Journal of the American Pomological Society 73(4): 254-268 2019

Frequency of Harvest affects Berry Weight, Firmness, Titratable Acidity, and Percent Soluble Solids of Highbush Blueberry Cultivars in Oregon

Bernadine C. Strik[1]

Additional index words: *Vaccinium corymbosum*, picking frequency, sugar to acid ratio, harvest efficiency

Abstract

The impact of picking frequency was studied over 2 years in seven cultivars ('Aurora', 'Bluecrop', 'Draper', 'Duke', 'Liberty', 'Legacy', and 'Ozarkblue') of highbush blueberry (*Vaccinium* sp. L.) in Aurora, Ore. In 2011, fruit were picked every 2–3 d, 4–5 d, or 7d. Picking frequency was adjusted from 2011 to 2012 to be more typical of the range in commercial practice. In 2012, picking frequency was every 4 d ("high"; when fruit was first fully blue), 8 d ("medium"), and 12 d ("low"). When fruit were picked every 7–8 d, there was no effect of year on yield, berry weight, firmness, percent soluble solids (TSS), titratable acidity (TA), or sugar to acid ratio (TSS:TA). Berry weight declined consistently over the harvest season for 'Aurora' and 'Ozarkblue', was smaller on the early harvests with high frequency picking for 'Draper', 'Legacy', and 'Liberty', and was quite stable over the season for 'Bluecrop' and 'Duke'. 'Bluecrop', 'Draper', and 'Duke' berries were less firm on the last harvest of the season for medium and low picking frequency, whereas there were fewer effects of harvest date within treatment for the other cultivars. In general, TSS increased and TA decreased during the harvest season for each cultivar leading to an increase in TSS:TA. Picking frequency had no effect on yield, but picking every 12 d instead of 4 d increased average berry weight by 5%, 14%, 20%, 25%, and 29% in 'Aurora', 'Liberty', 'Legacy', 'Duke', and 'Draper', respectively. Picking every 12 d decreased average fruit firmness 5–8 % for 'Draper', 'Aurora', 'Bluecrop', and 'Liberty' and 12% for 'Duke' compared to picking every 4 d, but had no effect for 'Legacy' and 'Ozarkblue'. While there was no effect of picking frequency on TSS of 'Duke', in all of the other cultivars, harvesting every 12 d increased TSS compared to harvesting every 4 d. Berry TA was much greater and TSS:TA much lower with a high picking frequency than either medium or low frequency in all cultivars. With a high picking frequency, focused on harvesting berries when first blue, the fruit were not fully ripe and thus while they were firm they had a relatively low berry weight and TSS, high TA, and low TSS:TA. Reducing hand-picking frequency from every 4 to 12 d reduced labor costs 64% from fewer passes through the field and likely improved picking efficiency from larger berries. The results confirm that harvest interval may be extended in this region to reduce harvest costs with little to no negative impact on fruit quality variables and some positive impact on TSS:TA and berry weight.

Blueberry fruit (e.g. *Vaccinium corymbosum* L.) do not change much visibly during the latter stages of ripening. However, berry size (diameter and weight) and percent soluble solids (TSS) increase and titratable acidity (TA) decreases from first fully blue to the full ripe stage (Kushman and Ballinger, 1968; Sargent et al., 2006). In blueberry fruit, glucose and fructose are the main sugars and citric acid is the predominant organic acid (Forney et al., 2012). The amount of cuticular wax ("bloom") on the surface of the blueberry fruit is cultivar dependent and increases during ripening (Sapers et al., 1984; Yang, 2018), and quantity of bloom is related to storage quality (Chu et al., 2018). Stage of blueberry fruit ripeness is also related to storage quality (Ballinger and Kushman, 1970; Ballinger et al., 1978; Galletta et al., 1971; Kushman and Ballinger, 1963; Woodruff et al, 1960). Blueberry fruit do not further ripen after harvest (Hancock et al., 2008; Sargent et al., 2006), making picking at an optimal stage for fruit quality important.

The time between successive harvests when hand picking can be adjusted based on grower or packer preference and goals and production conditions. In some production

[1] Professor: bernadine.strik@oregonstate.edu

regions, highbush blueberries are picked after they first turn blue with a goal of having firmer fruit that will ship better (e.g. in Chile; Lobos et al., 2014). However, berries at this stage have a relatively low sugar to acid ratio (TSS:TA) and consumer acceptance compared to fully ripe fruit (Bremer et al., 2008; Saftner et al., 2008). The characteristic flavor and aroma of a particular cultivar develop during the latter stages of ripening, an additional 2–8 d after first fully blue (Sargent et al., 2006). Retamales and Hancock (2012) report an optimal time of harvest of a few days after fruit turn blue. Despite the desire to have sweet-tasting fruit with good flavor, the negative association between sugar to acid ratio and storage quality in blueberry (Galletta et al., 1971; Woodruff et al., 1960) and a perceived or actual decline in fruit firmness tend to drive earlier or more frequent harvests to ensure fruit can be adequately stored. However, others have found little effect of stage of ripeness on storage quality of blueberry fruit, as long as fruit was not overripe (Kushman and Ballinger, 1963; Lobos et al., 2014). Most changes in firmness of blueberry fruit occur from the green to fully blue stage (Forney et al., 2012) with relatively little change during the latter stages of ripening (Ballinger et al., 1973). Cultivars differ in their innate firmness and the ability to maintain this firmness during ripening after the fruit first turn fully blue (Ehlenfeldt, 2005). Furthermore, the fruit of some cultivars increases in firmness once cooled during storage (Ballinger et al., 1973; Hancock et al 2008; Vance et al., 2017).

Fruiting season and associated price for fruit can influence picking schedules with early-season cultivars initially harvested at earlier stages of ripeness whereas later-season cultivars may be harvested at later stages of ripeness for higher returns. When machine harvesting, berries are at a more advanced stage of development upon the first harvest and there is a longer interval between successive harvests, in general, than for hand harvest to improve machine harvest efficiency and reduce losses. The frequency of harvest affects the average fruit maturity and quality whether harvesting by hand or by machine. Leaving fruit on the bush longer between successive harvests increases the risk of loss to insect, disease, and vertebrate pests and environmental stress including sunburn (Yang, 2018), fruit splitting or loss of firmness with rain (Lyrene, 2006; Marshall et al., 2006), or high temperature (e.g. in 'Liberty'; Strik personal observation), and rain further delaying harvest (Lyrene, 2006). In addition, when fruit reaches the latter stages of ripening, titratable acidity and firmness may decline to levels that reduce storage or shelf life (Galletta et al., 1971; Woodruff et al., 1960). Reducing the number of harvests per cultivar by increasing harvest interval reduces harvest costs, but may also reduce average fruit quality.

Oregon produced the largest volume of blueberries in the U.S. in 2018 (61 million kg) and, along with Washington, produced over 60% of U.S. organic blueberry volume (North American Blueberry Council, unpublished; Oregon Blueberry Commission, unpublished). In Oregon, harvest frequency ranges from an average of about 4 days between picks to as long as 14 days, depending on harvest method, cultivar, weather, and grower or shipper/packer preference. There is a trend for more machine harvesting for fresh market and increased intervals between successive hand and machine harvests due to reduced availability and increased cost of labor. Methods to reduce harvest labor costs are a key research priority in the region (Oregon Blueberry Commission, 2018; Northwest Center for Small Fruits Research, 2018). While there is much speculation about the impact of "letting fruit hang" longer on the bush on fruit quality, particularly firmness, there is little, if any, published information for the cultivars grown in Oregon under our climatic conditions. Temperatures during the latter stages of ripening vary greatly from early- (June) to late-season (August) cultivars and night-time temperatures may be cool relative to the day in our region (Strik et al., 2014; U.S. Dept. Interior, 2014). Cool nighttime temperatures increase the acidity of fruit relative to the same cultivars grown in areas with higher nighttime temperatures (Lyrene, 2006). Others have found variability in TSS and TA with year or fruiting season (Bremer et al., 2008; Skupień, 2006).

