Breeding Highbush Blueberry Cultivars Adapted to Machine Harvest for the Fresh Market

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SUMMARY. In recent years, world blueberry (*Vaccinium* sp.) production has been split evenly between processing and fresh fruit markets. Machine harvest of highbush blueberry {northern highbush blueberry [NHB (*V. corymbosum*)], southern highbush blueberry [SHB (*V. corymbosum* interspecific hybrids)], and rabbiteye blueberry [RE (*V. virgatum*)]} typically has been used to obtain large volumes of fruit destined for processing. Because of financial and labor concerns, growers are interested in using machine harvesting for fruit destined to be fresh marketed. Bush architecture, harvest timing, loose fruit clusters, easy detachment of mature berries compared with immature berries, no stem retention, small stem scar, a persistent wax layer, and firm fruit are breeding goals to develop cultivars amenable to machine harvest. Progress in selecting for these traits has been made in existing highbush blueberry breeding programs, but will likely intensify as the need for cultivars suitable for machine harvest for the fresh market increases.

Highbush blueberry production passed the 1-billion-pound mark for the first time in 2012 (Brazelton, 2013). From 2010–12, there was a near equal split between highbush blueberry fruit sent to fresh or process markets (Brazelton, 2013). Until recently, machine-harvested fruit were predominantly destined for processed blueberry products due to the potential for fruit damage leading to reduced marketability and post-harvest life. Strik and Yarborough (2005) reported that the percentage of machine-harvested highbush blueberries for processing ranged from 50% in Washington to 100% in Georgia and Michigan, with typically lower percentages of fruit for fresh utilization being machine harvested. The percentage of acreage harvested by machine had increased from 40% for both markets in a similar survey the

decade previously (Moore, 1994). The authors of both reports indicated that the trend for machine harvest would continue increasing, a trend that has been consistent for at least the past two decades. More recently, Brazelton (2013) reported an increased interest in using machine harvest among SHB cultivars, particularly for use in machine harvest for fresh fruit (MFF) marketing.

An ideal highbush blueberry plant for machine harvest was first described by Galletta (1975) and summarized in Dale et al. (1994). As described, this machine-harvestable highbush blueberry would have an upright bush architecture, few low-growing canes, a narrow crown, easy detachment of mature berries compared with immature berries, loose fruit clusters, a small stem scar, firm fruit, and a concentrated ripening period. These characteristics are adapted to the tunnel design commonly employed in current over-the-row harvester designs that have evolved with process highbush blueberry production in mind. Few attempts have been made to design machine harvesters suitable for MFF, and the one example developed was not adopted

by producers (Peterson et al., 1997; Takeda et al., 2008).

With concerns about hand-harvest labor availability and decreasing profit margins due to competition from lower cost of production locations, producers are looking toward MFF as a solution. Many have experimented with using existing harvesters and cultivars for MFF, with varying degrees of success. Few breeding programs have developed cultivars with MFF in mind. The notable exceptions are from the North Carolina State University breeding program, where several cultivars (i.e., Reveille, Bladen, Craven, Pamlico, Lenoir, Carteret, and Beaufort) were developed and are described as being adapted to MFF (Ballington, 2013). Food safety is a driver toward more machine harvesting, as fruit untouched by human hands is desirable to reduce the risk of food-borne illness. Our belief is that the need for MFF cultivars will continue to increase, and blueberry programs must adopt selection strategies that will result in cultivars adapted to MFF production. Our objectives were to describe the short-, medium-, and long-term strategies a highbush blueberry breeding program might take to enable selection for MFF.

Short-term strategy

Because the development timeline for highbush blueberry cultivars can take 10–15 years, adoption of MFF in the near future will require the use of existing cultivars. Experience has shown that there are no “perfect” cultivars for MFF, and to our knowledge, no grower has been able to harvest a complete crop using a MFF strategy. However, analyzing what makes a cultivar amenable or not to MFF helps to define breeding goals that will be used to improve MFF characteristics in future cultivars.

