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Fruit Development in Blackberry Types and Cultivars – Impact of Days and Temperature from Bloom to Stages of Ripening

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Abstract

The number of growing degree days (GDD) may be correlated with fruiting season but this has not been well documented in blackberry (*Rubus* L. subgenus *Rubus*, Watson). Twelve trailing ('Black Diamond', 'Black Pearl', 'Boysen', 'Everthornless', 'Kotata', 'Logan', 'Marion', 'Metolius', 'Nightfall', 'Obsidian', 'Silvan', 'Siskiyou'), two erect ('Navaho', 'Ouachita'), and two semierect ('Chester Thornless', 'Triple Crown') cultivars were studied. Year 1 was warmer than year 2, with higher overall GDD starting in June. At early-, mid-, and late-bloom, 10 flowers of each cultivar were selected randomly from an inflorescence, tagged and the stage of development recorded twice per week (bloom, first red, fully red, first black, glossy black, and dull black). The number of days and GDD (using daily minimum and maximum temperatures, base 10 °C, max. 30 °C, "standard model", from an on-site weather station) from bloom to ripening stage and GDD from 1 Jan. to bloom were recorded. Year, cultivar, flowering season, and their interactions were significant for GDD from 1 Jan. to bloom for all blackberry types, indicating the standard model could not predict bloom date. The GDD formula was modified to base 5 °C and max. 25 °C (trailing) or 35 °C (erect and semierect) with little to no improvement in prediction of bloom to any stage of development. Year, cultivar, and flowering season (with interactions) also affected days from open flower to developmental stage [e.g. from bloom to glossy black: 42–62 days (trailing), 55–65 days (erect), and 58–67 days (semierect); and averaging 3–5 additional days to reach dull black]. Using the standard or modified GDD models, we were not able to consistently predict bloom date or time from bloom to fruit ripening stages.

Oregon is among the top blackberry (*Rubus* L. subgenus *Rubus*, Watson) producing states in the United States, with over 18 million kg of fruit harvested from 2,550 ha in 2017 (USDA NASS 2018). There are three types of floricane-fruiting blackberries grown for the fresh and processed markets: trailing, which are predominantly machine harvested for processing in early summer, and erect and semierect blackberries, which are mostly hand-picked for fresh markets in mid- to late-summer, but can be machine harvested as well (Strik and Finn, 2012). Floricane-fruiting blackberries produce flowers and fruit in the second year of cane growth, after which the floricane senesces and the primocane (the first year cane) is trained onto the trellis.

The ability to predict bloom date, various stages of fruit development, and harvest date, is a useful tool for growers and packers who need to plan for labor, maintenance tasks, crop harvest, and markets/volumes. Currently there is not a simple, consistent way to relate blackberry development to a particular number of days or environmental conditions for most of the blackberry types grown in the Pacific Northwest. In many agricultural crops, models have been developed based on the idea that heat accumulation over the growing season promotes plant growth and phenology. These models take into account the maximum and minimum daily temperatures, and use species-specific thresholds for which plant development occurs, with the result called a growing degree-day model (GDD;

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Baskerville and Emin, 1969). Cumulative GDD can be calculated using many different methods, including the simple average air temperature from 1 Jan., which is calculated by many weather stations to provide GDD information to users, as well as more complex methods that use the same daily maximum and minimum temperatures with more complex mathematical equations and variations in start date (Wilson and Barnett, 1983). Some researchers have used growing degree-hours (GDH) as a more accurate way to model plant phenology due to the ability to measure temperature fluctuation throughout the day and the use of hourly rather than daily maximum and minimum temperatures (Black et al., 2008; Day et al., 2008).

While there have been some studies that have attempted to equate GDD accumulation to blackberry development, a clear relationship has not been established in the cultivars grown in the Pacific Northwest. Jennings (1979) found no relationship between GDD from 1 Jan. and bloom time in several blackberry cultivars with European (e.g., 'Himalaya Giant'), eastern North American (e.g., 'Darrow'), and western North American (e.g., 'Chehalem') origin, grown in Scotland, but accumulated heat units and days required from flowering to ripening differed by cultivar. They also found that the variation in ripening time in blackberry could be partially attributed to when the flowers opened. In Oregon, flowering can occur over a two-week period within each blackberry cultivar, while the harvest season is three- to five-weeks long, depending on type (Finn and Strik, 2014; Strik and Vance, 2017).

An important consideration when using GDD to model phenology is the upper and lower temperature threshold at which plant development occurs, however, few studies have investigated this in blackberry. Black et al. (2008), using a combination of field and growth chamber studies, found that a linear GDH model using a base temperature of 6 °C and an optimum temperature of 25 °C best predicted bloom date for 117 *Rubus* genotypes grown over four seasons in the field, but was not accurate for predicting harvest date. They suggested that light and photosynthesis may need to be included as additional variables to improve the model. Jennings (1979) used a base of 6 °C in studying the ripening time of semierect ('Ashton Cross', 'Himalaya Giant', 'Bedford Giant', 'Darrow', 'Thornfree', 'Black Satin', 'Dirksen's Thornless') and trailing ('Chehalem') blackberry cultivars in Scotland, but no explanation was provided for selecting this temperature. In raspberry (*Rubus idaeus* L.), Hoover et al. (1989) used a base temperature of 5 °C and no upper threshold, while 5 °C and 29 °C were used as lower and upper thresholds, respectively, in cranberry (*Vaccinium macrocarpon* Ait.; Chasen and Steffan, 2017). The general standard for GDD calculation used by the U.S. Department of Interior AgriMet weather stations is based on the corn (*Zea mays* L.) model, that uses a base of 10 °C and an upper threshold of 30 °C (Integrated Plant Protection Center, 2018; U.S. Department of Interior, 2016).

