Journal of the American Pomological Society 71(3): 183-191 2017

Adaptability of Blackberry Cultivars to a High-Elevation Arid Climate

Brent Black[1,2], Thor Lindstorm[2], Tiffany Maughan[2], Britney Hunter[3] and Shawn Olsen[3]

Additional index words: Rubus, yield reliability

Abstract

Winter-hardy, high-yielding cultivars with good consumer acceptance and few production problems are critical to the economic viability of growing blackberries for local consumption in high elevation arid climates. A replicated experiment was planted in 2006 to evaluate 19 cultivars and 2 numbered selections of blackberry for suitability to commercial production in the US Intermountain West. Factors evaluated included winter survival, yield, and fruit size. Winter bud survival varied among cultivars and over seasons. Semi-erect and erect cultivars averaged the highest winter bud survival and trailing cultivars consistently had the poorest winter bud survival. Per plant yields were higher when bud survival was greater, with trailing types producing the lowest average yields and semi-erect types the highest. Production from primocane-fruiting types was slowed by cold temperatures before full production was reached and consequently, yields were lower. The cultivar Triple Crown had the most consistently high overall yield (highest yield reliability index) and was among the cultivars with the largest berry size. 'Illini Hardy' had the highest yield reliability index among erect types. In general, semi-erect types had the highest and most consistent yields for the U.S. Intermountain West.

Historically, the high elevation valleys of the U.S. Intermountain West have not had significant blackberry production, likely due to harsh winters and frequent late spring freezes that result in significant blackberry cane damage and crop loss. However, local production would be advantageous as the delicate berries have a short shelf life that makes shipping to distant markets difficult. Small-acreage farmers are interested in blackberry as a high-value diversification opportunity, but need cultivars adapted to the regional climate and markets.

Winter cane dieback and winter bud damage are major limitations to floricane-fruiting blackberry production in the U.S. Intermountain West region. A typical low temperature limit for blackberries is -18 °C (Dana and Goulart, 1989). However, winter hardiness varies among growth type and cultivar. In a freezing survival study on 8 erect blackberry types, Warmund and George (1990) found that the T_{50} of primary buds was between -11.9 °C and -19 °C, with the exception of one cultivar, Darrow, which survived below -25 °C. Erect blackberries are generally considered to be more hardy than trailing types, and thorny blackberries more hardy than thornless (Crandall, 1995). Cane survival can also be negatively influenced by desiccating winds (Crandall, 1995) which can be a serious problem in the arid U.S. Intermountain West.

In areas with a sufficiently long freeze-free period, primocane-bearing cultivars may be a good option as the overwintering of floricanes is not necessary. However, in the Northern locations where the primocane-fruiting cultivars Prime-Jan and Prime-Jim were first evaluated, the first day that fruit ripened was 1 Sept. (Clark, 2008) leaving only a short window of production before fall freezes.

The objective of this research was to

[1] Corresponding author: brent.black@usu.edu
[2] Department of Plants, Soils and Climate, Utah State University, Logan, UT 84322-4820
[3] Utah State University Cooperative Extension, Davis County, Farmington, UT 84025

evaluate blackberry cultivars for suitability to field production in alkaline soils and high elevation valleys typical of the U.S. Intermountain West. Representative cultivars and advanced selections were included to represent all four blackberry growth types (trailing, semi-erect, erect and primocane-fruiting), with evaluation based on winter survival, yield, fruit size, and fruiting season.