The objectives of this study were to determine the impact of hand harvest frequency on yield and berry quality traits for early- to late-season commercial cultivars commonly grown in the northwestern region of the United States.

Materials and Methods

The study was conducted in 2011 and 2012 in a planting of highbush blueberry established in Oct. 2006 at Oregon State University's North Willamette Research and Extension Center, Aurora, OR (NWREC; Aurora, OR, USA; lat. 45°16'47"N, long. 122°45'23"W). Weather data for this site are available from an AgriMet weather station (U.S. Dept. Interior, 2014). Temperature and rainfall during the fruiting season of 2011–2012 are in Figure 1. Soil at the site was a Willamette silt loam (fine-silty mixed superactive mesic Pachic Ultic Argixeroll) and had a pH of 4.9 and 3.7% organic matter at planting. Plants were established on raised beds at 0.75 m in the row with 3.0 m between rows (4385 plants/ha). Irrigation was with a single line of polyethylene drip tubing (Netafim, Fresno, CA) with 2 $L \cdot h^{-1}$ pressure-compensating, inline emitters spaced every 0.3 m. Honey bees (*Apis mellifera* L.) were introduced to the field at about 5–10% bloom at a stocking rate of 10 hives/ha. Additional details of planting establishment, management, fertilization, and leaf nutrient sufficiency levels are published elsewhere (Strik et al., 2017; Strik and Vance, 2015).

Treatments included seven cultivars ('Aurora', 'Bluecrop', 'Draper', 'Duke', 'Liberty', 'Legacy', and 'Ozarkblue') to offer a range in fruiting season (Table 1) and three harvest intervals per year. In 2011, fruit were picked every 2–3 d, 4–5 d, or 7d. Picking frequency was adjusted from 2011 to 2012 to be more typical of the range in commercial practice. In 2012, picking frequency was every 4 d ("high"; when fruit was first fully blue), 8 d ("medium"), and 12 d ("low"). The number of harvests per picking frequency treatment varied with cultivar and year (Table 1).

Treatments were arranged in a split plot with 4 replicates of the main plot (cultivar) and sub-plot (harvest frequency). Harvest frequency treatments were randomly assigned within the seven-plant plots with an experimental unit of one plant per treatment combination.

Ripe fruit (or first fully blue fruit for the high frequency treatment) were harvested by hand, using shallow buckets, and were

Table 1. Fruiting season and the number of harvests for each picking frequency treatment (high, medium, and low) for seven highbush blueberry cultivars grown at Oregon State University's North Willamette Research and Extension Center in 2011 and 2012.

	Harvest season		Number of harvests per season					
			2011			2012		
Cultivar	2011	2012	High[z]	Medium	Low	High	Medium	Low
Duke	5 - 27 July	28 June - 17 July	8	7	3	5	4	3
Bluecrop	15 July - 5 Aug.	3 July - 7 Aug.	9	5	3	8	4	3
Draper	13 July - 5 Aug.	6 - 24 July	10	6	4	6	4	3
Legacy	25 July - 26 Aug.	12 July - 15 Aug.	11	7	4	10	5	3
Liberty	1 - 22 Aug.	17 July - 11 Aug.	9	5	3	8	3	2
Ozarkblue	1 Aug. - 15 Sep.	17 July - 28 Aug.	14	8	5	12	6	4
Aurora	15 Aug. - 29 Sep.	1 Aug. - 1 Sep.	11	5	4	9	4	3

[z] Frequency of harvests were as follows. In 2011: High (every 2–3 d); Medium (4–5 d); and Low (7 d) and in 2012: High (4 d); Medium (8 d); and Low (12 d).

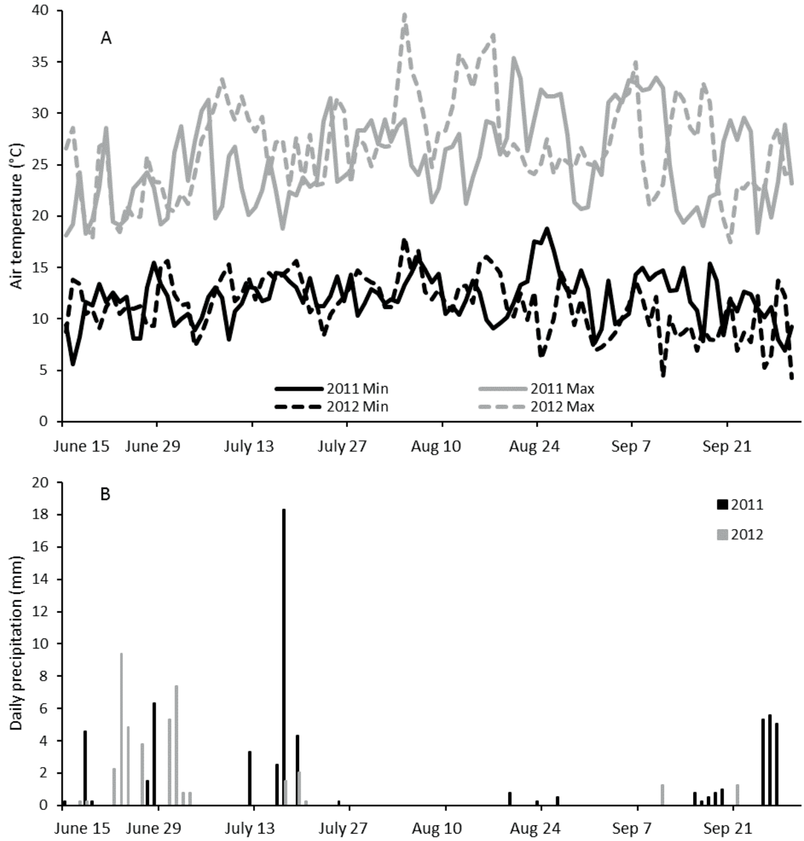

Fig. 1. Maximum and minimum daily air temperature (**A**) and precipitation (**B**) in 2011 and 2012 from 15 June to 30 Sep. at Oregon State University's North Willamette Research and Extension Center, Aurora, Ore. Weather data from an on-site AgriMet weather station (U.S. Dept. Interior, 2014).

weighed for each harvest. Cumulative yield per plant was calculated. A random subsample of 25 berries on each harvest date was used to determine average berry weight and firmness (FirmTech II; BioWorks, Inc.; Wamego, KS), the day of harvest while fruit were at room temperature. The fruit were then placed in a 1-L polyethylene re-sealable bag and crushed by hand to obtain a homogeneous mixture for measuring percent total soluble solids (TSS, °Brix) using a temperature-compensated digital refractometer (Atago, Bellevue, WA). The remaining crushed, bagged fruit was used to determine titratable acidity (TA) using an automatic titrator (DL 12, Mettler-Toledo, LLC, Columbus, OH) with 0.1 N NaOH (BDH brand, VWR International LLC., Radnor, PA) as a reagent to a pH endpoint of 8.2, and acidity was calculated as percent citric acid. The sugar to acid ratio was calculated from TSS and TA. A weighted seasonal average was calculated for each variable for analysis of average effects for the season.

Statistical analyses were performed using SAS 9.4 (Cary, NC). An initial split-plot analysis (PROC MIXED) of the effect of year (n=2) and cultivar (n=7) was done only for the 7 d harvest interval for 2011 and the 8 d interval for 2012 – the only frequency treatments that were similar enough for comparison. Subsequent analyses were done by year to determine the impact of cultivar (main plot; n=7) and harvest frequency (split plot; n= 3) on yield and fruit quality variables using PROC MIXED. Means were separated at the 5% level using Tukey's honest significant difference test.

