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Leisso, R., Jarrett, B., & Miller, Z. (2021). Haskap Preharvest Fruit Drop and Stop-drop Treatment Testing. HortTechnology, 1(aop), 1-8.

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ADDITIONAL INDEX WORDS. **blue honeysuckle, camerise, honeyberry, *Lonicera caerulea*, plant growth regulators**

SUMMARY. **Haskap (*Lonicera caerulea*), also known as honeyberry, is a relatively new fruit crop in North America. To date, most academic activity and research in North America involving haskap has focused on cultivar development and health benefits, with relatively few field experiments providing information to guide field planning and harvest management for the recently released cultivars. In 2020, we documented preharvest fruit drop (PHFD) rates for 15 haskap cultivars planted in a randomized block design at our research center in western Montana with the aim of preliminarily determining whether certain cultivars may be prone to this phenomenon. Additionally, we evaluated two plant growth regulators (PGRs) to reduce PHFD in two cultivars previously observed to have high rates of PHFD. Results suggest cultivar-specific variations in PHFD near berry maturation. Because haskap harvest indices are not well-defined and may be cultivar-specific, we share our 1-year study results as preliminary information and as a call for further research. Cultivars Aurora, Boreal Blizzard, Borealis, Indigo Gem, Kapu, and Tana all had PHFD rates less than 12% of yield, where yield is the weight of berries lost to PHFD plus marketable yield and marketable yield is fruit remaining on the shrub at harvest. Cultivars Chito, Kawai, and Taka had the highest rates of PHFD, although marketable yields were still relatively high, especially for Kawai. We note that ease of fruit detachment is an important consideration in mechanical harvest, and this characteristic could be advantageous if managed appropriately. The PGRs evaluated (1-napthaleneacetic acid and aminoethoxyvinylglycine) did not influence PHFD rates; however, our study was limited by the sample size and by the lack of information regarding haskap abscission physiology. In summary, the haskap cultivars evaluated exhibited variable PHFD rates in the year of the study, and further research is needed to understand haskap fruit maturation, harvest indices, and abscission.**

Haskap (*Lonicera caerulea*), also known as honeyberry or blue honeysuckle, is a relatively new berry crop in North America. The woody perennial shrub produces edible blue berries that vary greatly in flavor, shape, and size. The flavor has been described as a combination of raspberry (*Rubus* sp.) and blueberry (*Vaccinium* sp.) (Bors et al., 2012), ranging from mild, sweet, variably tart, to slightly bitter (Thompson, 2006). Studies have indicated the berries have higher antioxidant capacity than many other small fruit crops, including blueberry (Rupasinghe et al., 2012), and a review of the recent literature lists numerous health benefits, including anti-diabetic, anti-inflammatory, and anti-cancer properties (Rupasinghe et al., 2018).

In Montana, average fruit weights of North American commercial cultivars are between 0.96 and 1.70 g (Setzer, 2020), and the shape varies from rounded oval to greatly elongated (Bors et al., 2015). Haskap can be grown in areas that are too cold or alkaline for blueberry because of its tolerance to a wide range of soil pH (up to 8.0) and exceptional cold hardiness (Bors et al., 2012, 2015; Gerbrandt, 2014). In addition, their blossoms can withstand freezing temperatures (Gasic et al., 2018). It is an early-season fruit crop and, in some locations, it ripens before or concurrent with June-bearing strawberry [*Fragaria* ×*ananassa* (Gerbrandt, 2014; Gerbrandt et al., 2017)]. Pollinizer plants (compatible cultivars) are required for good fruit set (Gerbrandt, 2014; Plekhanova, 1996).

Haskap breeding materials, collection, evaluation, and breeding efforts (Bors et al., 2009, 2012, 2015; Gerbrandt et al., 2017, 2018, 2020; Thompson, 2006, 2016a, 2016b, 2016c, 2016d, 2017a, 2017b; Thompson and Barney, 2007) have supported the expanding industry in both the United States and Canada. Canadian haskap production increased 64% from 2018 to 2019 (Statistics Canada, 2020), and farms range in size from 0.5 to 40 acres or more. Haskap production in the United States is not tracked by government reporting.

Although the amount of information about haskap cultivars and their cultivation is increasing (Jurikova et al., 2009; Małodobry et al., 2010; Skupień et al., 2009), details regarding cultivars typically available in North America are

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0781	fl oz/100 gal	mL·L^{-1}	12.8000
0.0731	fl oz/acre	L·ha^{-1}	13.6840
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
10	gal/100 gal	L·m^{-3}	0.1
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha^{-1}	0.8922
28.3495	oz	g	0.0353
1	ppm	mg·L^{-1}	1
1	ppm	μL·L^{-1}	1
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Received for publication 6 June 2021. Accepted for publication 25 Aug. 2021.