Materials and Methods

Planting. A replicated blackberry cultivar trial was carried out at the Utah State University Agricultural Research Farm in Kaysville, Utah (41.01 N latitude, 1330 m elevation). The average freeze-free season is 165 d, with the average last spring freeze on 5 May and average first fall freeze on 9 Oct. (Moller and Gillies, 2008). The soil is a Kidman fine sandy loam with a pH of 7.5 and 1.5% organic matter. In 2006, blackberry plants of 19 cultivars and 2 numbered selections were obtained from commercial nurseries or from the breeder. Plants were established in 2 replicate plots arranged in a randomized block design with blocking by location within the field and by trellis type. Plants were spaced 1.5 m within the row, and rows were spaced 3 m apart. Each plot consisted of 2 or 3 plants. Cultivars included: six trailing cultivars and two trailing numbered selections, five semi-erect, six erect, and two primocane-fruiting types. Trailing cultivars from the Pacific Northwest included: Newberry (Finn et al., 2010), Siskiyou (Finn et al., 1999), Obsidian (Finn et al., 2005c), Black Diamond (Finn et al., 2005a), Metolius (Finn et al., 2005b), Marion (Moore, 1997), and the numbered selections ORUS 1793-1 and ORUS 1939-4 from the USDA-ARS breeding program at Corvallis, OR.Semi-erect cultivars included selections from Maryland [Hull (Galletta, 1981), Chester Thornless (Galletta et al., 1998a), and Triple Crown (Galletta et al., 1998b)],] Indiana [Doyle's Thornless (Doyle, 1977)] and Scotland [Loch Ness (Moore, 1997)]. Erect cultivars from the University of Arkansas breeding program included [Navaho (Moore and Clark, 1989), Arapaho (Moore and Clark, 1993), Kiowa (Moore and Clark, 1996), Apache (Clark and Moore, 1999), and Ouachita (Clark and Moore, 2005)] and from Illinois, Illini Hardy (Skirvin and Otterbacher, 1993). The primocane-fruiting cultivars from Arkansas included Prime-Jan and Prime-Jim (Clark et al., 2005). Plants of several of the cultivars were not available in time for the 2006 planting, and were planted one year later. Yield data for these were not collected until 2009.

Cultural practices. The space between plots within the row was covered with landscape fabric (5 oz. per yd^2, Dewitt, Sikeston, MI) to suppress weeds. Alleyways were planted in the summer of 2006 to a 1:1 mix of perennial ryegrass (*Lolium perenne* L.) and creeping red fescue (*Festuca rubra* L.) at a seeding rate of 56 $kg \cdot ha^{-1}$. In-row weed control was a combination of annual applications of a pre-emergent herbicide (1.9 to 2.8 $L \cdot ha^{-1}$ Surflan, Southern Agric. Insecticides, Palmetto, FL) and hand weeding. The alleyway grass was mowed at ~ 3-week intervals.

Plant nutrient needs were supplied with applications of 135 $kg \cdot ha^{-1}$ of 16.0N-7.0P-13.2K fertilizer in mid-April and again in early June of each year, banded in the blackberry row. Cane thinning and pruning was according to typical regional practices, where spent floricanes were removed and primocanes were positioned on the trellis according to conventions for the trellis system as described below.

The 2 blocks were each trained to a different trellis system. One block of all cultivars was placed on a stationary vertical trellis, with three wires on one side of the post, positioned 50 cm apart up to a height of approximately 1.5 m. The first five primocanes from each plant were attached to the wires using a commercial tape fastening system. Additional primocanes were removed. The second block was trained to a rotating cross arm (RCA) trellis (Takeda et al., 2013). Briefly, the first few primocanes were attached horizontally to the lowest training wire, and then tipped to force lateral branching. These laterals were then attached to the wires on the rotating arm portion of the trellis. During the winter months, the RCA trellis was lowered to the ground and covered with spun-bonded row covers (1.5 oz. per yd^2). After the first 3 years, the RCA trellises were fixed in a vertical position year-round and primocane training was as described for the vertical system.

Irrigation was provided using both drip and overhead systems. A single drip tape (RO-DRIP Lo Flo, 15 cm emitter spacing, John Deere Water Irrigation Products, Moline, IL), was installed in the center of each row at planting. The system was designed to supply 1.9 $mm \cdot h^{-1}$ of irrigation to the 90-cm wide root zone. An overhead irrigation system was also installed to maintain the grass cover crop in the alleyways. The overhead system consisted of mini sprinklers (2.38 mm orifice, mini-Wobbler®, Senninger Irrigation, Inc., Clermont, FL) set at 2.4 m height, placed in every third row at a 9.1 m in-row spacing, and designed to supply 3.38 $mm \cdot h^{-1}$. Irrigation scheduling was to supply crop needs based on evapotranspiration estimates from a nearby weather station, with approximately 25 mm per week applied through the overhead system and 17 to 25 mm per week applied by drip.