The objectives of this study were to determine if any relationship exists between GDD and stages of fruit development for 16 blackberry cultivars, and whether that relationship varies, within cultivar, for fruit developing from early-, mid-, and late-season flowers. In addition, GDD models using different temperature thresholds were explored to try to create a more accurate model for blackberry in Oregon.

Materials and Methods

Study site. The study was conducted in 2009 and 2010 in a mature planting at Oregon State University's North Willamette Research and Extension Center, Aurora, OR [lat. 45°16′47″N, long. 122°45′23 ″W; USDA Plant Hardiness Zone 8b (U.S. Department of Agriculture, Agricultural Research Service, 2012); the weather records for this site can be viewed at U.S. Department of Interior (2017)]. The soil is mapped as a Willamette silt loam, classified as a fine-silty, mixed, superactive, mesic Pachic Ultic Argixeroll. A permanent grass cover crop grew between the rows. The in-row area was maintained (bare soil) with preemergence herbicides and hoeing, as needed. Plants were spaced 1.5 m apart within rows and 3 m between rows, and were irrigated with a single line of drip tubing (UniRam; Netafim USA, Fresno, CA) containing pressure compensating emitters (1.9 $L \cdot h^{-1}$ in-line) spaced every 0.6 m.

Cultivars. Twelve trailing blackberry cultivars (Black Diamond, Black Pearl, Boysen, Everthornless, Kotata, Logan, Marion, Metolius, Nightfall, Obsidian, Silvan, and Siskiyou), two erect cultivars (Navaho and Ouachita) and two semierect cultivars (Chester Thornless and Triple Crown) were studied (Finn and Strik, 2014).

Data collection. A total of ten flowers (five on the west side and five on the east side of North-South oriented rows) were selected from three contiguous plants and tagged at early-, mid, and late bloom, which occurred approximately one week apart within each cultivar, for a total of 30 flowers tagged per cultivar. At early-bloom, the flowers selected were typically the primary flower at the distal ends of the fruiting laterals while at mid- and late-bloom, the flowers were selected at random from primary, secondary, and tertiary flowers from more proximal regions along the fruiting lateral. The stage of development for each fruit was recorded twice per week. Significant developmental stages used in this study were bloom (open flower), first red (portion of berry red), full red (entire berry red), first black (portion of berry black), glossy black (considered ripe for hand picking), and dull black (considered ripe for machine harvest). In 2009, no ‘Silvan’ flowers were tagged at the early-bloom stage, in error, and in 2010, no data for ‘Logan’ were available because plants were removed.

GDD temperature thresholds. The standard model used by the on-site AgriMet weather station (U.S. Department of Interior, 2017) calculates GDD using the average of the daily maximum (at or below the 30 °C threshold) and minimum (base temperature of 10 °C) temperatures, minus the base temperature of 10 °C (the simple average degree-days method, U.S. Department of Interior, 2016). To determine if modified thresholds would be more appropriate for these blackberry types, GDD was also calculated using a base of either 5 °C or 10 °C and maximum of 25 °C for trailing cultivars (which ripen earlier in the season when temperatures are generally cooler) and a base of either 5 °C or 10 °C and maximum of 35 °C for erect and semierect cultivars (which ripen during the hotter portion of the summer) (Finn and Strik, 2014; Strik and Vance, 2017). Hourly temperature data were not available so GDH could not be calculated.

Data analysis. Each tagged flower served as a replicate. Trailing, erect, and semierect blackberry types were analyzed separately due to their wide range in flowering dates. In addition, because ‘Everthornless’ had a widely different flowering and ripening season than the other trailing cultivars due to its unique genetic background (McPheeters and Skirvin, 2000), the trailing cultivars were analyzed without ‘Everthornless’. No improvements in the model were seen so all data presented include ‘Everthornless’ with the other trailing cultivars. Data were analyzed using PROC MIXED (SAS version 9.4, Cary, NC) as a split-split plot with effects of year as the main plot, cultivar as the subplot, and bloom season (early-, mid-, or late-) as the sub-sub plot. Mean separations were performed with the DIFF option in the LSMeans statement. Treatment effects on time between stages (days) and GDD from 1 Jan. to open flower (bloom) and each ripening stage, as well as from bloom to each ripening stage were analyzed for each set of GDD thresholds.

Results and Discussion

Weather. Overall, 2009 was a warmer year than 2010 (Fig. 1). However, in 2010 the spring was warmer than in 2009 until early June when growing degree accumulation in