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This project was funded by the Montana Specialty Crop Block Grant AM200100XXXXG026. We thank Montana State University (MSU)-Bozeman and MSU-Western Agricultural Research Center staff Amy Darling, Haydon Davis, Kyrstan Hubbel, Ashley Kapus, Katrina Mendrey, Kierstin Schmitt, Alex Hooglund, Shawna Medlar, Frances Rafferty, Rebecca Richter, Olivia Soller, and Andrea Ziolkowski for administrative and technical support. We also thank the HortTechnology editors and anonymous reviewers whose feedback greatly improved the presentation of these results.

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https://doi.org/10.21273/HORTTECH04861-21

limited and, due to breeding materials originating from different locales, these cultivars may have climate limitations (Gerbrandt et al., 2017, 2018). There are relatively few resources to guide growers regarding cultivar selection, plant management, and harvest parameters. In research plots near Elora and Simcoe, Ontario, Canada, MacKenzie et al. (2018) compared fruit weight, yields, titratable acidity, pH, and soluble solids content [SSC (12.4% to 17.9%)] of five cultivars (Borealis, Indigo Gem, Indigo Treat, Tundra, Czech no. 17). They commented on the difficulty of determining harvest timing because fruit color darkens before maturity, making it challenging to determine the optimum harvest stage. In Poland, Ochmian et al. (2012) performed multiple haskap fruit harvests based on color for cultivars Wojteck and Brazowa, with six and seven harvests, respectively. The SSC was lower for initial harvests (10.3% and 9.6%, for 'Wojteck' and 'Brazowa', respectively) and higher for later harvests (14.1% and 12.6%), which they attributed to higher temperatures later in the season. Importantly, cultivars compatible with a (one-pass) mechanical harvest are a goal for the haskap breeding program based at the University of Saskatchewan, Saskatoon, Saskatchewan, Canada (Bors et al., 2015).

In the first several bearing years of our cultivar comparison field trial (2017–19), we observed that certain cultivars had substantial PHFD before reaching our harvest maturity indices. The PHFD phenomenon was also documented by MacKenzie et al. (2018), who indicated that applications of 0.02% hexanal did not mitigate PHFD. Thompson (2006) also noted variations in berry attachment to the pedicel, which can be so tight that fruit ruptures when harvested or so loose that fruit falls before harvest. This could be alternately interpreted as cultivar-specific differences in abscission regulation in relation to fruit maturity. Preharvest dropped fruit are not only lost yield but also a potential reservoir for pests and diseases. Determining which cultivars are prone to PHFD would be important information for guiding harvest management.

Relatively few treatments that could alter preharvest drop rates have been tested, and little has been reported regarding abscission physiology to inform the choices of products to test. PGRs can be used to mitigate preharvest drop of other fruit species, including apple [*Malus ×domestica* (Robinson et al., 2010)], plum [*Prunus* subgenus *Prunus* sp. (Kaur et al., 2004)], and citrus [*Citrus* sp. (Nawaz et al., 2008)]; modes of action include delaying fruit maturity via the ethylene biosynthesis inhibiting aminoethoxyvinylglycine [AVG (Layne et al., 2002)] and affecting abscission physiology via a synthetic auxin, 1-napthaleneacetic acid [1-NAA (Nartvaranant, 2018)].

The objectives of our 2020 haskap field trials were to record PHFD rates among haskap cultivars, collect at-harvest SSC to provide regional growers with a baseline for comparison, and test the utility of two PGRs for preventing PHFD of two of the cultivars previously observed to be susceptible.