Two cultivars resulting from the typical SHB breeding priorities that can be used to illustrate the difficulty in adapting existing cultivars to MFF are Emerald and Springhigh. ‘Emerald’ was introduced in 1999, and ‘Springhigh’, in 2006, from the University of

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4536	lb	kg	2.2046

Florida breeding program (Clark and Finn, 2006; Lyrene, 2008). Both cultivars have been planted widely enough worldwide that their flaws related to MFF are evident.

‘Emerald’ and ‘Springhigh’ are planted in some of the lowest chilling requirement production regions worldwide. Both have proven to be tolerant to many diseases problematic in humid subtropical production areas. ‘Emerald’ has high yields of large, firm fruit, but several characteristics have severely limited its use for MFF. ‘Emerald’ fruit are borne in very tightly packed clusters (Fig. 1) that do not release effectively during the machine harvest process. ‘Emerald’ bushes are vigorous and healthy, but they have a spreading growth habit with a relatively wide base that prevents existing harvesters from sealing completely around the base of the plant resulting in significant fruit loss. Finally, although ‘Emerald’ has high total yields, its harvest season is longer than many cultivars, necessitating many machine harvest passes through the field. ‘Springhigh’ matures much earlier than ‘Emerald’, and has an upright growth habit, which is valuable for MFF. However, ‘Springhigh’ has a darker fruit with a less persistent

Fig. 1. Compact fruit cluster of ‘Emerald’ southern highbush blueberry. Short pedicels and large fruit size contribute to a cluster architecture that is “tight” and not amenable to machine harvest.

wax layer, even when hand-harvested. It is very dark when machine harvested because the wax is removed during the harvest process. Additionally, ‘Springhigh’ fruit are among the least firm of cultivars released from the University of Florida breeding program, and the scar has a tendency to be wet when harvested at higher temperatures.

In contrast, two examples of cultivars that have been successfully used for MFF are Duke and O’Neal. ‘Duke’ was a 1987 NHB release from the USDA-ARS and the New Jersey Agricultural Experiment Station (Draper et al., 1987), while ‘O’Neal’ was a 1987 SHB release from the North Carolina Agricultural Research Service and the USDA-ARS (Ballington et al., 1990).

‘Duke’ and ‘O’Neal’ are major cultivars produced worldwide in temperate and midhill production areas, respectively. The characteristics that make both cultivars amenable to MFF include high yields of very firm fruit, low retention force when ripe, great fruit color, and small, dry picking scars. Interestingly, the release notice for ‘O’Neal’ specifically states that the cultivar is not adapted for MFF (Ballington et al., 1990). ‘Duke’ is notable for having a concentrated ripening period, which has been valuable for MFF and machine harvest for processing, while ‘O’Neal’ has a longer maturity period. For both cultivars, growers using an MFF strategy will typically hand-harvest the first picking. Both cultivars are early maturing for their production areas, and that early fruit is often the most valuable, making hand harvest of a limited number of ripe fruit in relation to the total crop economically viable. In ‘Duke’, this initial hand harvest also serves to break up the tightly packed fruit clusters, enabling later machine harvest (W.O. Cline, personal communication).

These examples support that the traits needed for a good MFF cultivar are not much different from a hand-harvest cultivar. In most cases, the thresholds for the traits that are already priorities (e.g., firmness, stem scar size, color) have to be significantly better for MFF cultivars. A cultivar developed for MFF would likely be an excellent hand-harvest cultivar as well.

Medium-term strategy

From a breeding perspective, the medium-term strategies primarily involve

identifying the traits necessary for selection and improvement, determining the crosses to make to develop populations segregating for these traits, and developing a strategy for selection that will include screening thousands of individuals. In this regard, it is fortunate that many of the trait priorities remain the same. Here, we describe what we feel are the most critical traits for MFF.