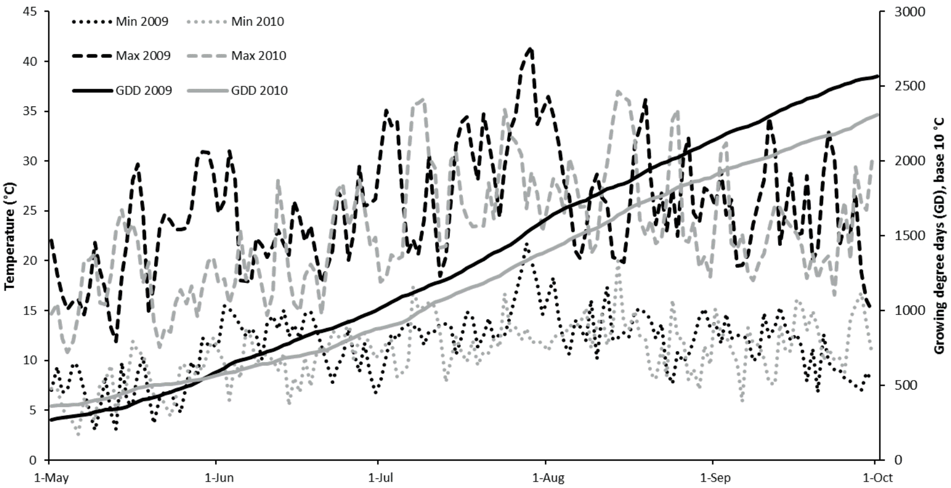

Fig. 1. Minimum and maximum daily temperature and growing degree days (GDD; base 10 °C, maximum 30 °C) for the 2009 and 2010 growing seasons at Oregon State University's North Willamette Research and Extension Center (Aurora, OR).

2009 surpassed 2010 and remained higher the rest of the year.

Temperature thresholds. Lowering the upper temperature threshold from 30 °C to 25 °C and the lower temperature threshold from 10 °C to 5 °C (and combinations of each upper and lower threshold) did not change the significance or outcome of the tested models, indicating that those temperatures were not any more or less appropriate for trailing blackberry cultivars (data not shown). Similarly, increasing the upper threshold to 35 °C and lowering the base temperature to 5 °C for erect and semierect cultivars did not improve tested models. As the same results were achieved using these different temperature thresholds as with the original GDD model (base 10 °C and upper threshold of 30 °C) readily available and accessible to growers (U.S. Department of Interior, 2016), this original model was used for the analysis presented herein.

Typically, temperature thresholds at which key developmental stages occur (such as bud break or bloom), are established using controlled temperature studies, such as in blueberry (*Vaccinium corymbosum* L.; Kirk and Isaacs, 2012) and blackberry (Black et al., 2008), rather than through observational studies, or with larger data sets consisting of many years of data (Ruml et al., 2010). Further physiological studies that are beyond the scope of this study would need to be performed to fully understand the upper and lower growth and developmental temperature thresholds for these blackberry cultivars.

Growing degree days. The number of GDD from 1 Jan. and open flower to various stages of fruit development in trailing blackberry cultivars were significantly affected by year, cultivar, bloom season, and the interactions between each factor, except for bloom to glossy black and bloom to dull black, for which there was no significant three-way interaction (Table 1). Winter and spring temperatures can be quite variable in the period prior to bud break (typically in March for these cultivars), which may explain in part why there is an effect of year on GDD from 1 Jan. to each stage. For this reason, we focused more on the relationship between bloom and ripening stages here.

Table 1. Analyses of variance for growing degree-days (GDD, base 10 °C, maximum 30 °C) from 1 Jan. and bloom (open flower) to subsequent fruit developmental stages in trailing blackberry cultivars grown at Oregon State University's North Willamette Research and Extension Center (Aurora, OR) in 2009 and 2010.

	Growing degree days from 1 Jan.						Growing degree days from Bloom				
	Bloom	First red	Fully red	First black	Glossy black	Dull black	First red	Fully red	First black	Glossy black	Dull black
Year											
2009	559 a[z]	988 a	1123 a	1171 a	1226 a	1297 a	435 a	570 a	618 a	677 a	747 a
2010	525 b	928 b	995 b	1053 b	1102 b	1166 b	400 b	467 b	525 b	575 b	639 b
Cultivar											
Black Diamond	504 e	910 c	1007 de	1052 de	1105 de	1166 d	405 cd	502 cd	547 cd	600 cd	661 d
Black Pearl	556 b	922 c	1027 c	1093 c	1145 c	1208 c	369 e	474 e	539 cd	591 cd	653 d
Boysen	505 d	947 b	1013 cd	1066 d	1124 cd	1197 c	441 b	508 c	561 c	619 c	691 c
Everthornless	915 a	1595 a	1777 a	1870 a	1969 a	2036 a	683 a	866 a	958 a	1060 a	1127 a
Kotata	504 e	926 c	1058 b	1116 b	1179 b	1252 b	422 c	555 b	614 b	677 b	750 b
Logan	523 -	1059 -	1107 -	1147 -	1184 -	1240 -	532 -	580 -	621 -	657 -	713 -
Marion	504 e	842 d	982 e	1037 e	1084 e	1146 d	338 f	478 de	533 d	580 d	642 d
Metolius	504 de	844 d	912 fg	945 f	989 f	1052 e	344 ef	413 fg	446 e	490 e	554 e
Nightfall	512 c	910 c	1016 cd	1062 d	1128 cd	1215 c	398 d	505 c	550 cd	616 c	703 c
Obsidian	504 e	868 d	956 fg	992 f	1034 f	1088 e	362 ef	449 f	485 e	527 e	581 e
Silvan	453 -	883 -	980 -	1038 -	1102 -	1168 -	432 -	530 -	587 -	652 -	718 -
Siskiyou	503 e	851 d	921 g	958 f	1009 f	1076 e	348 ef	417 g	454 e	506 e	572 e
Season[y]											
Early-	469 c	860 c	939 c	988 c	1030 c	1087 c	394 c	473 c	523 c	568 c	625 c
Mid-	541 b	964 b	1069 b	1123 b	1184 b	1253 b	420 a	525 b	579 b	640 b	708 b
Late-	614 a	1053 a	1179 a	1234 a	1291 a	1368 a	441 b	566 a	621 a	682 a	757 a
Significance[x]											
Year (Y)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar (C)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Y x C	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0006	NS	<0.0001	0.0005
Season (S)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Y x S	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0021	<0.0001	<0.0001	<0.0001	<0.0001
C x S	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Y x C x S	<0.0001	<0.0001	<0.0001	<0.0001	0.0122	0.0040	<0.0001	<0.0001	<0.0001	NS	NS