Results and Discussion

Maximum air temperatures during the fruiting season were considerably warmer in 2012 than 2011, leading to an earlier fruiting season for the cultivars studied (Fig. 1; Table 1). There was more rain during the fruiting season of early cultivars in 2011 than in 2012, but in general there was little rain during the fruiting season, as is typical for this region (Fig. 1). Despite these differences in weather between years, there was no effect of year on yield or any of the fruit quality variables when fruit were picked every 7–8 d (data not shown).

Treatment effects over the season

Changes in yield, berry weight, firmness, TSS, TA, and sugar to acid ratio (TSS:TA) over the fruiting season in 2012 as affected by harvest frequency are shown for the seven cultivars in Figures 2–8; data are not shown for 2011 when there was less of a range in picking frequency.

In general, there were from 3 to 4 harvests with the high picking frequency before the medium and low frequency harvests began, depending on cultivar. This was because fruit

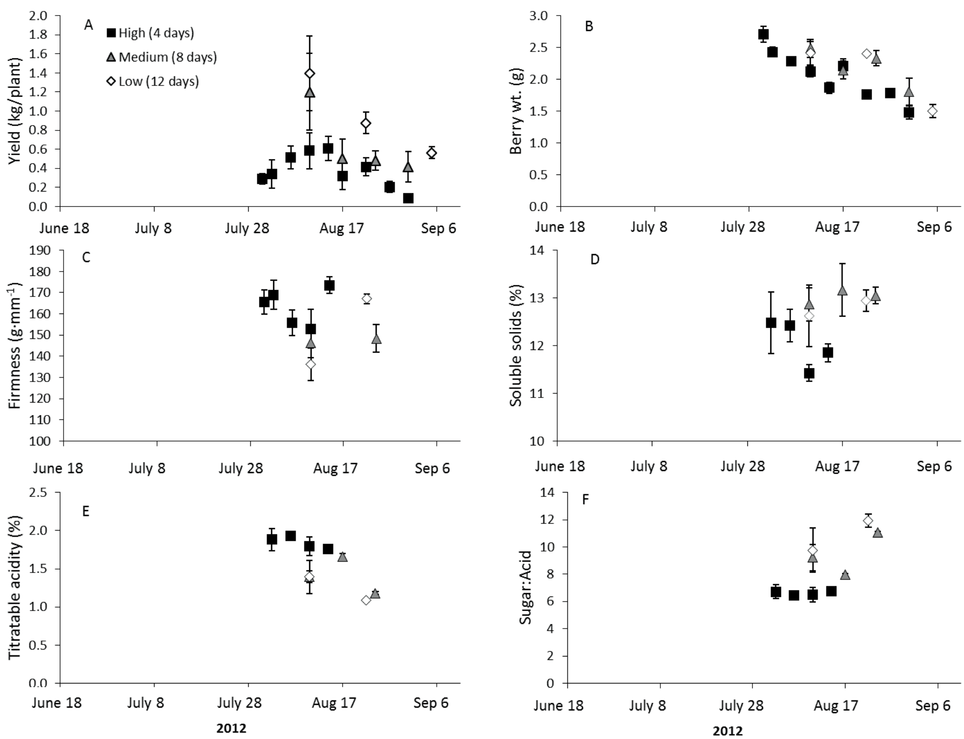

Fig. 2. The impact of picking frequency (high every 4 d; medium every 8 d; and low every 12 d) on the **A**) yield, **B**) berry weight, **C**) firmness, **D**) soluble solids concentration, **E**) titratable acidity, as percent citric acid, and **F**) sugar to acid ratio of fresh fruit over the harvest season in 2012 for 'Aurora'.

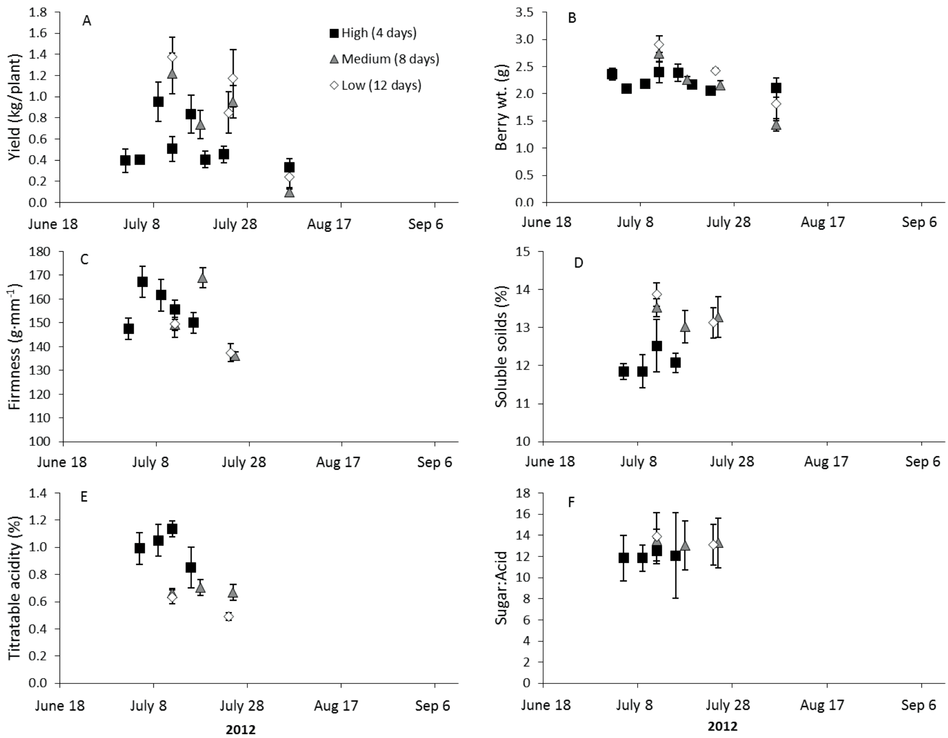

Fig. 3. The impact of picking frequency (high every 4 d; medium every 8 d; and low every 12 d) on the **A**) yield, **B**) berry weight, **C**) firmness, **D**) soluble solids concentration, **E**) titratable acidity, as percent citric acid, and **F**) sugar to acid ratio of fresh fruit over the harvest season in 2012 for 'Bluecrop'.

had to be picked once fully blue in the high frequency treatment. The largest proportion of total yield, in general, was harvested when the low and medium frequency harvests began for each cultivar (Fig. 2–8A).

Berry weight declined consistently over the harvest season in 'Aurora' and 'Ozarkblue' (Fig. 2B, 8B). In 'Draper', 'Legacy', and 'Liberty' berry weight was much smaller on the early high frequency harvests than the first medium and low frequency harvest (Fig. 4B, 6B, and 7B). In 'Bluecrop' and 'Duke' berry weight was quite stable until the last harvest (Fig. 3B and 5B). Firmness was quite variable, even among high-frequency harvests in most cultivars (Fig. 2–8C). In 'Bluecrop', 'Draper', and 'Duke', firmness was lowest on the last harvest of the season for medium and low frequency treatments, whereas there were fewer effects of harvest date within treatment for the other cultivars. With these cultivars differing in fruiting season (Table 1), the weather during various stages of fruit development may have had an impact on firmness (Fig. 1). While day temperature may be warm in our region, night temperatures are often cool, particularly in early and late summer (Fig. 1), maintaining fruit firmness (Lyrene, 2006).

In general, TSS (Fig. 2–8D) increased and TA (Fig. 2–8E) decreased during the harvest season for each cultivar. The large decline in TA over the season led to an increase in the TSS:TA over the picking season (Fig. 2–8F) with the exception of 'Bluecrop' where there was less change in TSS:TA over the season.