Selection for upright bush architecture and narrow crowns are necessary for adaptation to existing over-the-row machine harvester designs. Galletta and Mainland (as cited in Dale et al., 1994) found that upright bushes with stocky canes performed well in early evaluations of machine harvest potential using handheld equipment. During machine harvesting of highbush blueberries, ground losses in the 10% to 25% range have been reported (Mainland et al., 1975; Strik and Buller, 2002; van Dalfsen and Gaye, 1999) although this figure has approached 50% in at least one study (Mainland et al., 1975). These losses are largely due to how catcher plates on existing machines seal around the base of the plant. Restricting crown width with fewer canes has been an effective method to reduce ground losses (Rohrbach and Mainland, 1989; Strik and Buller, 2002; Takeda et al., 2013), while pruning strategies to limit ground loss may also be an option (Takeda et al., 2008). Crown width and architecture of highbush blueberry have ample variation and Olmstead et al. (2013) describe additional efforts to use sparkleberry (*Vaccinium arboreum*) as a source of upright bush architecture. Others are using sparkleberry genotypes as monopodial rootstocks for highbush blueberry cultivars (Ballington et al., 1989; Galletta and Fish, 1972; Williamson et al., 2012).

Harvest timing is a critically important factor in cultivar success for MFF. In high-value production areas and times, hand-harvest intervals may be as short as 3 d as growers often seek to maximize the volume of fruit harvested in the high-value window. This has often resulted in selection for very early maturity; largely without consideration of how concentrated the ripening period may be (Table 1). However, to realize maximum machine harvest efficiency, a much larger

Table 1. Harvest timing for three genotypes from the University of Florida southern highbush blueberry breeding program with similar seasonal harvest totals but very different harvest timings. Pounds per week calculated from the total marketable harvest of five-bush plots in an unreplicated breeding selection trial near Haines City, FL.

Week of yr ^z	Total wt (lb/plot) ^y		
	FL selection 1	FL selection 2	'Jewel'
5	3.0	0.0	0.0
6	0.0	0.0	0.0
7	1.2	0.0	0.0
8	0.9	0.0	0.0
9	0.0	0.0	0.0
10	3.6	0.1	0.0
11	2.8	0.1	0.0
12	5.4	0.4	0.0
13	3.8	1.0	0.0
14	4.3	5.5	5.7
15	4.8	8.6	8.5
16	2.7	7.9	16.7
17	3.4	6.4	4.5
18	4.2	11.6	8.7
19	1.4	3.4	0.9
Season total	41.4	45.0	44.9

^zWeek of year: 5 = first week of February, 19 = first week of May.

^y1 lb = 0.4536 kg.

volume of fruit must be ripe at the same time. One alternative to breeding for a concentrated ripening period is to select for the ability of the fruit to hang on the plant without a loss of quality. Ehlenfeldt (2005) described fruit holding ability as the ability to maintain high levels of fruit firmness after initial ripening has occurred; 'Duke', 'Reveille', and 'Cara's Choice' were able to ripen and retain firmness on the bush. However, a concentrated ripening period was more desirable for mechanical harvest than extended holding ability, as an extended holding ability tended to be associated with reduced yield. Additionally, fruit hanging on the plant for a long time is also more likely to be attacked by pests, especially the spotted winged drosophila (*Drosophila suzukii*). They emphasized that breeders should strive to develop cultivars incorporating both traits. Although the work is still preliminary and has only been evaluated in a few cultivars, crisp blueberry fruit texture described by Blaker et al. (2014) may facilitate holding ability and reduce subsequent postharvest losses (Sargent et al., 2013).

Cluster architecture and fruit detachment are also key components of machine harvest efficiency. Tight clusters resulting from short pedicel lengths relative to fruit size tend to

have reduced efficiency during machine harvest. A common strategy employed by those using MFF is to hand-harvest the first pick, thereby removing some fruit and "loosening" up the clusters before the first machine harvest (W.O. Cline, personal communication). In most production regions, the first harvest is the highest valued fruit, making this strategy economically attractive. Pedicel lengths vary by cultivar, and selection for increased pedicel length resulted in loose fruit clusters amenable to MFF in 'FL 01-173' (Meadowlark) (Olmstead et al., 2013).