Materials and methods

Field plots. The haskap planting used for this project is located at Montana State University Western Agricultural Research Center (MSU-WARC), Corvallis (lat. 46°19′45.5″N, long. 114°5′7.4″W). Most plants in the research block were planted in 2015, although cultivars Boreal Blizzard and Boreal Beauty were planted in 2016 and 2018, respectively. Each cultivar was planted in a randomized complete block design, with three blocks and three plants per cultivar per block, with 3-ft in-row spacing and 12-ft spacing between rows. The shrubs were not mulched and were irrigated with drip emitters two to three times per week originally at a rate of 10 gal/week via a 1-gal/h pressure-compensating emitter (Vortex Emitter; Spot Systems, Santa Rosa, CA). As plants increased in size, a second 1-gal/h emitter was added to each plant at an increased distance from the plant to accommodate the growing root system. For the 2019 and 2020 growing seasons, plants were irrigated at a rate of 14 gal/week, with additional irrigation during weeks when temperatures above 90 °F were maintained and likely to led to plant stress. Weed management consisted of hand weeding and spot spraying with glyphosate (RoundUp; Bayer, Whippany, NJ) in the first year. After the first growing season, we added dormant applications of granular pre-emergent herbicide [dichlobenil (Casoron 4G; OHP, Bluffton, SC)]; at a rate of 100 lb/acre. Fertility management followed standard recommendations for macronutrients (nitrogen, phosphorus, and potassium) in bush berries [e.g., saskatoon serviceberry (*Amelanchier alnifolia*) and blueberry (Miller et al., 2021)]. Plants were protected with bird netting [blue-green polyethylene with ≈1-inch holes and reinforced edges (SmartNet Systems; Comox, BC, Canada)] beginning the first week of June, before external full color for any haskap cultivars.

We collected data regarding PHFD and assessed PGRs in Summer 2020. Air temperatures during harvest (18 June–23 July 2020) were higher than typical, with average maximum and minimum daily temperatures of 78 and 49 °F, respectively. The only major rainfall (2 inches) was recorded between 28 and 30 June. Growing degree-days [GDD (base 50 °F, no maximum, simple average calculation)] from 1 Jan. 2020 were 251 GDD on 18 June (first harvest), and 754 GDD by 23 July (last harvest). Temperature data used for these calculations originated from the Corvallis weather station located at MSU-WARC, and GDD summaries were calculated using an online phenology and degree-day model (Integrated Plant Protection Center at Oregon State University, 2021).

Preharvest fruit drop and harvest. To enable easy recovery of dropped fruit, we placed lightweight agricultural rowcover cloth on the ground beneath one randomly selected row per block for all haskap cultivars and beneath all plants for Kawai and Taka during the first week of June. Any berries that dropped from the plants before harvest were gathered and weighed weekly on a per-plant basis. Fruit were harvested from individual plants using a reciprocating saw [variable speed (DCS381; DEWALT Industrial Tool Co., Towson, MD)] fitted with an adapter (Quick-Change Adapter/ReciproTools RCT-A10; Jore Corp., Ronan, MT) with a padded U-shape attachment (custom welded to a hex bit) to pummel branches. Detached fruit dropped into two large, angled catch trays with long opposing bristles (≈6 inches) that were placed on either side of the base of the plant. We noted that some cultivars were becoming more prone to dropping fruit as the season progressed; even the slightest jostling of branches to gather dropped fruit could result in further drop. As a result, for all harvests on and after 2 July 2020, we collected dropped fruit from the ground immediately after harvest and weighed it to quantify lost yield. Although we took great care not to drop fruit on the ground during harvest, the PHFD data collected after harvest may include a negligible number of berries lost during harvest because of berries falling between the bristles of the catch trays.

Harvest indices. Samples of berries on each plant were collected and assessed approximately every 3 d after external full color for SSC. Cultivar harvest decisions were based on the harvest indices of full blue exterior color for all fruit, ≈14% SSC (n = ≈27) combined with a subjective cultivar-specific assessment of fruit flavor (performed by the same harvest manager from preliminary harvests in 2016 through the end of the 2020 harvest season). The target SSC of ≈14% was established in 2017, when repeated measurements of SSC after external full color and subjective flavor evaluations revealed a continued increase in SSC more than ≈14% and improvement in flavor after fruit had developed full color.

SCC at harvest. On the day of harvest, 15 to 20 berries were collected from each plant (representing all sides and canopy positions of each shrub) in the trial (for a total of 135 to 180 fruit per cultivar) and gently placed in a small container. Sixty berries were randomly selected for measuring SSC of the juice. Berries were individually punctured with a 2-mm-diameter probe and gently squeezed to express the juice onto the lens of a digital handheld refractometer (model HI96801; HANNA Instruments, Woodsocket, RI).