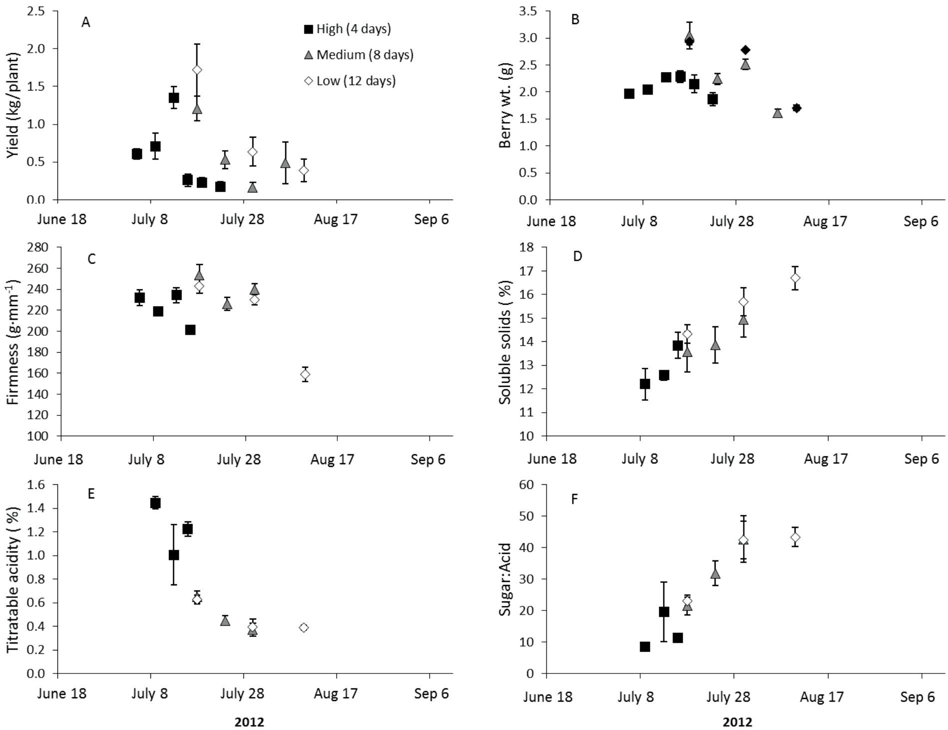

Fig. 4. The impact of picking frequency (high every 4 d; medium every 8 d; and low every 12 d) on the **A**) yield, **B**) berry weight, **C**) firmness, **D**) soluble solids concentration, **E**) titratable acidity, as percent citric acid, and **F**) sugar to acid ratio of fresh fruit over the harvest season in 2012 for 'Draper'.

In 'Draper', 'Legacy', 'Liberty', and 'Ozarkblue' the early picks from the high frequency harvest treatment had a very low TSS:TA compared to the other harvest dates and frequency treatments (Fig. 4F, 6F, 7F, and 8F).

With a high picking frequency, focused on picking fruit when it first turned blue, the fruit were not fully ripe and thus while these fruit were firm they had a relatively low berry weight and TSS, high TA, and low TSS:TA. In addition, with a high picking frequency, the chance of removing berries that appeared fully blue yet still had a ring of red around the pedicel or stem scar end increased. With a medium picking frequency, there was likely a range in fruit ripeness for the berries harvested from those that were just fully blue to more mature, especially in the early harvests. By contrast, with a low picking frequency, there would be more uniformly ripe fruit, particularly in later harvests. The exception appeared during the last harvests for some of the cultivars, where the low TA and high TSS and reduced firmness indicated that fruit may have been overripe or of lower quality for fresh market or storage.

We confirmed that TA declined with harvest date within cultivar (Sapers et al., 1984; Woodruff et al., 1960). In Michigan, Woodruff et al. (1960) also reported increased TSS and decreased TA as the season progressed in 'Jersey'. The TSS of southern highbush (complex hybrids of *V. corymbosum* and *V. darrowii*) cultivars increased with harvest number in tunnels (Ogden and van Iersel, 2009). By contrast, Kushman and Ballinger

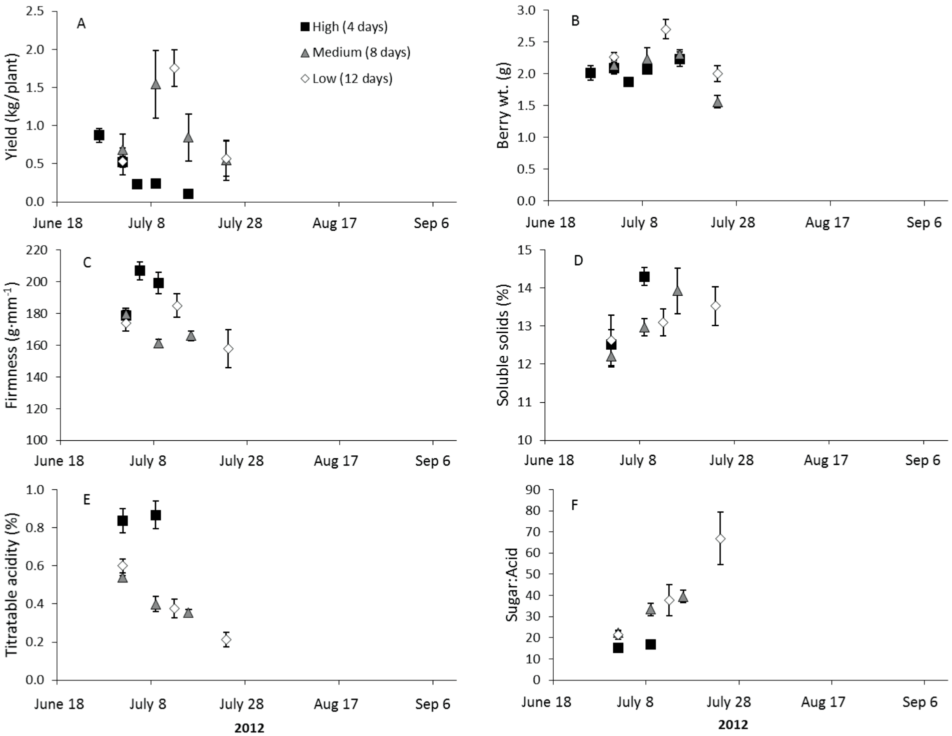

Fig. 5. The impact of picking frequency (high every 4 d; medium every 8 d; and low every 12 d) on the **A**) yield, **B**) berry weight, **C**) firmness, **D**) soluble solids concentration, **E**) titratable acidity, as percent citric acid, and **F**) sugar to acid ratio of fresh fruit over the harvest season in 2012 for 'Duke'.

(1963) found that TA decreased with harvest number and with picking interval but found no consistent effect on TSS. Hancock et al. (2008) reported greater berry weight, higher TSS and less firmness from the first harvest than from the second harvest in five cultivars. In many of these same cultivars in Oregon, seed number per berry declined along with berry weight during the harvest season (Strik and Vance, 2019) and berries with fewer seeds have been shown to ripen more slowly (Ehlenfeldt and Martin, 2010; Taber and Olmstead, 2016) perhaps affecting the results. While smaller fruit are generally more firm within a cultivar (Ballinger et al., 1973), this relationship was not evident in our study where late-season fruit were smaller in many cultivars but were not more firm (Figs. 2–8). The last harvest within a cultivar is often delayed to ensure that the remaining fruit can all be picked likely reducing average fruit firmness.

Effects on seasonal averages

Yield and berry weight. There was a cultivar effect on yield with 'Legacy' and 'Ozarkblue' having a higher yield than all other cultivars in both years (Table 2). Frequency of harvest had no effect on yield in either year, even though weighted average seasonal berry weight was greater when harvest was at a low compared to a high harvest frequency in both years. Berry quality traits were affected by cultivar, harvest frequency and their interaction (Table 2). Results were very similar between years so interaction ef-

Table 2. The effect of hand harvest frequency on yield and fruit quality of highbush blueberry cultivars grown at Oregon State University's North Willamette Research and Extension Center in 2011 and 2012 (n=4).