Data collection. Each spring from 2007 to 2012, each plot was visually evaluated to quantify winter injury based on percent of total bud survival. In the 2008 to 2012 growing seasons, plots were evaluated for total yield, fruit size, and timing of the production season. Ripe fruit in each plot was harvested three times per week, and total ripe fruit per plot weighed. For one harvest per week, mean fruit weight was determined for a 5-fruit subsample, and the seasonal weighted average was used to compare cultivars over the three seasons. Attempts were made to quantify consumer preference at a local farmers' market as described previously (Black et al., 2013). However, because of differences in ripening time among cultivars and due to crop loss from winter injury, the data were too incomplete for meaningful analysis and are not included.

A yield reliability index was calculated according to Kataoka (1963). Briefly, a reliability index is used to compare yields among locations or years, and provides a confidence interval based on a specified probability.For this study, we used a reliability index with a probability of 75% (RI_{75}), so that the calculated index value indicates the minimum yields one would expect to obtain 75% of the time.

A weather station located ~130 m from the plots recorded air temperature, humidity, wind speed, precipitation and solar radiation. Data were archived by the Utah Climate Center as part of their Fruit Grower data network (Utah Climate Center, 2016).

Data for winter survival, yield, fruit size and harvest season were analyzed as repeated measures using the GLM procedures in the SAS software package (SAS versions 9.1, Cary, NC). Means separations were calculated using the pdiff option in GLM with a threshold of $p=0.05$.

Results and Discussion

Winter injury. Winter survival differed among cultivars and across seasons (Table 1). Several cultivars were not planted in 2006, or else did not show adequate growth in 2006 to be included in the 2007 winter bud survival evaluation. Despite these missing values, there was significant year × cultivar interaction and so data were analyzed and means separations calculated separately for each year. The lowest average bud survival was noted in the spring of 2008 and 2011, but the lowest winter temperatures in these years did not differ from the other years of the study. The most likely cause of this higher mortality was sudden temperature drops in the fall, prior to adequate bud acclimation. For example, after a very mild fall where temperatures rarely dropped below freezing,

Table 1. Winter floricane survival of blackberry cultivars at the Utah State University Kaysville Research Farm. Evaluations are based on visual ratings of percent bud survival (% survival). Analysis was carried out on arcine transformed data. Means followed by the same letter are not significantly different (α=0.05) from other means within the same season.

Cultivar	2007	2008	2009	2010	2011	2012	Mean
Semi-erect							
Chester Thornless	72.5 abc	72.5 ab	95.0 a	95.0 a	67.5 abc	95.0 ab	82.9
Triple Crown		42.5 bc	80.0 abc	95.0 a	90.0 a		76.9
Hull	55.0 bc	20.0 cd	90.0 ab	75.0 abc	50.0 cd	97.5 a	64.6
Doyle's Thornless	67.5 abc	5.00 d	72.5 a-d	65.0 a-d	57.5 bcd	90.0 abc	59.6
Loch Ness	35.5 cd	15.0 cd	85.0 abc	60.0 a-d	72.5 abc	77.5 a-d	57.5
Erect							
Illini Hardy	100 a	90.0 a	92.5 a	95.0 a	92.5 a	90.0 abc	93.3
Apache	92.5 ab	80.0 a	80.0 abc	100 a	90.0 a		88.5
Navaho	77.5 ab	65.0 ab	70.0 a-d	95.0 a	87.5 a	75.0 b-e	78.3
Arapaho		40.0 bc	72.5 a-d	97.5 a	92.5 a	72.5 cde	75.0
Ouachita	100 a	15.0 cd	70.0 a-d	90.0 a	85.0 ab	17.5 fg	62.9
Kiowa	10.0 d	0.00 d	45.0 def	25.0 de	5.00 ef	12.5 fg	16.3
Trailing							
Newberry		0.00 d	77.5 abc	47.5 b-e	82.5 ab	80.0 a-d	71.9
Siskyou		20.0 cd	57.5 c-f	87.5 ab	45.0 cd		42.0
Black Diamond		0.00 d	75.0 a-d	17.5 e	7.50 ef	60.0 de	40.0
ORUS 1793-1		0.00 d	65.0 a-e	42.5 cde	5.00 ef	22.5 f	33.8
ORUS 1939-4		0.00 d	60.0 b-f	40.0 cde	32.5 de	0.00 g	33.1
Metolius		0.00 d	30.0 f	37.5 cde	5.00 ef	55.0e	31.8
Obsidian	65.0 abc	0.00 d	60.0 b-f	35.0 cde	5.00 ef	15.0 fg	30.8
Marion	50.0bcd	15.0cd	35.0ef	7.50e	0.00f	7.50fg	19.2
Analysis of Variance							
Cultivar	0.01	0.01	0.02	<0.001	<0.001	<0.001	
Block	0.18	0.55	0.37	<0.001	0.14	0.928	

Means separation was by the pdiff option in PROC GLM, with a $p < 0.05$

temperatures dropped from 12.9 °C to -13.1 °C over a 4-day period during the week of 20 Nov. 2010 (Utah Climate Center, 2016). If unseasonal freezing temperatures occur before adequate acclimation, cane damage is very likely (Crandall, 1995).