Pilot study: Plant growth regulators to prevent preharvest drop. Treatments to prevent drop were applied to cultivars Kawai and Taka; these were chosen because of prior observations of their propensity for PHFD and their similar harvest dates in prior years. We randomly assigned one plant from each of three blocks to each treatment (three plants per treatment): an untreated control, AVG (ReTain OL; Valent BioSciences, Libertyville, IL) and 1-NAA (Fruitone L; Amvac Chemical Co., Los Angeles, CA). Per the manufacturer's directions, treatments were applied on 15 June, when fruit were nearing full size and ≈50% of the berries were partially blue color, and again on 10 July, 1 week before harvest on 16 July. Treatments were applied using a 1-gal manual sprayer (400 g–1 G; Solo, Newport News, VA) and applied to one plant per block for cultivars Kawai and Taka between 6:00 and 7:00 AM. Both PGRs were applied at label rates of 10 fl oz/acre in a volume of water (3 L, 160 ppm PGR) previously determined to ensure full coverage of plants. A nonionic surfactant (Rainier-EA; Wilbur-Ellis, San Francisco, CA) was used for 1-NAA and horticultural oil (Wil-Gro Hort Oil 98-2, Wilbur-Ellis) for AVG. Surfactants were used at rates of 32 fl oz of nonionic surfactant per 100 gal of spray (0.25%) and 1 gal of horticultural oil per 100 gal water (1%). The same volume of water was applied to control plants. Separate hand pumps were used for each treatment.

Statistics. Data were analyzed with statistical analysis software (SAS version 9.4; SAS Institute, Cary, NC). Assumptions of normality were assessed using the Shapiro-Wilk test statistic performed with PROC UNIVARIATE and homogeneity of variance with Levene's test. For all analyses, post hoc means separations were established per Fisher's least significant difference at $P < 0.05$. Cultivar SSC, in-field fruit drop, yield, and related measures were analyzed in PROC GLM. The SSC was analyzed with a one-way Welch's analysis of variance (ANOVA) because of the lack of homogeneity of variance according to cultivar and the inability to achieve homogeneity of variance with transformations. 'Boreal Beauty' and 'Boreal Blizzard' were excluded from yield-based comparisons because these cultivars were planted later than the main trial cultivars. For PGR applications, data were analyzed with PROC GLM with the factors of cultivar and treatment. Boxplots were generated by the open-source statistical analysis and data visualization software (R Foundation for Statistical Computing, Vienna, Austria) with the tidyverse (Wickham et al., 2019) and ggplot2 (Wickham, 2009) packages. Because PGR application effects on preharvest drop were not significant, we performed a power analysis using G*Power (Faul et al., 2009) to determine the power and effect size (for one-way ANOVA according to the cultivar) based on the preharvest drop as well as yield lost to preharvest drop (percent) means and SDs for each treatment for Kawai and Taka. We further estimated the recommended sample size for future studies based on the effect size.

Results

The first haskap harvest was 18 June 2020 ('Sugar Mountain Blue'), and the last harvest was 23 July 2020 ('Kapu') (Table 1). Warmer temperatures before and during harvest resulted in a shorter harvest season than that during previous years. 'Borealis' and 'Boreal Blizzard'—which have been harvested typically in July—were harvested in June.

Cultivars differed in marketable yield, yield potential, and percent of yield potential lost to PHFD (Table 2). Marketable yields (fruit remaining on the plant at harvest) and yields (marketable yield plus PHFD) represent only plants for which PHFD data were also collected (n = 3). Marketable yields 6 years after planting ranged more than 12-fold, from 609 to 7648 g/plant. Unnamed cultivar 85-19 had the highest marketable yield, followed by Tana (5676 g/plant). The earliest ripening cultivars, Blue Goose, Sugar Mountain Blue, and Wild Treasure, had generally lower yields (<800 g/plant) than later-

Table 1. Harvest dates for haskap cultivars in 2020 at Corvallis, MT.

Cultivar	Harvest date
Aurora	2 July 2020
Blue Goose	19 June 2020
Boreal Beauty	6 July 2020
Boreal Blizzard	26 June 2020
Borealis	24 June 2020
Chito	11 July 2020
Indigo Gem	22 June 2020
Kapu/SOLO[z]	23 July 2020
Kawai	20 July 2020
Keiko	20 July 2020
Sugar Mountain Blue	18 June 2020
Taka	16 June 2020
Tana	20 July 2020
Wild Treasure	19 June 2020
85-19[y]	9 June 2020

[z] SOLO is the name trademarked by Spring Meadow Nursery, Grand Haven, MI.

[y] An unnamed cultivar by Dr. Maxine Thompson.