Fruit that require low detachment force at the mature blue stage compared with green fruit are the best for MFF. Variation in fruit detachment force among SHB selections has been documented (Sargent et al., 2010), and abscission agents such as ethephon and methyl jasmonate have been tested to reduce fruit detachment force as an aid for mechanical harvest with varying results (Malladi et al., 2012). An abscission zone between the fruit and pedicel resulting in a small, dry stem scar is desirable for MFF. Interestingly, Vashisth and Malladi (2013) reported that the natural abscission zone in the RE cultivars examined was at the pedicel to peduncle junction, not the fruit to pedicel junction. However, during

simulated mechanical harvesting, the fruit detached at the fruit to pedicel junction consistent with physical breakage. Variation for these traits is still high among NHB, RE, and SHB germplasm, as stem scar was recently ranked among breeders as one of the top five priorities for selection (Finn et al., 2014). The interplay between holding ability, fruit detachment, stem scar, and stem retention will likely be key to development of improved MFF cultivars.

One trait that may be difficult to address with breeding is fruit color. The light blue color desired for fresh blueberry fruit is a result of the wax layer on the fruit that is easily abraded during the machine harvest process. For processing fruit, this is not necessarily a problem, but the degree of persistence of the wax layer will be important to select for when employing MFF.

Fruit firmness plays a role in suitability for machine harvest. Evaluations comparing hand- and machine-harvested highbush blueberry fruit have consistently shown a significant increase in bruising and decrease in firmness of machine-harvested fruit, which was directly correlated to an increase in unmarketable fruit and decay in postharvest storage (Ballinger et al., 1973; Brown et al., 1996; Mainland et al., 1975). Among a large group of highbush and hybrid blueberry cultivars, an approximate 2.4-fold difference in fruit firmness was measured (Ehlenfeldt, 2005; Ehlenfeldt and Martin, 2002). Many of the firmer selections were recent breeding releases, indicating that progress in developing firmer highbush blueberry cultivars has been made (Ehlenfeldt, 2005). However, Takeda et al. (2013) report significant variation in the relationship between firmness and percent bruising after hand harvest for several SHB cultivars and selections. Some cultivars had high firmness at harvest, but bruising developed as a result of impact damage after storage, while others had high firmness at harvest and low incidence of bruising after storage. In general, it was cultivars and selections with crisp fruit texture (Blaker et al., 2014) that had the lowest bruising percentage. Similarly, genotypes with crisp, firm fruit texture resulted in final packout percentages and low postharvest disease incidences similar to hand-harvested

fruit with standard fruit texture (Mehra et al., 2013; Takeda et al., 2013).

Long-term strategy

In the long term, efficient selection for MFF will require incorporation of actual machine harvest or a suitable facsimile earlier in the breeding cycle than typically employed now. Currently, most blueberry breeding strategies involve selecting for the traits listed previously using methods that closely approximate actual machine harvest. For example, fruit retention force can be measured with handheld equipment (Malladi et al., 2013) or by physical shaking of a cane. Various pieces of equipment can be used to measure firmness and skin texture, and are often already employed in breeding programs (Ehlenfeldt, 2005). However, it is often not until the very end, when the machine is used in a larger plot of elite plant material that the practical deficiencies of a genotype are discovered. Since the early 2000s, some red raspberry (*Rubus idaeus*) breeders in the Pacific northwestern United States have successfully used machine harvesters to identify selections in their seedlings with superior machine harvestability characteristics. The sooner blueberry breeders adopt similar procedures, the sooner we will make substantial progress toward selecting MFF cultivars.

Conclusions

Using MFF for highbush blueberries is not a new concept and is likely an underreported statistic as many brokers are reluctant to purchase mechanically harvested fresh blueberries due to the mistaken perception they are of lesser quality. The traits that would be desirable for MFF cultivars are not different from those cultivars destined for hand-harvest fresh markets. However, there will be even more pressure to incorporate suitable levels of each of these traits into a final cultivar suitable for MFF. The natural genetic variation appears to be present within highbush blueberry and related *Vaccinium* germplasm to improve these traits. Developing successful MFF cultivars will require a strong interdisciplinary team of research, extension, and grower cooperators for successful, rapid implementation of new releases.

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