Averaged over seasons, 'Illini Hardy', 'Apache', and 'Chester Thornless' had the highest rate of winter bud survival with 93, 89, and 83%, respectively. Overall, semi-erect and erect cultivars had much higher rates of winter bud survival than trailing types. The trailing types had relatively low bud survival, ranging from a high of 58% average for 'Newberry' to a low of 19% average survival for 'Marion'. Interestingly, the erect-type 'Kiowa' had the lowest rate of bud survival (16%) among all cultivars tested. This was different from what Moore and Clark (1996) reported where 'Kiowa' showed no visible injury following field exposure to -23 °C.

There was no significant difference in bud survival rates between the vertical trellis and the RCA trellis blocks during the first three years (block effect, Table 1). In addition, some cane damage occurring in the erect and semi-erect types as the trellis was moved to or from the horizontal position. Therefore, the RCA trellis was fixed in the vertical position after the first 3 seasons and cane positioning was the same as for the vertical trellis. Note that winter injury is not reported for 'Prime-Jim' or 'Prime-Jan' (primocane-fruiting cultivars) as canes were removed to the ground each winter.

Yield. The five semi-erect cultivars planted had the highest average yields of all the cultivars, suggesting semi-erect types are the best suited for Utah production. 'Triple Crown' was numerically the highest yielding cultivar in three of the 5 years, and had the highest overall average yield of 3.69 kg/plant (Table 2). Erect types were the next highest performing, with 'Illini Hardy' and 'Arapaho' being the highest yielding of the erect cultivars planted (average 2.09, and 1.53 kg/plant, respectively). Previous reports of Illini Hardy yields are difficult to interpret on a land area basis. However, these yields for 'Arapaho' were far less than the 7.8 kg/plant reported by Moore and Clark (1993) in Clarksville, AR. Strang et al. (2003) reported that in Kentucky, 'Arapaho' was the lowest yielding of the cultivars tested (0.62 kg/plant).

Interestingly, for some semi-erect and erect cultivars, most notably Hull and Illini Hardy, a tendency toward cyclic high and low producing years was observed. This pattern was also observed in an un-replicated demonstration planting in Logan, Utah (Wytsalucy et al., 2015).

Not surprisingly, yields were correlated with

Table 2. Total yield (kg/plant) of blackberry cultivars at the USU Kaysville Research Farm over 5 years (2008-2012). Reliability index (RI_{75}) is the predicted minimum yields that could be expected in at least 75% of the production years.