Table 2. Marketable yield, yield, percent yield lost to preharvest fruit drop (PHFD), and individual haskap berry soluble solids content (SSC) in haskap cultivars in 2020 at Corvallis, MT. Yield data are excluded for 'Boreal Blizzard' and 'Boreal Beauty' because they were planted 1 and 3 years later, respectively, than the other cultivars in the trial.

	Marketable yield (g)[z]	Yield (g)[y]	Yield lost to PHFD (%)[x]	SSC (%)
Cultivar	mean ± SE			
Aurora	3201 ± 721 bc[w]	3332 ± 738 cde[w]	4.0 ± 0.94 cd[w]	15.5 ± 0.19 cde[v]
Blue Goose	654 ± 132 e	661 ± 133 f	1.0 ± 0.02 f	14.4 ± 0.21 f
Boreal Beauty	Not reported	Not reported	30.5 ± 3.31 ab	13.0 ± 0.32 g
Boreal Blizzard	Not reported	Not reported	11.7 ± 3.60 bc	14.8 ± 0.18 def
Borealis	3151 ± 248 abc	3188 ± 253 cde	1.2 ± 0.54 ef	14.5 ± 0.15 ef
Chito	2170 ± 744 c	3603 ± 882 cd	42.5 ± 5.84 a	14.6 ± 0.17 ef
Indigo Gem	1626 ± 334 cd	1642 ± 332 ef	1.2 ± 0.41 ef	15.8 ± 0.32 cd
Kawai	2452 ± 283 bc	4774 ± 768 bc	47.6 ± 3.35 a	14.6 ± 0.17 ef
Keiko	2572 ± 1089 c	3162 ± 796 cde	29.9 ± 22.37 ab	17.3 ± 0.21 ab
Kapu	3070 ± 261 bc	3443 ± 265 cd	10.8 ± 3.37 bc	18.4 ± 0.27 a
Sugar Mountain Blue	759 ± 211 de	772 ± 216 f	1.6 ± 0.27 def	16.2 ± 0.27 bc
Taka	1603 ± 270 cd	2865 ± 186 de	43.6 ± 9.42 a	14.2 ± 0.34 f
Tana	5676 ± 978 ab	5809 ± 1018 b	2.8 ± 0.34 def	14.5 ± 0.21 ef
Wild Treasure	609 ± 232 e	634 ± 225 f	7.1 ± 4.89 cd	15.3 ± 0.25 cdef
85-19	7648 ± 728 a	7946 ± 824 a	3.6 ± 0.76 cde	16.1 ± 0.19 c

[z] Mean per-plant weight of all fruit harvested from plants within a cultivar; 1 g = 0.0353 oz.

[y] Marketable yield + mean per-plant weight of PHFD within a cultivar.

[x] (PHFD ÷ yield) × 100.

[w] Means (n = 3 plants) in a column followed by the same lowercase letter are not significantly different (Fisher's least significant difference test at $P < 0.05$).

[v] Means (n = 60 berries) in a column followed by the same lowercase letter are not significantly different (Welch's one-way ANOVA); we used Welch's one-way ANOVA due to the lack of homogeneity of variance among cultivars.

ripening cultivars. Yields for 85-19 (7946 g/plant) and 'Tana' (5809 g/plant) were greater than those for most cultivars, followed by Kawai (4774 g/plant), which was nominally higher but not significantly different from the yields of Chito (3603 g/plant) and Kapu. The next three highest-yielding cultivars were Aurora, Borealis, and Keiko, with $\approx$3200 g/plant.

The cultivars with the highest percentage of yield lost to PHFD were Kawai (47.6%), Taka (43.6%), and Chito (42.5%) (Table 2). 'Boreal Beauty' and 'Keiko' yield losses (both $\approx$30%) were not statistically different from 'Boreal Blizzard' and 'Kapu' (both $\approx$12%). Cultivars with the lowest yield lost to PHFD were Tana (2.8%), Sugar Mountain Blue (1.6%), Indigo Gem (1.2%), Borealis (1.2%), and Blue Goose (1.0%). After comparing the marketable yield to the yield changes, the top five highest-yielding cultivars were 85-19, Tana, Aurora, Borealis, and Kapu (marketable yield), and 85-19, Tana, Kawai, Chito, and Kapu (yield).

At-harvest SSC (for fruit remaining on plants) varied among cultivars, with Kapu at the high end (18.4%) and Boreal Beauty at the low end (13.0%) (Table 2).