[z] Means followed by the same letter within year, cultivar, or bloom season are not significantly different (LSMeans) (P>0.05). A "-" indicates no mean comparison was possible due to missing data from one year.

[y] Season = bloom or flowering season for the cultivars studied.

[x] P-value provided when $P \leq 0.05$. NS indicates not significant (P>0.05).

On average, more GDD were required from bloom to all stages of ripening in 2009 than in 2010 and (Table 1). Early-season flowers required the fewest GDD from open flower to ripening stages and late-season flowers the most, on average. 'Everthornless' required the most GDD to reach all developmental stages, while 'Metolius', 'Obsidian', and 'Siskiyou' required the fewest, particularly for bloom to glossy and dull black stages. While there were more GDD attained from bloom to earlier stages of ripening (red and first black stages) in 2009 than in 2010, there were smaller differences between years found in 'Black Pearl', 'Metolius', and 'Siskiyou' than in the other cultivars (data not shown). In several cultivars (Black Pearl, Metolius, Obsidian, Silvan, and Siskiyou), more GDD accumulated between bloom and red and first black stages for late-season flowers. In the other cultivars (Boysen, Kotata, Marion, and Nightfall), that pattern was seen in 2009 but not 2010. 'Everthornless' showed similarities between early- and late-bloom season in 2009, while all bloom seasons had similar GDD accumulation at early ripening stages in 2010 (data not shown).

The GDD from bloom to glossy black and dull black stages in trailing cultivars were affected by year x season and cultivar × season interactions (Table 1). In 2009, the GDD from bloom to glossy and dull black stages differed by bloom season, while in 2010 only early-season flowers required fewer GDD to each stage (Fig. 2). The impact of flowering season on GDD from bloom to glossy and dull black depended on cultivar (Fig. 3). In general, late-season flowers within a cultivar accumulated more GDD to ripening than early-season flowers.

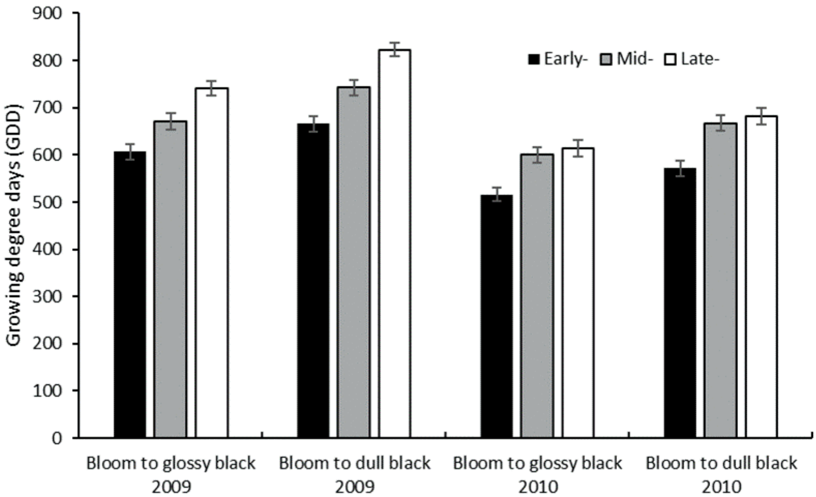

Fig. 2. Number of growing degree days (GDD; base 10 °C, maximum 30 °C) from bloom (open flower) to glossy black and dull black fruit ripeness stages in early-, mid-, and late-season flowers in trailing blackberry cultivars in 2009 and 2010 at Oregon State University's North Willamette Research and Extension Center (Aurora, OR), averaged over cultivar and flowering season. Bars indicate standard error (n=120).

Table 2. Analyses of variance for growing degree-days (GDD, base 10 °C, maximum 30 °C) from 1 Jan. and bloom (open flower) to subsequent fruit developmental stages in erect blackberry cultivars grown at Oregon State University's North Willamette Research and Extension Center (Aurora, OR) in 2009 and 2010.