Treatments	Yield (kg/plant)		Berry weight (g)		Firmness (g·mm^{-1})		Titratable acidity (%)[w]		Soluble solids (%)		Sugar : Acid[w]	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Cultivar[z]												
Duke	2.6 b[v]	2.8 b	2.1 a	2.2 cd	172 cd	179 b	0.56 e	0.56 e	13.3 bc	13.2 b	26.1 a	26.2 a
Draper	2.5 b	2.8 b	2.2 a	2.5 ab	204 a	224 a	0.72 c	0.73 d	14.0 b	14.1 a	22.3 b	24.3 a
Bluecrop	3.1 b	3.6 b	2.2 a	2.2 d	149 f	150 e	0.74 c	0.75 cd	12.9 cd	13.0 bc	18.9 c	18.8 b
Legacy	6.8 a	6.7 a	1.8 c	2.2 cd	177 b	164 c	0.64 d	0.60 e	12.7 de	13.0 bc	23.9 ab	26.8 a
Liberty	3.3 b	3.7 b	2.1 a	2.3 bc	156 e	158 d	0.94 b	0.84 b	14.5 a	13.8 a	15.8 d	17.6 b
Ozarkblue	6.1 a	7.2 a	2.2 a	2.5 a	168 d	157 d	0.77 c	0.82 bc	12.2 e	12.3 d	16.6 cd	16.7 b
Aurora	3.4 b	2.9 b	2.0 b	2.2 cd	174 bc	154 de	1.36 a	1.48 a	12.5 de	12.6 cd	9.7 e	8.9 c
Frequency[y]												
High	3.9 a	4.7 a	1.9 b	2.2 b	175 a	175 a	1.09 a	1.17 a	12.8 b	12.3 c	12.6 c	11.2 c
Medium	4.0 a	4.1 a	2.0 b	2.4 a	170 b	168 b	0.74 b	0.67 b	13.2 ab	13.3 b	20.0 b	23.1 b
Low	4.1 a	4.0 a	2.3 a	2.4 a	168 b	165 b	0.64 c	0.63 b	13.4 a	13.8 a	24.4 a	25.4 a
Significance[x]												
Cultivar (C)	<.0001	<.0001	0.0001	0.0009	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Frequency (F)	0.7559	0.1493	<.0001	0.0002	0.0001	<.0001	<.0001	<.0001	0.0044	<.0001	<.0001	<.0001
C x F	0.9737	0.4104	<.0001	0.0012	0.0008	<.0001	<.0001	0.0045	0.0014	<.0001	<.0001	<.0001

[z] Cultivars arranged in approximate order of ripening (starting in late June for 'Duke' and mid-August for 'Aurora')
[y] Frequency of harvest. In 2011: High (2–3 d between successive hand harvests); Medium (4–5 d); and Low (7 d). In 2012: High (4 d); Medium (8 d); and Low (12 d).
[x] *P* value provided for analysis of variance by year.
[w] Titratable acidity (TA) expressed as percent citric acid per unit fresh weight. Sugar to acid ratio equal to percent soluble solids divided by TA.
[v] Means followed by the same letter within treatment and year are not significantly different (Tukey's HSD) (P>0.05).

fects are only shown for 2012 when there was a larger range in picking frequency (Fig. 9A). While picking frequency had no effect on yield picking every 12 d instead of 4 d increased weighted average seasonal berry weight significantly by 5%, 14%, 20%, 25%, and 29% in 'Aurora', 'Liberty', 'Legacy', 'Duke', and 'Draper', respectively (Fig. 9B). The high picking frequency thus led to fruit being harvested before it was fully sized or ripe. Sargent et al. (2006) estimated that one third of total fruit size is reached in the final 5 to 6 d of ripening. By contrast, delaying harvest of 'Bluecrop' reduced berry weight by 18%, likely because larger fruit became overripe and more fell off the bush during harvest, reducing average weight. In 2011, there was no effect of harvest frequency on berry weight in 'Bluecrop', but the longest interval was only 7 d that year (data not shown). In 2012, there was no effect of harvest frequency on berry weight of 'Ozarkblue' (Fig. 9B) whereas in 2011 berries picked at the highest frequency (7 d) had 10% greater weight than those at 2–3 d (data not shown). There was no difference between an 8- and 12-day-long picking interval for berry weight in 'Draper', 'Legacy', 'Liberty', and 'Aurora' in 2012 (Fig. 9B). On average, 'Ozarkblue' and 'Draper' had the highest berry weight in 2012, whereas only 'Legacy' and 'Aurora' had significantly lower berry weight in 2011 (Table 2).

Even though harvest interval affected berry weight in most cultivars, there was no effect on yield, agreeing with Kushman and Ballinger (1963). It is likely that increasing harvest interval leads to greater losses of fruit while harvesting (fruit drop) and to depredation, particularly birds at our site.

Firmness. Reducing picking frequency to harvesting every 12 d decreased fruit firmness 5–8 % in 'Draper', 'Aurora', 'Bluecrop', and 'Liberty' and 12% in 'Duke' compared to picking every 4 d, but had no effect in 'Legacy' and 'Ozarkblue' (Fig. 2C). There was no difference in fruit firmness between an 8- and 12-day picking interval for all cultivars except for 'Draper' where the longer interval reduced firmness by 12%. Decreases

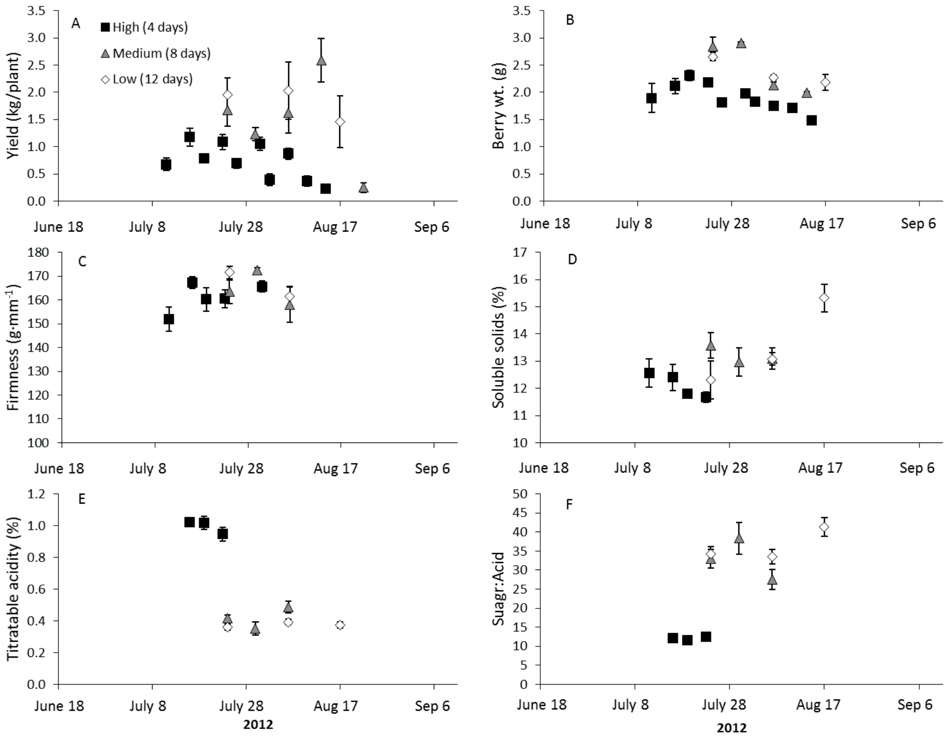

Fig. 6. The impact of picking frequency (high every 4 d; medium every 8 d; and low every 12 d) on the **A**) yield, **B**) berry weight, **C**) firmness, **D**) soluble solids concentration, **E**) titratable acidity, as percent citric acid, and **F**) sugar to acid ratio of fresh fruit over the harvest season in 2012 for 'Legacy'.