In our pilot study, PHFD (as measured by the percent of yield potential) was not significantly influenced by PGR treatment (Fig. 1). A follow-up statistical analysis (power analysis) indicated the experiment was underpowered, with the power $(1-\beta)$ of present results being between 0.07 and 0.37 according to the dependent variable and cultivar. Recommended samples sizes for future work, assuming similar experimental conditions, are between 48 and 207 plants or, assuming one control and two PGR treatments, between 16 and 70 plants per treatment.

Discussion

Haskap has only recently been bred and cultivated as a commercial berry crop in North America. Predilection to PHFD could be an important factor in cultivar selection and management. Little to no research of haskap PHFD has been performed to compare cultivars, understand its physiological basis, and manage the phenomenon. Although the present data are limited in terms of plant numbers and represent one field season, the lack of harvest indices for specific cultivars complicates the study beyond simply gathering an additional year of data of PHFD. We share these preliminary results for cultivar comparison of PHFD to enhance the research of establishing harvest indices as well as PHFD management, and we further include pilot study results involving PGRs intended to prevent fruit drop of haskap.

Marketable yields. Because most cultivars were 6 years old in 2020, the plants would have been approaching mature yields (Hummer, 2006). We excluded 'Boreal Blizzard' and 'Boreal Beauty' from our yield-related analyses because we planted them one and three growing seasons later, respectively, than the other cultivars in the trial were planted. Our yield data represent only plants for which we also recorded PHFD; further yield information is available on the MSU-WARC website (Z. Miller and B. Jarrett, unpublished data).

Preharvest fruit drop. Cultivars Kawai, Chito, and Taka exhibited PHFD of 40% to 50% loss of the potential yield per plant. Because of low plant numbers and variability in drop and yield, 'Boreal Beauty' and 'Keiko' PHFD yield losses of $\approx$30% did not differ significantly from those of 'Boreal Blizzard' and 'Kapu', which had nominally lower yield losses to PHFD of 11.7% and 10.8%, respectively. Although we do not have quantitative data regarding PHFD from prior years,

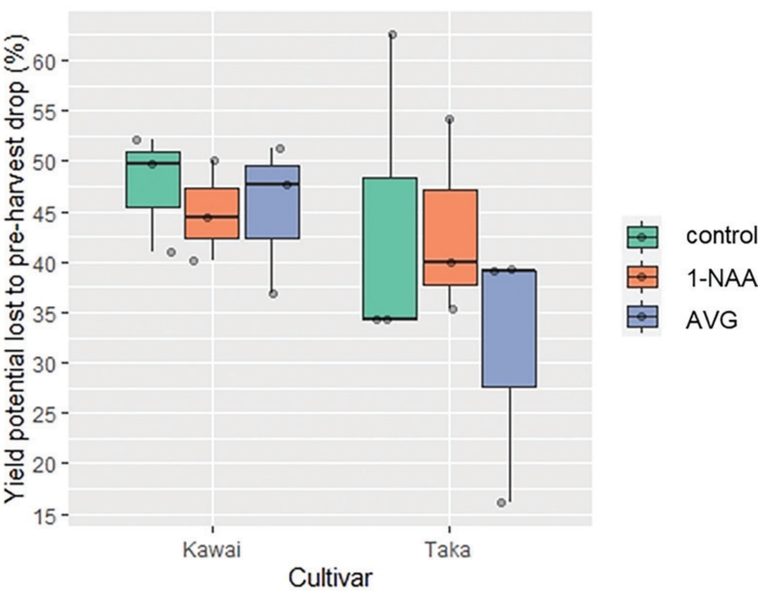

Fig. 1. A pilot trial using plant growth regulators (PGRs) aminoethoxyvinylglycine (AVG) and 1-napthaleneacetic acid (1-NAA) did not demonstrate any influence of PGRs on preharvest fruit drop (PHFD) rates for haskap cultivars Kawai and Taka. PGRs were each applied at a rate of 10 fl oz/acre (160-ppm solution in water to thoroughly coat plants) with a nonionic surfactant and horticultural oil, respectively, when ≈50% of the berries were partially blue (15 June 2020) and 1 week before harvest (10 July 2020). Control plants were sprayed with the same volume of water as treatments. Percent yield lost to PHFD [weight of berries dropped preharvest ÷ (weight of berries dropped preharvest + yield harvested from the plant at commercial maturity) × 100] did not differ according to treatments. Each boxplot represents three plants indicated by the points. 1 fl oz/acre = 0.0731 L·ha^{-1}; 1 ppm = 1 mg·L^{-1}.