Cultivar	2008	2009	2010	2011	2012	mean	RI_{75}
Semi-erect							
Triple Crown	1.75 ab	4.37 a	3.72 a	5.21 a	3.38 bc	3.69	2.24
Doyle's Thornless	1.33 ab	4.06 ab	2.29 b	1.75 bc	5.99 a	3.09	1.76
Hull	0.47 cde	4.72 a	0.87 c-f	0.72 cde	5.21 ab	2.40	1.23
Chester Thornless	0.61 cd	2.94 a-d	1.15 cde	1.48 bcd	5.28 ab	2.29	1.15
Loch Ness	0.16 de	3.23 abc	0.55 def	1.24 cde	2.95 cd	1.63	0.66
Erect							
Illini Hardy	0.63 cd	3.46 abc	0.68 def	4.12 a	1.56 cde	2.09	1.00
Arapaho	0.31 de	1.83 c-f	1.28 cd	2.78 b	1.45 cde	1.53	0.60
Ouachita	0.03 e	2.25 b-e	1.72 bc	1.73 bc	1.15 de	1.38	0.49
Apache	0.31 de	0.85 ef	0.66 def	1.51 bcd	0.66 e	0.80	0.12
Navaho	0.95 bc	1.17 def	0.35 def	0.51 cde	0.71 e	0.74	0.09
Kiowa	0.32 de	1.95 c-f	0.43 def	0.00	0.71 e	0.68	0.06
Trailing							
Newberry		1.21 def	0.26 ef	1.26 cde	0.99 de	0.93	0.00
Siskyou	0.01 e	0.99 ef	0.32 def	0.22 de	0.00 e	0.31	0.00
Black Diamond	<0.01e	1.06 ef	0.00 f	0.01 e	0.22 e	0.26	0.00
ORUS 1793-1		0.72 ef	0.30 def	0.04 e	0.22 e	0.32	0.00
Obsidian		0.88 ef	0.28 ef	0.05 e	0.05 e	0.31	0.00
ORUS 1939-4		0.66 ef	0.06 f	0.34 de	0.02 e	0.27	0.00
Metolius	<0.01e	0.24 f	0.28 ef	0.07 e	0.31 e	0.18	0.00
Marion	0.01 e	0.39 f	0.00 f	0.01 e	0.05 e	0.09	0.00
Primocane-fruiting							
Prime-Jim	0.27 de	0.62 ef	0.48 def	0.64 cde	0.75 e	0.55	0.00
Prime-Jan	0.08 de	0.43 ef	0.30 def	0.26 de	0.67 e	0.35	0.00
Analysis of Variance							
Cultivar	<0.001	<0.001	<0.001	<0.001	<0.001		
Block	0.527	0.59	0.10	0.278	0.027		

Means separation was by the pdiff option in PROC GLM, with a $p < 0.05$

Table 3. First and last freeze dates recorded at the Utah State University Kaysville Research Farm, approx. 130 m from the blackberry plots.

	Freeze Dates		Harvest Dates	
	Last Spring	First Fall	First	Last
2008	10-May	10-Oct	30-Jul	10-Oct
2009	27-Apr	2-Oct	8-Jul	28-Sep
2010	7-May	27-Oct	19-Jul	11-Oct
2011	2-May	26-Oct	20-Jul	9-Oct
2012	28-Apr	7-Oct	6-Jul	5-Oct

winter bud survival, and the trailing types were the lowest yielding cultivars in the study due to lack of winter hardiness. Of the 8 trailing cultivars planted, Newberry was the highest yielding with an average of 0.93 kg/plant. 'Newberry' actually had a higher average yield than two erect cultivars, Navaho and Kiowa. However, it was still much lower than the 'Newberry' yield of 10.5 kg/plant observed in Willamette, OR (Finn et al., 2010).

'Prime-Jim' and 'Prime-Jan' performed similarly to the trailing types with a yield of 0.55 and 0.35 kg/plant, respectively. This is much lower than what was seen by Clark et al. (2005) in Aurora, OR where the average primocane yield over two years for 'Prime-Jim' and 'Prime-Jan' were 14.8 and 14.5 kg/plant, respectively. Clark et al. (2005) reported that primocane yield for both 'Prime-Jim' and 'Prime-Jan' varied greatly by location and in Clarksville, AR the three-year average primocane yield was 0.71 and 2.66 kg/plant, respectively. The low yields reported in this study were likely related to growing season length, as the primocane fruiting types did not reach peak yield before cool fall temperatures slowed production (Table 3).

Table 4. Harvest season as defined by first, last and peak harvests of blackberry cultivars over two years, 2009 and 2011.