in firmness from the first harvest (more ideally chosen than when fruit were harvested at high frequency) to the next harvest were less than 10% for the medium picking frequency for most cultivars, and ranged from 1 – 15% when the picking interval was extended. On average, 'Draper' had the firmest fruit in both years and 'Bluecrop' (both years), 'Liberty' (2011) and 'Aurora' (2012) the lowest (Table 2). Cultivars that are genetically more firm can have a longer picking interval (Ehlenfeldt, 2005). The relatively small effect of picking interval on fruit firmness in these cultivars agrees with others who found that most softening in blueberry occurs during the green to fully blue stages with little change as fully blue fruit ripened further (Ballinger et al., 1973; Ehlenfeldt, 2005; Forney et al., 2012; Sargent et al., 2006). An added advantage for blueberry is that fruit firmness may increase after harvest while fruit are cold stored, but this depends on cultivar and likely climate or growing and harvesting conditions (Sargent et al., 2006; Vance et al., 2017). For example, Ehlenfeldt (2005) found that 'Legacy' retained its firmness well after harvest but we (Vance et al., 2017) found that firmness of this cultivar declined after harvest. Blueberry holding ability is complex and may not be predicted based on initial firmness (Ehlenfeldt, 2005; Perkins-Veazie et al., 1995).

Soluble solids. While there was no effect of picking frequency on TSS of 'Duke', in all of the other cultivars, harvesting every 12 d increased TSS compared to harvesting ev-

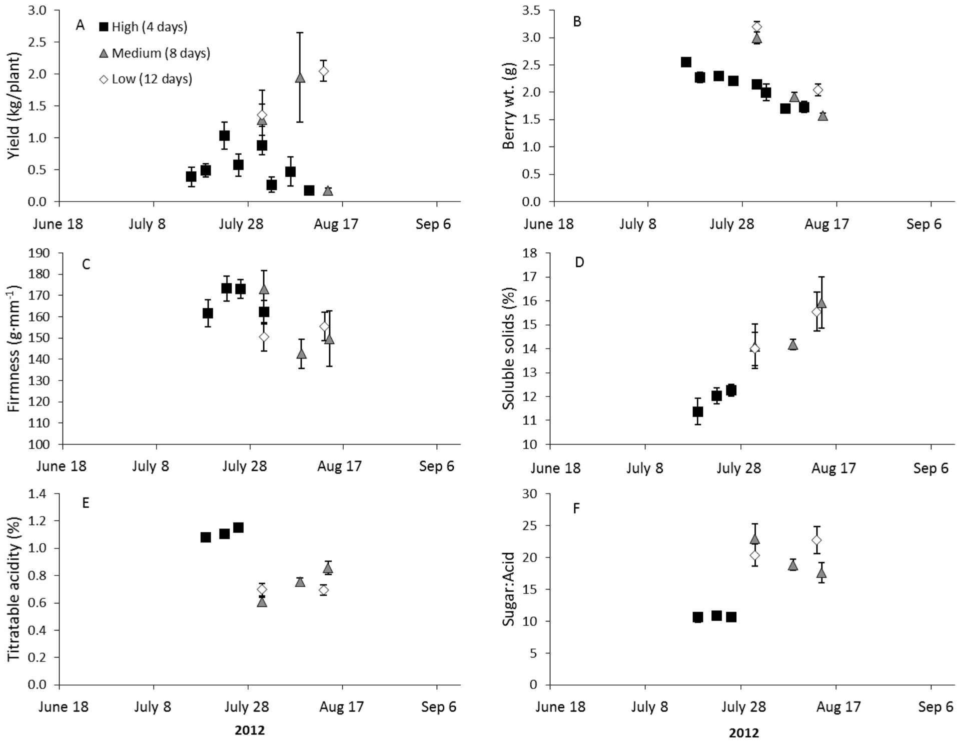

Fig. 7. The impact of picking frequency (high every 4 d; medium every 8 d; and low every 12 d) on the **A**) yield, **B**) berry weight, **C**) firmness, **D**) soluble solids concentration, **E**) titratable acidity, as percent citric acid, and **F**) sugar to acid ratio of fresh fruit over the harvest season in 2012 for 'Liberty'.

ery 4 d (Fig. 9D). In 'Bluecrop', 'Legacy', 'Liberty', and 'Aurora' there was no difference in berry TSS when picking at medium or low frequency. On average, 'Liberty' had the highest TSS and 'Ozarkblue' the lowest in 2011, whereas in 2012 'Liberty' and 'Draper' had the highest TSS and 'Ozarkblue' the lowest (Table 2). Kushman and Ballinger (1963) found little effect of harvest interval (3- to 12-d) on TSS of 'Wolcott'. The TSS of 'Jersey' blueberry fruit increased from 0 to 9 d after berries were red, but then remained constant thereafter (Woodruff et al., 1960). Hancock et al. (2008) reported a TSS of 13.7% for 'Legacy' at the fully blue stage of ripeness, higher than what we found. Climate and production system may impact TSS (Lyrene, 2006; Strik et al., 2017) as can light exposure or canopy density (Lobos et al., 2013).

Titratable acidity and sugar:acid. Berry TA was much greater when picking at high frequency than either medium or low frequency (Fig. 9E). There was no difference in berry TA when picking at medium or low frequency. 'Aurora' had the highest TA and 'Legacy' and 'Duke' the lowest in both years (Table 2). Similarly, the sugar to acid ratio (TSS:TA) was highest in all cultivars when picking at medium or low frequency with significantly lower levels at the high picking frequency (Fig. 9F). The sugar to acid ratio was highest in 'Duke' and lowest in 'Aurora' in 2011 whereas in 2012 more cultivars had high TSS:TA ('Duke', 'Draper', and 'Legacy') likely due to the longer picking interval.

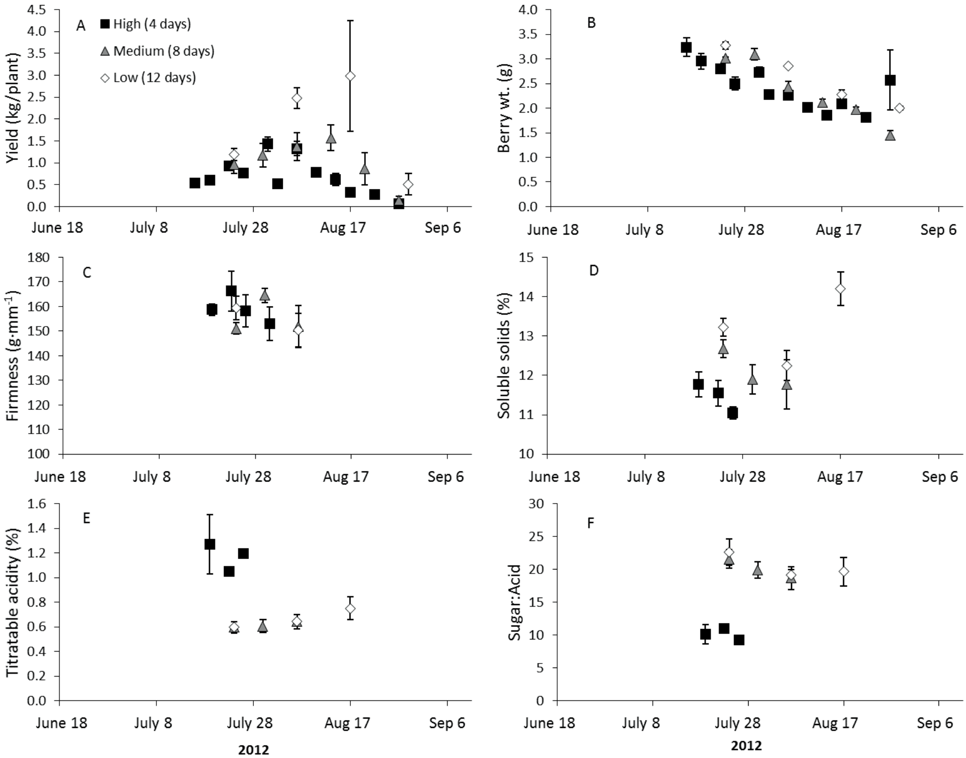

Fig. 8. The impact of picking frequency (high every 4 d; medium every 8 d; and low every 12 d) on the **A**) yield, **B**) berry weight, **C**) firmness, **D**) soluble solids concentration, **E**) titratable acidity, as percent citric acid, and **F**) sugar to acid ratio of fresh fruit over the harvest season in 2012 for 'Ozarkblue'.