	Growing degree days from 1 Jan.						Growing degree days from Bloom				
	Bloom	First red	Fully red	First black	Glossy black	Dull black	First red	Fully red	First black	Glossy black	Dull black
Year											
2009	671 a[z]	1138 b	1437 a	1513	1594	1686 a	464	763	839	917	1009
2010	627 b	1257 a	1416 b	1518	1574	1663 b	626	785	887	941	1028
Cultivar											
Navaho	690 a	1233 a	1476 a	1592 a	1677 a	1773 a	535	777	894 a	975 a	1066 a
Ouachita	608 b	1160 b	1375 b	1434 b	1485 b	1573 b	557	771	831 b	881 b	969 b
Season[y]											
Early-	532 c	1061 c	1226 c	1310 c	1372 c	1454 c	531 b	695 c	780 c	841 c	925 c
Mid-	645 b	1152 b	1395 b	1497 b	1569 b	1662 b	504 b	747 b	849 b	922 b	1014 b
Late-	770 a	1372 a	1649 a	1737 a	1797 a	1889 a	598 a	875 a	960 a	1020 a	1108 a
Significance[x]											
Year (Y)	<0.0001	<0.0001	NS	NS	NS	0.0395	<0.0001	NS	NS	NS	NS
Cultivar (C)	<0.0001	0.0035	0.0024	<0.0001	<0.0001	<0.0001	NS	NS	0.0202	0.0002	0.0003
Y x C	<0.0001	0.0477	NS	0.0030	0.0196	0.0038	NS	NS	0.033	NS	NS
Season (S)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Y x S	<0.0001	0.0093	0.0001	0.0251	0.0148	0.0215	0.0004	NS	NS	NS	NS
C x S	<0.0001	0.0012	<0.0001	<0.0001	<0.0001	<0.0001	NS	0.0196	0.0002	<0.0001	<0.0001
Y x C x S	<0.0001	0.0035	0.0192	NS	NS	0.017	NS	NS	NS	NS	NS

[z]Means followed by the same letter within year, cultivar, or bloom season are not significantly different (LSMeans) (P>0.05).
[y]Season = bloom or flowering season for the cultivars studied.
[x]P-value provided when $P \leq 0.05$. NS indicates not significant (P>0.05).

Mid-season flowers within a cultivar were inconsistent as some had a similar GDD to late-bloom (e.g., 'Black Diamond' and 'Kotata'), some needed more GDD to late-bloom (e.g., 'Boysen'), and some needed less than both early- or late-season flowers (e.g., 'Everthornless'). Overall, no general conclusions could be made for trailing cultivars on GDD accumulation due to the influences of year and bloom season even within a given cultivar.

In the two erect cultivars compared to the trailing cultivars, there were fewer impacts of year, cultivar, and flowering season for GDD from bloom to developmental stages than there were for the period from 1 Jan. to each stage (Table 2). More GDD were required for 1 Jan. to bloom and dull black in 2009 than in 2010, but the opposite was found for the first red stage. In 2010, more GDD were required for bloom to first red stage, but no differences were apparent between years for the other stages. Early-season flowers required the fewest GDD from 1 Jan. to all stages and from bloom to all ripening stages except first red, on average. For the relevant

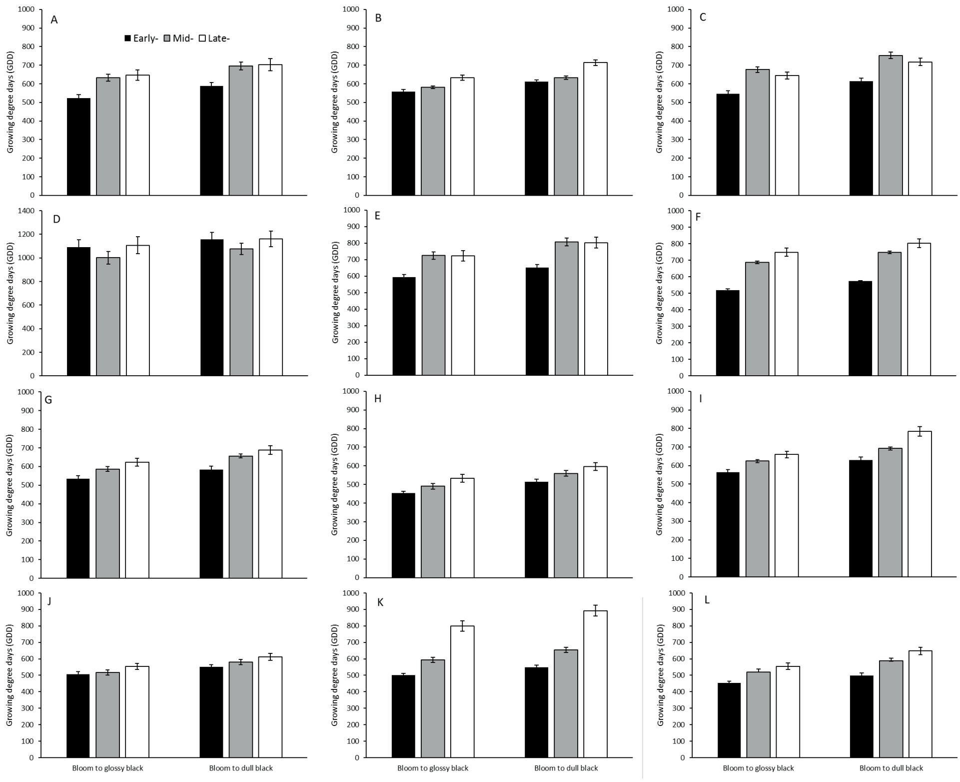

Fig. 3. Number of growing degree days (GDD; base 10 °C, maximum 30 °C) from bloom (open flower) to glossy black and dull black fruit ripeness stages in early-, mid-, and late-season flowers in trailing blackberry cultivars [A) Black Diamond, B) Black Pearl, C) Boysen, D) Everthornless (note different y-axis scale), E) Kotata, F) Logan, G) Marion, H) Metolius, I) Nightfall, J) Obsidian, K) Silvan, L) Siskiyou] at Oregon State University's North Willamette Research and Extension Center (Aurora, OR), averaged over 2009-2010. Bars indicate standard error (n=20). No data were available for 'Logan' in 2010 or for early-season flowers of 'Silvan' in 2009.