the cultivars found to have high PHFD were consistent with prior observations. However, 'Boreal Beauty' was planted in 2018, and the fact these plants were younger than the others should be taken into consideration when interpreting results. Despite high PHFD rates, some cultivars (i.e., Kawai) still had relatively high marketable yields (2452 g/plant). More than half the cultivars in our trial exhibited reasonably low yield lost to PHFD (3% to 12% of yield). Notably, unnamed cultivar 85-19 had the highest marketable yield and a low percentage of yield lost to PHFD (3.6%). Cultivars Blue Goose, Wild Treasure, and Sugar Mountain Blue had low PHFD; however, these cultivars are not likely to be well-suited for commercial production in Montana because of susceptibility to early (January–February) budbreak and subsequent cold injury, small fruit, low yields, and unpalatable bitterness.

Preharvest fruit drop may be attributable to cultivar-specific regulation of fruit abscission combined with uneven maturity, with some cultivars dropping berries at or near maturity and others retaining mature fruit longer. Similar phenomena occur in other commercial fruit species and can be different according to cultivar. For example, the apple cultivar McIntosh is extremely prone to fruit drop near maturity (Robinson et al., 2010), whereas other cultivars are less so (e.g., Empire, Gala, Fuji) (Irish-Brown et al., 2011). Supporting the hypothesis of uneven fruit maturity, in haskap foundation germplasm, Gerbrandt et al. (2017) documented extended bloom duration as well as staggered external color development. We have made similar observations regarding bloom and external berry color development in our haskap field trial (Z. Miller and B. Jarrett, unpublished data).

Additional conditions associated with PHFD in other fruit species include malnutrition, water stress, pests, disease (Nawaz et al., 2008), heat stress (Robinson et al., 2010), and high winds (van Rhee, 1958). In our study, PHFD was concentrated in later-season cultivars for which higher temperatures could have contributed to heat stress leading to PHFD, although some later-season cultivars (e.g., Tana and Kapu) still had low levels of PHFD. Plants in our trial received the same quantity of water via drip irrigation, but it is possible that cultivars have differing water needs, and that cultivars with high PHFD needed more water than was provided. However, no symptoms of water or heat stress (leaf wilting or curling) were observed for any cultivars in our trial. Similarly, the plants experienced no pest or disease problems, no extreme winds before harvest, and no extensive PHFD after several rainy days at the end of June.

HARVEST MANAGEMENT AND PHFD. The simplest method to reduce yield lost to PHFD would be to harvest before or when fruit drop is first noted, assuming all berries on a plant have attained full exterior blue color. Gerbrandt et al. (2020) harvested 3 to 5 d after all fruit on the shrub reached full color. The SSC in their study were lower than those reported in the present work, but the location and cultivar differences between our studies confound any interpretation of lower SSC in relation to flavor or eating quality. As discussed, our experience recommends against harvesting solely based on exterior color, but we have no data regarding product quality or fresh fruit consumer preference with which to validate these concerns.

Alternately, cultivars prone to PHFD may be best-suited to backyard growers or fresh market operations where fruit can be hand-harvested multiple times. However, where unevenness in fruit maturity exists, determining optimal ripeness may be problematic, as discussed in relation to harvest indices.

SSC AND OTHER PROPOSED HARVEST INDICES. In the present study, SSC (along with full fruit color and the subjective flavor evaluation) was one of the primary harvest indices. The SSC is a commonly used horticultural maturity index for many types of fruit (Reid, 2002). Optimal SSC can vary widely among cultivars within a species, and the present study illustrates the challenges of applying a uniform harvest index across cultivars within a novel fruit crop, with the summary concern being that delaying harvest to achieve higher SSC led to higher PHFD in some cultivars in our study. However, because PHFD does not appear to be explicitly tied to high SSC based on the present data, cultivars likely vary in the optimal SSC at harvest.

Limited information is available regarding SSC specific to a given haskap cultivar at optimal maturity, and when it is reported, it is typically not described in the context of harvest management for fruit flavor or quality. MacKenzie et al. (2018) compared SSC (values from 12.4% to 17.9%) along with other fruit characteristics at harvest for five cultivars (Borealis, Indigo Gem, Indigo Treat, Tundra, Czech no. 17). In their study, SSC reported at harvest varied among cultivars, locations, and years. Our data include only two of the same cultivars—Borealis and Indigo Gem—and their SSCs in 2020 had similar ranges. 'Borealis' and 'Indigo Gem' had SSC of 8.7% and 12.4%, respectively, according to research by Gerbrandt et al. (2020), and 'Chito', 'Kapu', 'Kawai', 'Keiko', and 'Tana' had SSCs between 13.0% and 14.6% listed in their patents (Thompson 2016a, 2016b, 2016c, 2016d, 2017a, 2017b). However, the climates in which this information was collected are quite different from that of Montana (temperate coastal with mild winters and cool summers in Fraser Valley, British Columbia, Canada, compared to continental with cold winters and hot summers). Climate can affect SSC, along with many other aspects of berry quality (Barnuud et al., 2014).