We confirmed a large difference between cultivars in TA when harvested at similar developmental stages (Sapers et al., 1984). While Skupień (2006) reported that TSS and TA of 'Bluecrop' varied by year in Poland, we found the difference between cultivars was considerably larger than any difference between years (Table 2). Bremer et al. (2008) reported that TSS and TA of southern highbush blueberry cultivars varied by year and those with a TA of 0.3%, despite a TSS of 10–12%, were not acceptable to consumers. The TSS or TA alone was not a good indicator of consumer perspective of sweetness in blueberry.

A TSS:TA of 18 or lower was recommended by Galletta et al. (1971) for good keeping quality, while cultivars with 18–32 had medium keeping quality. Woodruff et al. (1960) found that TSS:TA below 14 and 17 in 'Jersey' were needed to keep fruit deterioration below 5% and 10%, respectively, after storing fruit at 4.4 ºC for 18 d. They recommended the TSS:TA as a ripening index. Ballinger et al. (1978) recommended northern highbush blueberry cultivars be harvested at a TSS:TA of <20 for long-distance shipping by boat (7–10 d), 20–27 for transcontinental shipping (4–5 d) and 27–30 for local sales. However, some common cultivars currently grown often have a lower TSS:TA (e.g. reported near 10 in 'Elliott' and 'Aurora' by Lobos et al., 2013). There has been a large range in TSS:TA reported

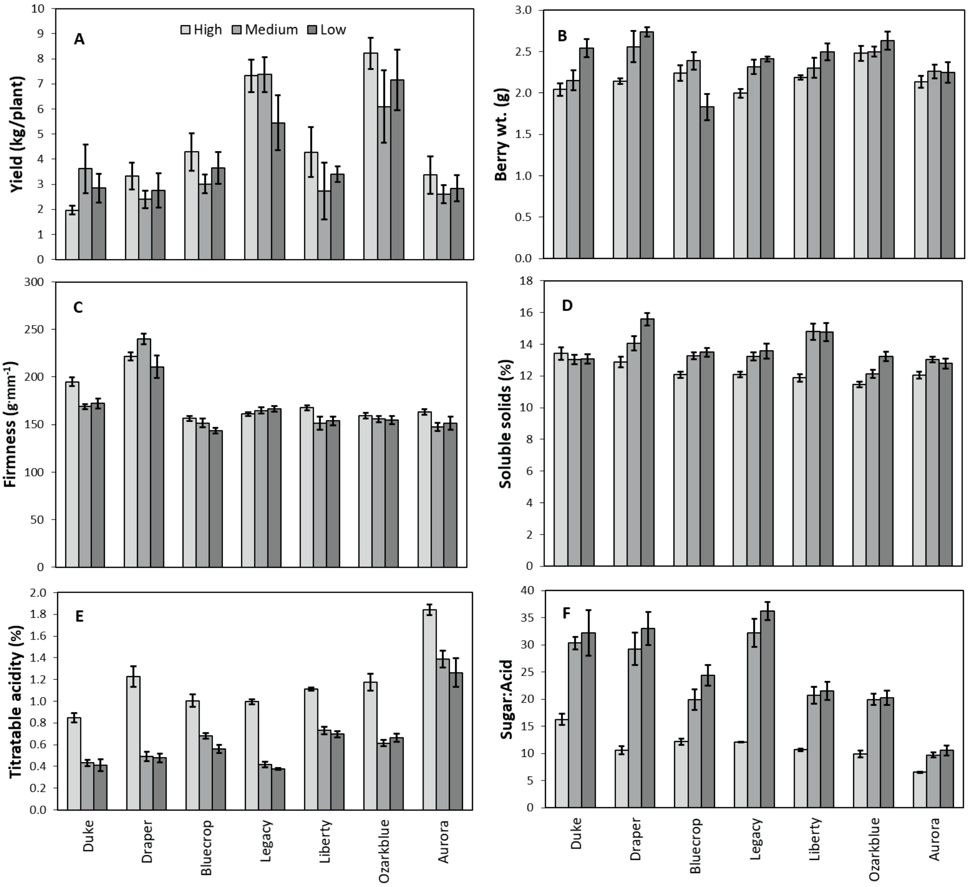

Fig. 9. The effect of harvest frequency, low (picking every 4 d), medium (8 d), and high (12 d), in 2012 on (**A**) yield/plant, (**B**) berry weight, (**C**) berry firmness, (**D**) percent soluble solids, (**E**) titratable acidity, as percent citric acid per unit fresh weight, and (**F**) sugar to acid ratio of seven cultivars of northern highbush blueberry. Mean ± SE (n=4).

in the literature [e.g. 11.4–40.5 and 10–19 in southern highbush cultivars by Bremer et al. (2008) and Perkins-Veazie et al. (1995), respectively; and 10–26 for northern highbush cultivars by Hancock et al. (2008), Lobos et al., (2014), Saftner et al., (2008), and Sapers et al., (1984)]. While Saftner et al. (2008) suggested there may be a large environmental effect on TSS:TA, we found more of an effect of cultivar on TSS:TA than year, despite large differences in temperature and fruiting season between years (Fig. 1; Tables 1 and 2). While TSS:TA may be affected by canopy density or shade (Lobos et al., 2013) it was not affected by nitrogen fertilization treatment (Hammett and Ballinger, 1972). While the sugar to acid ratio may be a better indicator of consumer preference the proportions of the various acids in the fruit may also be important (Bremer et al., 2008; Saftner et al., 2008).

Summary

There was no effect of year on yield, berry weight, firmness, TA, TSS, or TSS:TA, on average, when fruit were picked every 7–8 d during the fruiting season for seven cultivars. Extending the interval between successive harvests from 4 d to 12 d in 2012 reduced TA 46% and increased TSS 12% and TSS:TA 127%, on average. The longer picking interval improved sweetness of fruit and flavor (personal observation), and reduced berry firmness by 6%, on average. We did not compare treatment effects on fruit quality during storage, but others have found no impact of these harvest intervals on the storage quality of 'Liberty', 'Elliott' and 'Aurora' (Lobos et al., 2014). They also noted improved flavor with the delay in harvesting. While scheduling harvests every 12 d increased berry weight 9% compared to picking fruit every 4 d, there was no effect on yield. Regardless of the yield, reducing picking frequency would reduce labor costs considerably from fewer passes through the field (e.g. 8.3 vs. 3, for the high compared to low picking frequency, on average) and harvesting of larger berries (greater picking efficiency). However, picking frequency would likely need to be altered through the season, rather than remain constant as in this study, to account for changes in weather and rate of ripening for maximum berry quality in our region and others.

In our climate growers have the option of leaving fruit on the bush longer to improve sugar to acid ratio and flavor and reduce labor costs. However, we do have an ideal climate with warmer summer day temperatures, and cooler night temperatures that maintain fruit firmness, and little rain during the fruit harvest period.