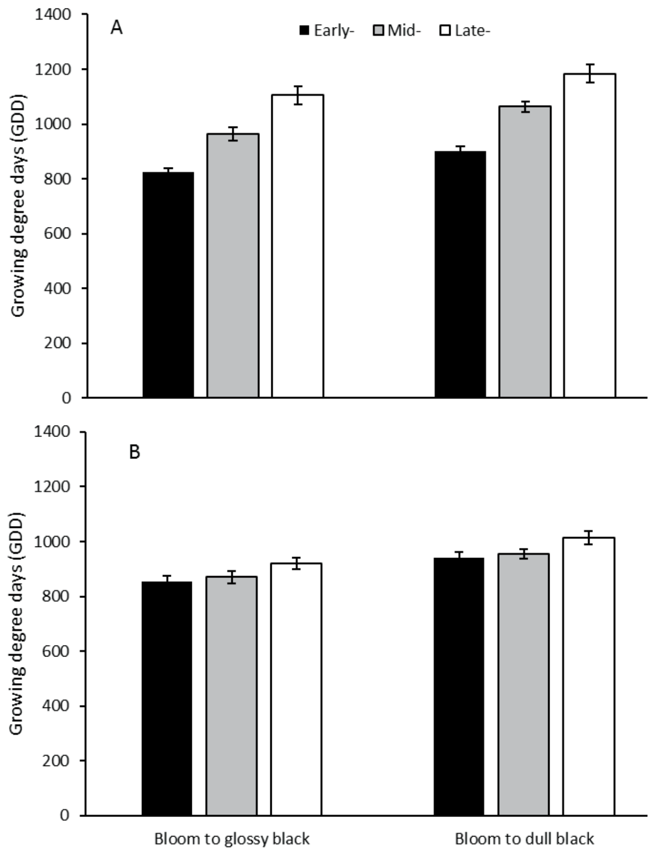

Fig. 4. Number of growing degree days (GDD; base 10 °C, maximum 30 °C) from bloom (open flower) to glossy black and dull black fruit ripeness stages in early-, mid-, and late-season flowers in erect blackberry cultivars Navaho (A) and Ouachita (B) at Oregon State University's North Willamette Research and Extension Center (Aurora, OR), averaged over 2009-2010. Bars indicate standard error (n=20).

stages of berry harvest, there were cultivar by season interactions on the GDD from bloom to glossy black or dull black stages. There was a larger impact of flowering season in 'Navaho' than in its offspring 'Ouachita' (Fig. 4). Early- to late-season flowers of 'Ouachita' required similar GDD to stages of ripeness as early-season 'Navaho' flowers. These erect cultivars required approximately 80–100 additional GDD to reach dull black stage after the glossy black stage.

In the semierect cultivars Chester Thornless and Triple Crown, there was a year by flowering season effect and a main effect of cultivar on GDD from bloom to all or all but first red stage of development, respectively (Table 3). 'Chester Thornless' required more GDD from open flower to fully red through dull black stages of fruit development than 'Triple Crown'. On average, early-season flowers required the fewest GDD from bloom to ripening stages and late-season flowers the most. For both cultivars, the GDD from bloom to glossy or dull black harvest stage was lower in 2009 than in 2010 only for mid-season flowers, whereas early- and late-season flowers required fewer GDD in 2010 (Fig. 5).

Table 3. Analysis of variance for growing degree-days (GDD, base 10 °C, maximum 30 °C) from 1 Jan. and bloom (open flower) to subsequent fruit developmental stages in semierect blackberry cultivars grown at Oregon State University's North Willamette Research and Extension Center (Aurora, OR) in 2009 and 2010.

	Growing degree days from 1 Jan.						Growing degree days from Bloom				
	Bloom	First red	Fully red	First black	Glossy black	Dull black	First Red	Fully red	First black	Glossy black	Dull black
Year											
2009	722 b[z]	1189 b	1627	1686 b	1733	1800	465 b	902 a	961	1012	1079
2010	768 a	1462 a	1616	1720 a	1767	1834	696 a	852 b	956	1001	1068
Cultivar											
Chester Thornless	754 a	1334 a	1685 a	1768 a	1805 a	1876 a	582	936 a	1020 a	1061 a	1132 a
Triple Crown	736 b	1324 b	1554 b	1635 b	1695 b	1758 b	585	814 b	894 b	951 b	1013 b
Season[y]											
Early-	603 c	1073 c	1321 c	1435 c	1478 c	1559 c	469 c	717 c	831 c	873 c	954 c
Mid-	730 b	1308 b	1611 b	1681 b	1747 b	1812 b	574 b	874 b	945 b	1010 b	1076 b
Late-	902 a	1613 a	1949 a	2008 a	2043 a	2097 a	712 a	1047 a	1107 a	1143 a	1197 a
Significance[x]											
Year (Y)	<0.0001	<0.0001	NS	0.0479	NS	NS	<0.0001	0.0300	NS	NS	NS
Cultivar (C)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS	<0.0001	<0.0001	<0.0001	<0.0001
Y x C	<0.0001	<0.0001	NS	NS	NS	NS	0.0053	NS	NS	NS	NS
Season (S)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Y x S	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0006	0.0032	0.0377	0.0203
C x S	<0.0001	<0.0001	0.0433	NS	NS	NS	0.0383	0.0284	NS	NS	NS
Y x C x S	<0.0001	<0.0001	0.0207	0.0129	NS	NS	NS	0.0132	0.0085	NS	NS

[z] Means followed by the same letter within year, cultivar, or bloom season are not significantly different (LSMeans) (P>0.05).
[y] Season = bloom or flowering season for the cultivars studied.
[x] P-value provided when P≤0.05. NS indicates not significant (P>0.05).