The other harvest indices we combined with SSC were color (all fruit on a shrub must have full blue exterior color) and flavor evaluation, the latter of which is difficult to measure quantitatively and communicate effectively. In our first harvest season (2017), we harvested based on surface color alone (exterior fruit color having changed from green to blue) and found the fruit to be extremely tart and sour, and the overall flavor to be "green" and unappealing. Our conclusion was that, unlike many other berries, the exterior color of haskap fruit changes from green to blue before fruit reaches horticultural maturity (defined as optimum eating quality) (Reid, 2002) according to our observations and those of MacKenzie et al. (2018). The sour taste we noted could likely be approximated by titration (Da Conceicao Neta et al., 2007). Titratable acidity as well as the ratio of SSC to titratable acidity are used for other fruit crops as harvest indices (Reid, 2002). These indices may be best considered in a climate-region specific manner, and we recommend that growers and researchers should track and share these measures in relation to flavor and other fruit quality aspects to support the possible establishment of these parameters as harvest indices in their region.

PLANT GROWTH REGULATOR INFLUENCE ON PREHARVEST FRUIT DROP. Applying 1-NAA and AVG twice, with the last application 1 week before harvest, had no statistically significant influence on PHFD rates for cultivars Kawai and Taka. Because of our field trial size, treatments were applied to only one plant per block, for a total of three plants per treatment. The follow-up power analysis indicated this experiment was underpowered; therefore, we consider this a pilot study and the results should be considered primarily to guide future PGR work. Based on the power analysis, the recommended numbers of plants (divided into three treatment groups) are between 48 and 207, depending on the dependent variable (PHFD or PHFD relative to total potential yield) and cultivar (Kawai and Taka). However, we are unaware of any local growers who have planted these cultivars in larger quantities than those in our field trial.

When attempting to mitigate haskap PHFD, we chose to test two commercially available PGRs that are commonly used in the fruit industry. However, these PGRs are typically used for fruit crops in the plant families including apple and plum (Rosaceae), grape (Vitaceae), and citrus (Rutaceae), whereas haskap is in the honeysuckle (Caprifoliaceae) family. Biochemical maturation and abscission physiology in haskap may differ enough that these PGRs do not have the intended effect. This points to the need for research of physiological mechanisms of haskap fruit maturity and abscission to inform selection or development of effective stop-drop treatments. However, even in fruit crops (e.g., apple) for which maturation and abscission physiology are relatively well understood, the ability of PGRs to reduce PHFD can vary according to treatment quantity and timing, cultivar, and other environmental or management factors (Schwallier and Irish-Brown, 2014). Therefore, optimizing application timing or rates for specific PGRs may assist their effectiveness in minimizing haskap PHFD.

Conclusions

Preharvest drop of haskap fruit varied among cultivars, with Kawai, Chito, and Taka presenting the highest PHFD, although marketable yields for some cultivars (especially Kawai) were still within the range of other cultivars with high marketable yield and lower PHFD rates. Approximately half of the cultivars had PHFD rates that were less than 5% of the potential yield. These results are based on 1 year of data. Because of the limited information available about the North American cultivars for this novel fruit crop, harvest timing may not have coincided with optimal harvest indices for the cultivars in our trial, resulting in higher PHFD than may be expected if fruit are harvested at different harvest indices. Currently, the simplest route to reduce PHFD yield loss in these cultivars is harvesting earlier—most likely before the target SSC level in this trial, which was ≈14% SSC. It is necessary to develop additional simple harvest indices and cultivar-specific harvest management guidelines for haskap, which could prove challenging because of the plethora of cultivars available and the varied locations and environments with which haskap production may be compatible. We present our preliminary PHFD results and SSC at harvest to contribute to these efforts, which may be best performed in a region-specific manner.

Using 1-NAA and AVG in an attempt to prevent PHFD for cultivars Kawai and Taka did not result in a statistically significant effect on PHFD rates, but we share the results as those of a pilot study with the intent that they may be useful to any future PGR research to mitigate PHFD.

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