Similar to the MeJa applications, the application of ethephon (1000 mg·L^{-1}) reduced the time taken for fruit detachment upon mechanical shaking to 3.5 s (decrease by 4-fold).

Discussion

An easy-to-use, portable, handheld mechanical shaker was developed in this study. Mechanical shaking using this instrument resulted in consistent total fruit detachment, especially across multiple rabbiteye blueberry genotypes. In the rabbiteye blueberries, mechanical shaking with this instrument resulted in the detachment of the majority of the fruit (greater than 75%). Most of the fruit detachment was achieved within 3 to 4 s of shaking. Similar responses were observed over multiple years, suggesting that the instrument can potentially be used to determine fruit detachment characteristics. The response to shaking was variable among the southern highbush genotypes. Although TH907 was highly responsive to shaking, TH1129 displayed less than 50% fruit detachment in response to shaking. Similarly, the rabbiteye blueberry cultivar, Briteblue, displayed lesser fruit detachment than the other two cultivars. The variability in response to mechanical shaking may reflect the inherent differences in fruit detachment characteristics among the genotypes. These results suggest that the mechanical shaker can be an effective tool to determine the suitability of a given genotype for mechanical harvesting. However, it is also likely that some of the differences observed here reflect differences in the extent of fruit maturity during mechanical shaking. Additional research is essential to address this possibility.

The majority of fruit detachment in the rabbiteye cultivars and two of the southern highbush genotypes ('Camellia' and TH1129) occurred at the point of attachment of the pedicel to the berry, resulting in only a small proportion of the fruit retaining the stems (stemmy fruit). Presence of the pedicel on the fruit is considered a defect that can reduce fruit quality (USDA, 1995) and often requires destemming to make the fruit marketable. Under mechanical harvesting conditions, although the majority of fruit detachment may occur without the pedicel, a significant proportion of the fruit can be stemmy, similar to the results reported here while using the mechanical shaker (Takeda et al., 2008). It should be noted that the extent of stemmy fruit detachment was exceptionally high in the southern highbush genotype, TH907, and very low in the rabbiteye cultivar, Premier, suggesting that this instrument can be used to assess genotype differences in fruit detachment points during mechanical shaking. Also, differences across different years in the extent of fruit detachment along with the pedicel were observed in 'Climax' and 'Premier'. It is likely that such differences may be the result of differences in the extent of fruit maturity during the mechanical shaking.

Detachment of immature fruit is a common problem in mechanical harvesting of blueberry. In the current study with mechanical shaking, only a small proportion of the detached fruit was found to be immature in the rabbiteye cultivars, suggesting that the frequency/intensity used in mechanical shaking in this study results in the preferential detachment of mature fruit. In the southern highbush genotypes, as high as 23% of the detached fruit was found to be immature fruit, indicating that the extent of immature fruit detachment may differ considerably across different types of blueberry. These data indicate that the instrument can be used to study differences in the extent of immature fruit removal during mechanical harvesting. The small proportion of detached immature fruit may also reflect the smaller proportion of immature fruit present on the plant at the time of mechanical shaking. Further studies are required to determine if the extent of immature fruit detachment is affected by the level of fruit maturity.

The application of abscission agents can potentially be an effective means to induce fruit detachment and thereby aid in mechanical harvesting in a variety of fruit crops including blueberry (Burns, 2002; Burns et al., 2005; Malladi et al., 2012). In this study, the application of MeJa and ethephon resulted in a sharp decline in the time taken for complete fruit detachment on mechanical shaking. The two abscission agents effectively reduced the time for complete fruit detachment by 4 to 5-fold, underlining the potential of the abscission agents as harvest aids in blueberry. These data also suggest that the effect of such potential abscission agents on fruit detachment can be effectively evaluated using the instrument developed in this study.

The mechanical shaker developed here can have multiple potential applications for blueberry research programs evaluating fruit production. It may be useful for blueberry breeders to perform a simple, rapid, and reproducible analysis of the fruit detachment characteristics of a genotype and determine its suitability for mechanical harvesting. The short time taken for the evaluation using this instrument would allow for screening large populations in small research plots during selection for genotypes better suited for mechanical harvesting. Similarly, this instrument may be used effectively in evaluations of potential abscission agents as harvest aids

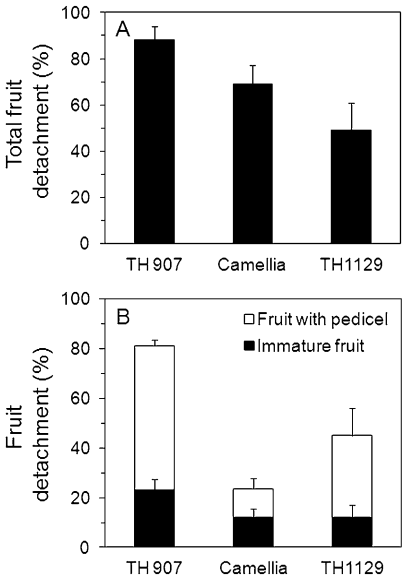

Fig. 3. Fruit detachment in response to mechanical shaking in three southern highbush blueberry genotypes. Individual branches were shaken for 5 s using the mechanical shaker. (**A**) Fruit number was recorded before and after mechanical shaking and used to determine the extent of fruit detachment facilitated by the shaker (total fruit detachment). (**B**) Fruit detached during shaking were collected in a catch frame and the proportion of fruit with the pedicel attached and the proportion of immature fruit were determined. Error bars indicate the SE of the mean (n = 4).

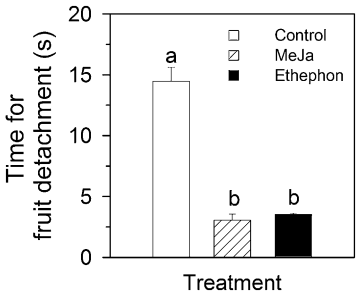

Fig. 4. Effect of abscission agents on time for fruit detachment on mechanical shaking. Rabbiteye blueberry plants of the cultivar, Briteblue, were treated with methyl jasmonate (MeJa; 20 mM), ethephon (1000 mg·L^{-1}), or only the adjuvant (Control). At 24 h after treatment, individual fruiting branches with ≈50 fruit each were shaken using the mechanical shaker, and the time taken for complete fruit detachment was determined. Mean separation was performed using Fisher's least significant difference (α = 0.05) after analysis of variance. Error bars indicate the SE of the mean (n = 3). Similar letters above the bar indicate that the means are not significantly different.

in mechanical harvesting. However, certain aspects of mechanical shaking may need further attention or analysis before such applications. It is essential to determine in future studies if the fruit detachment responses resulting from mechanical shaking using this instrument are similar to responses using a commercial mechanical harvester. Determining the correlation between the instrument and a mechanical harvester may ensure the wider applicability of this instrument for assessing fruit detachment. Additionally, the specific stage of maturity may need to be standardized to enable reliable comparison across genotypes.

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