In general, the trailing blackberry cultivars required fewer GDD from 1 Jan. to bloom and from bloom to each fruit developmental stage than the erect and semierect blackberry cultivars, with the exception of 'Everthornless', which flowers and ripens much later than the other trailing cultivars (Tables 1-3). As these types and cultivars have genetically distinct backgrounds, it may be necessary to develop cultivar-

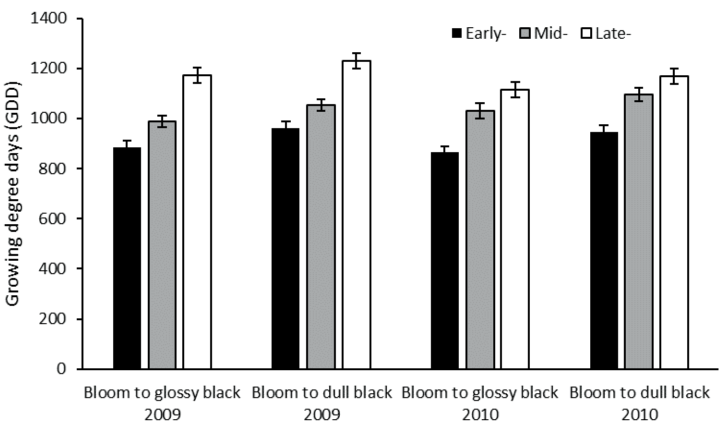

Fig. 5. Number of growing degree days (GDD; base 10 °C, maximum 30 °C) from bloom (open flower) to glossy black and dull black fruit ripeness stages in early-, mid-, and late-season flowers in 2009-2010, in semierect blackberry at Oregon State University's North Willamette Research and Extension Center (Aurora, OR), averaged over cultivar. Bars indicate standard error (n=20).

specific models for GDD that accurately predict harvest date as was done in blueberry (Carlson and Hancock, 1991), using different temperature thresholds and dates at which GDD accumulation begins based on historical data. Other researchers have found that the use of standard GDD models was not a reliable predictor for bloom date in blackberry, though both GDD and the number of days from bloom to ripening are more accurate (Black et al., 2008; Jennings, 1979).

Days to harvest. Since few relationships existed between GDD and developmental stages that were consistent across years, cultivars, or flowering season, the number of days from bloom to harvest was explored as well. In Oregon, the majority of trailing blackberries are grown for the processed market and are mechanically harvested at the dull black stage, therefore only this stage is presented. As with GDD, there were significant year, cultivar, flowering season, and interaction effects on days from bloom to dull black stage (Table 4). It took between 40 and 81 d from bloom to dull black stage, depending on cultivar, flowering season

Table 4. Analysis of variance for number of days from bloom (open flower) of early-, mid-, and late-season flowers, to dull black fruit stage in trailing blackberry cultivars grown at Oregon State University's North Willamette Research and Extension Center (Aurora, OR) in 2009 and 2010.

	Number of days from bloom to dull black					
Year						
2009			49			
2010			56			
		2009			2010	
Cultivar	Early-	Mid-	Late-	Early-	Mid-	Late-
Black Diamond	45 klmno[z]	49 fghijk	52 def	54 hijklm	58 efghi	50 mno
Black Pearl	43 mnop	44 lmnop	49 fghijkl	56 fghijk	48 no	49 no
Boysen	46 ijklmn	51 efghi	51 efgh	55 ghijkl	64 bcd	56 ghijkl
Everthornless	76 a	63 b	81 a	63 cde	62 cde	65 abc
Kotata	49 fghijkl	53 def	57 cd	57 fghi	68 ab	58 efghi
Logan	40 op	49 fghijk	51 efg		NA	
Marion	45 klmnop	46 jklmn	50 fghij	54 hijklm	58 efgh	52 jklmno
Metolius	40 p	41 nop	44 klmnop	50 mno	52 klmno	48 no
Nightfall	47 ghijklm	48 ghijkl	55 cde	56 fghij	61 cdef	57 efghi
Obsidian	40 op	42 mnop	44 lmnop	51 ijklmno	52 jklmno	50 mno
Silvan	NA[y]	47 ghijklm	58 c	60 defg	59 defg	70 a
Siskiyou	40 hijklmnop	42 mnop	46 ijklmn	48 o	53 hijklmn	50 lmno
Season[x]						
Early-		46 e			55 b	
Mid-		48 d			58 a	
Late-		53 c			55 b	
Significance[w]						
Year			<0.0001			
Cultivar			<0.0001			
Year x Cultivar			<0.0001			
Season			<0.0001			
Year x Season			<0.0001			
Cultivar x Season			<0.0001			
Year x Cultivar x Season			0.0031			

[z] Means followed by the same letter within year, cultivar, or bloom season or the interaction between year, bloom season, and cultivar are not significantly different (LSMeans) (P>0.05).
[y] NA indicates the data is not available.
[x] Season = bloom or flowering season for the cultivars studied.
[w] P-value provided when $P \leq 0.05$. NS indicates not significant (P>0.05).

and year. Generally, the development from bloom to dull black was faster (fewer days) in 2009 than in 2010, but the impacts of flowering season differed between years. For example, 'Black Diamond', 'Marion', 'Metolius', 'Nightfall', 'Obsidian', and 'Siskiyou' all had increasing numbers of days from bloom to dull black from early- to late-opening flowers in 2009 but fewer days for late-opening flowers compared to mid-season flowers in 2010. In 2009, late-season flowers took about one week longer to reach dull black stage than early flowers, while in 2010 the mid-season flowers took the longest to reach this stage and early and late flowers took the same number of days. 'Everthornless' had the longest period from bloom to dull black, particularly in early- and late-season flowers.