Literature Cited

Ballinger, W.E. and L.J. Kushman. 1970. Relationship of stage of ripeness to composition and keeping quality of highbush blueberries. J. Amer. Soc. Hort. Sci. 95:239–242.

Ballinger, W.E., L.J. Kushman, and D.D. Hamann. 1973. Factors affecting the firmness of highbush blueberries. J. Amer. Soc. Hort. Sci. 98:583–587.

Ballinger, W.E., E.P. Maness, and W.F. McClure. 1978. Relationship of stage of ripeness and holding temperature to decay development of blueberries. J. Amer. Soc. Hort. Sci. 103:130–134.

Bremer, V., G. Crisosto, R. Molinar, M. Jimenez, S. Dollahite, and C.H. Crisosto. 2008. San Joaquin Valley blueberries evaluated for quality attributes. Cal. Agr. 62:91–96.

Chu, W., H. Gao, H. Chen, X. Fang, and Y. Zhang. 2018. Effects of cuticular wax on the postharvest quality of blueberry fruit. Food Chem. 239:68–74.

Ehlenfledt, M.K. 2005. Fruit firmness and holding ability in highbush blueberry – implications for mechanical harvesting. Int. J. Fruit Sci. 5:83–91.

Ehlenfeldt, M.K. and R.B. Martin, Jr. 2010. Seed set, berry weight, and yield interactions in the highbush blueberry cultivars (*Vaccinium corymbosum* L.) 'Bluecrop' and 'Duke'. J. Amer. Pomol. Soc. 64:162–172.

Forney, C.F., W. Kalt, M.A. Jordan, M.R. Vinqvist-Tymchuk, and S.A.E. Fillmore. 2012. Compositional changes in blueberry and cranberry fruit during ripening. Acta Hort. 926:3331–337.

Galletta, G.J., W.E. Ballinger, R.J. Monroe, and L.J. Kushman. 1971. Relationships between fruit acidity and soluble solids levels of highbush blueberry clones and fruit keeping quality. J. Amer. Soc. Hort. Sci. 96:758–762.

Hammett, L.K. and W.E. Ballinger. 1972. Biochemical components of highbush blueberry fruit as influenced by nitrogen nutrition. J. Amer. Soc. Hort. Sci. 97:742–745.

Hancock, J., P. Callow, S. Serce, E. Hanson, and R. Beaudry. 2008. Effect of cultivar, controlled atmosphere storage, and fruit ripeness on the long-term storage of highbush blueberries. HortTechnology 18:199–205.

Kushman, L.J. and W.E. Ballinger. 1963. Influence of season and harvest interval upon quality of Wolcott blueberries grown in eastern North Carolina. Proc. Amer. Soc. Hort. Sci. 83:395–405.

Kushman, L.J. and W.E. Ballinger. 1968. Acid and sugar changes during ripening in Wolcott blueberries. Proc. Amer. Soc. Hort. Sci. 92:290–295.

Lobos, G.A., P. Callow, and J.F. Hancock. 2014. The effect of delaying harvest date on fruit quality and storage of late highbush blueberry cultivars (*Vaccinium corymbosum* L.) Postharv. Biol. & Tech. 87:133–139.

Lobos, G.A., J.B. Retamales, J.F. Hancock, J.A. Flore, S. Romero-Bravo, and A. del Pozo. 2013. Productivity and fruit quality of *Vaccinium corymbosum* cv. Elliott under photo-selective shading nets. Sci. Hort. 153:143–149.

Lyrene, P.M. 2006. Weather, climate, and blueberry production. p. 14–20. In: Childers, N.F. and P.M. Lyrene (eds.). Blueberries for growers, gardeners, and promoters. Dr. N.F. Childers Publications, Gainesville, FL.

Marshall, D.A., J.M. Spiers, and J.H. Braswell. 2006. Splitting severity among rabbiteye (*Vaccinium ashei* Reade) blueberry varieties in Mississippi and Louisiana. Intl. J. Fruit Sci. 6:77–81.

Northwest Center for Small Fruits Research. 2018. Blueberry research priorities. (accessed 15 Apr. 2019) http://www.nwsmallfruits.org/priorities/2018-19_NCSFR_priorities_rev2016_B_blueberry.pdf

Ogden, A.B. and M.W. van Iersel. 2009. Southern highbush blueberry production in high tunnels: Temperatures, development, yield, and fruit quality during the establishment years. HortScience 44:1850–1856.

Oregon Blueberry Commission. 2018. Request for proposals – research priorities. (accessed 15 Apr. 2019) https://agresearchfoundation.oregonstate.edu/sites/agresearchfoundation.oregonstate.edu/files/blueberry_research_rfp_2019-20.pdf

Perkins-Veazie, P. J.R. Clark, J.K. Collins, and J. Magee. 1995. Southern highbush blueberry clones differ in postharvest fruit quality. Fruit Var. J. 49:46–52.

Retamales, J.B. and J.F. Hancock. 2012. (eds.) Blueberries. CABI press, Cambridge, MA.

Saftner, R. J. Polashock, M.K. Ehlenfeldt, and B. Vinyard. 2008. Instrumental and sensory quality characteristics of blueberry fruit from twelve cultivars. Postharv. Biol. & Tech. 49:19–26.

Sapers, G.M. A.M. Burgher, J.G. Phillips, S.B. Jones, and E.G. Stone. 1984. Color and composition of highbush blueberry cultivars. J. Amer. Soc. Hort. Sci. 109:105–111.

Sargent, S.A., J.K. Brecht, and C.F. Forney. 2006. Blueberry harvest and postharvest operations: Quality maintenance and food safety. p. 139–151. In: Childers, N.F. and P.M. Lyrene (eds.). Blueberries for growers, gardeners, and promoters. Dr. N.F. Childers Publications, Gainesville, FL.

Skupień, K. 2006. Chemical composition of selected cultivars of highbush blueberry fruit (*Vaccinium corymbosum* L.). Folia Hort. 18:47–56.

Strik, B.C. and A. Vance. 2015. Seasonal variation in leaf nutrient concentration of northern highbush blueberry cultivars grown in conventional and organic production systems. HortScience 50:1453–1466.

Strik, B.C. and A. Vance. 2019. Northern highbush blueberry cultivars differ in the relationship between seed number and berry weight during the harvest season. HortScience (in press).

Strik, B.C., C.E. Finn, and P.P. Moore. 2014. Blueberry cultivars for the Pacific Northwest. Oregon. Ore. State Univ. Ext. Serv. PNW 656. (accessed 15 Apr. 2019) http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/45871/pnw656.pdf

Strik, B.C., A.J. Vance, and C.E. Finn. 2017. Northern highbush blueberry cultivars differed in yield and fruit quality in two organic production systems from planting to maturity. HortScience 52:844–851.

Taber, S.K. and J.W. Olmstead. 2016. Impact of cross- and self-pollination on fruit set, fruit size, seed number, and harvest timing among 13 southern highbush blueberry cultivars. HortTechnology 26:213–219.

U.S. Department of Interior. 2014. Bureau of Reclamation, Boise, ID. AgriMet Weather Station web site. (accessed 15 Apr. 2019) <www.usbr.gov/pn/agrimet/agrimetmap/araoda.html>

Vance, A.J., P. Jones, and B.C. Strik. 2017. Foliar calcium applications do not improve quality or shelf-life of strawberry, raspberry, blackberry, or blueberry fruit. HortScience 52:382–387.

Woodruff, R.E., D.H. Dewey, and H.M. Sell. 1960. Chemical changes of Jersey and Rubel blueberry fruit associated with ripening and deterioration. Proc. Amer. Soc. Hort. Sci. 75:387–401.

Yang, F-H. 2018. Predictions and practices for reducing heat damage in northern highbush blueberry (*Vaccinium corymbosum* L.). Ore. State. Univ., Corvallis, PhD Diss. (accessed 9 Apr. 2019) <https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/hx11xm620>.