Erect and semierect blackberries are predominantly hand-harvested for fresh market starting at the glossy black stage, but may also be harvested as late as the dull black stage. In erect cultivars, we found a significant year × cultivar × flowering season interaction on the days from bloom to glossy and dull black stages (Table 5). In 2009, 'Ouachita' and 'Navaho' required a similar number of days from bloom to glossy black, with relatively small differences between early-, mid-, and late-opening flowers. In 2010, early 'Ouachita' flowers required 6 to 7 more days to reach glossy black stage than mid- and late-season flowers and the opposite was seen in 'Navaho', where late flowers required 9 to 11 additional days to reach glossy black. Similar trends were seen for the number of days from bloom to dull black. Across both cultivars and all flowering seasons, 10 more days were required to ripen fruit in 2010 compared to 2009. A preliminary study in North Carolina by Shires and Fernandez (personal comm.) suggested that 'Ouachita' and 'Navaho' required approximately 51 d from bloom to harvest, which is shorter than the ripening season in Oregon, likely due to the warmer temperatures in that growing region. Similarly, these cultivars bloomed

Table 5. Analysis of variance for number of days from bloom (open flower) of early-, mid-, and late-season flowers, to glossy and dull black stage for erect blackberry cultivars grown at Oregon State University's North Willamette Research and Extension Center (Aurora, OR) in 2009 and 2010.

	Number of days from bloom to glossy black				Number of days from bloom to dull black			
Year								
2009	55 b[z]				60 b			
2010	65 a				70 a			
	2009		2010		2009		2010	
Season[y]	*Ouachita*	*Navaho*	*Ouachita*	*Navaho*	*Ouachita*	*Navaho*	*Ouachita*	*Navaho*
Early-	53 f	53 f	68 ab	61 cde	58 f	57 f	73 ab	65 cde
Mid-	55 def	57 cdef	62 bc	63 bc	60 def	62 def	66 cd	69 bc
Late-	54 ef	58 cdef	61 cd	72 a	59 ef	63 de	66 cd	77 a
Significance[x]								
Year	<0.0001				<0.0001			
Cultivar	NS				NS			
Year x Cultivar	NS				NS			
Season	NS				NS			
Year x Season	NS				NS			
Cultivar x Season	0.0009				0.0006			
Year x Cultivar x Season	0.0378				0.0463			

[z] Means followed by the same letter within year, cultivar, or bloom season or the interaction between year, cultivar, and bloom season are not significantly different (LSMeans) (P>0.05).
[y] Season = bloom or flowering season for the cultivars studied.
[x] P-value provided when P≤0.05. NS indicates not significant (P>0.05).

Table 6. Analysis of variance for number of days from bloom (open flower) of early-, mid-, and late-season flowers, to glossy and dull black stage for semierect blackberry cultivars grown at Oregon State University's North Willamette Research and Extension Center (Aurora, OR) in 2009 and 2010.

	Number of days	
Year	Bloom to glossy black	Bloom to dull black
2009	61 b[z]	64 b
2010	63 a	68 a
Cultivar		
Triple Crown	59 b	63 b
Chester Thornless	65 a	69 a
Season[y]		
Early-	58 c	62 c
Mid-	61 b	65 b
Late-	67 a	71 a
Significance[x]		
Year	0.0106	0.0014
Cultivar	<0.0001	<0.0001
Year x cultivar	NS	NS
Season	<0.0001	<0.0001
Year x Season	NS	NS
Cultivar x Season	NS	NS
Year x Cultivar x Season	NS	NS

[z] Means followed by the same letter within year, cultivar, or bloom season are not significantly different (LSMeans) (P>0.05).
[y] Season = bloom or flowering season for the cultivars studied.
[x] P-value provided when P≤0.05. NS indicates not significant (P>0.05).

earlier and ripened faster when grown in Arkansas (Clark, 2013; Clark and Moore, 2005), but GDD were not included in their studies.

The days from bloom to stages of ripeness in the semierect blackberry cultivars were affected by year, cultivar, and flowering season (Table 6). As with trailing and erect blackberries, more days were required to reach glossy and dull black stage in 2010 than in 2009, but the pattern of requiring more days to ripen berries from later season flowers was consistent in both years. 'Triple Crown' took fewer days from bloom to glossy and dull black than 'Chester Thornless', and ripened earlier in the season (as demonstrated by fewer GDD from 1 Jan. to those stages, Table 3).

Summary

Few consistent relationships were found between GDD and number of days from 1 Jan. or bloom to various fruit developmental stages of trailing, erect, or semierect blackberry cultivars. A better understanding of the physiological temperature thresholds at which development occurs in each type and cultivar may increase the reliability of GDD in predicting development. The impact of year, flowering time, and diverse genetic backgrounds makes it difficult to predict bloom or harvest times in these crops with confidence.

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