	2009			**2011**		
	First	Peak	Last	First	Peak	Last
Semi-erect						
Loch Ness	14-Jul	17-Aug	18-Sep	19-Jul	23-Aug	22-Sep
Hull	23-Jul	10-Aug	23-Sep	28-Jul	23-Aug	16-Sep
Triple Crown	23-Jul	17-Aug	18-Sep	1-Aug	21-Aug	9-Oct
Doyle's Thornless	29-Jul	24-Aug	23-Sep	4-Aug	27-Aug	16-Sep
Chester Thornless	31-Jul	24-Aug	28-Sep	1-Aug	29-Aug	22-Sep
Erect						
Arapaho	8-Jul	21-Jul	1-Sep	19-Jul	1-Aug	6-Sep
Ouachita	16-Jul	5-Aug	3-Sep	26-Jul	11-Aug	13-Sep
Illini Hardy	16-Jul	3-Aug	8-Sep	28-Jul	14-Aug	13-Sep
Kiowa	21-Jul	24-Aug	14-Sep			
Navaho	23-Jul	10-Aug	18-Sep	19-Jul	20-Aug	13-Sep
Apache	25-Jul	24-Aug	18-Sep	4-Aug	21-Aug	2-Oct
Trailing						
Siskyou	8-Jul	21-Jul	7-Aug	19-Jul	24-Jul	4-Aug
Obsidian	8-Jul	16-Jul	22-Aug	19-Jul	24-Jul	1-Aug
Metolius	8-Jul	18-Jul	24-Aug	21-Jul	1-Aug	4-Aug
Black Diamond	8-Jul	21-Jul	22-Aug	21-Jul	28-Jul	28-Jul
Newberry	10-Jul	16-Jul	24-Aug	19-Jul	1-Aug	14-Aug
ORUS 1793-1	10-Jul	25-Jul	27-Aug	28-Jul	27-Aug	22-Sep
ORUS 1939-4	14-Jul	25-Jul	27-Aug	19-Jul	30-Jul	21-Aug
Marion	14-Jul	29-Jul	24-Aug	28-Jul	28-Jul	1-Aug
Primocane-fruiting						
Prime-Jim	7-Aug	14-Sep	28-Sep	24-Jul	2-Oct	9-Oct
Prime-Jan	7-Aug	21-Sep	28-Sep	21-Aug	2-Oct	9-Oct

Cane tipping was used as described by Strik et al. (2012) to synchronize fruiting, but earlier cultivars or season advancing techniques such as high tunnels or row covers would be needed in order for primocane-fruiting types to be a commercially viable option for the U.S. Intermountain West. Strik et al. (2012) found the use of row covers advanced bloom by 14 days and Thompson et al. (2009) found that the use of high tunnels for primocane-fruiting types extended the season into the fall by 3 weeks.

Comprehensive statistical analysis of the harvest season was difficult due to early freeze damage in some years. Additionally, due to winter injury, some cultivars did not fruit in specific years. Table 3 shows first and last freeze dates as well as first and last harvest for each year. Although a comprehensive statistical analysis of all years is not possible, discussion of years where winter injury was minimal and early freezing did not occur gives a general idea of harvest season. Table 4 shows the first, peak, and last harvest dates for two years: 2009 and 2011. Both years were selected for high winter survival rates (Table 1). The earliest fall freeze occurred in 2009, and the latest was in 2011 (Table 3).

Fruit Size. Fruit size varied among cultivars. The erect type 'Kiowa', known for its large fruit size, had the largest average fruit

Table 5. Blackberry fruit size (g/fruit) over 5 years (2008-2012). Values are a weighted average based on weekly measurements of average fruit size weighted for weekly production.

Cultivar	2008	2009	2010	2011	2012	Mean
Semi-erect						
Triple Crown	5.20 abc	4.29 bcd	6.21 a	6.63 a	5.56 b	5.58
Hull	3.08 d	3.49 d-g	4.13 cd	5.17 bcd	4.27 cde	4.03
Doyle's Thornless	3.52 bcd	2.76 fgh	3.02 de	3.46 fg	3.25 def	3.20
Loch Ness	2.03 d	3.22 efg	2.96 de	3.91 efg	3.50 c-f	3.12
Chester Thornless	2.41d	2.15 h	2.83 e	3.32 g	3.22 def	2.79
Erect						
Kiowa	5.27 ab	5.96 a	5.65 ab		8.79 a	6.42
Apache	4.07 a-d	4.27 bcd	5.73 ab	6.77 a	4.98 bc	5.17
Ouachita	1.57 d	4.92 b	4.49 bc	5.87 ab	4.47 bcd	4.26
Arapaho	3.18 cd	3.73 c-g	4.07 cde	5.41 bc	4.05 cde	4.07
Illini Hardy	2.48 d	2.73 gh	3.31 cde	3.72 fg	2.65 f	2.98
Navaho	2.98 d	2.9 fgh	2.77 e	3.54 fg	2.42 f	2.92
Trailing						
ORUS 1793-1		4.89 b	3.90 cde	4.40 c-g	5.12 bc	4.58
Siskyou	6.40 a	4.10 b-e	3.60 cde	3.90 efg		4.50
Newberry		4.71 bc	3.89 cde	4.07 d-g	4.38 bcd	4.26
Obsidian		4.72 bc	4.03 cde	4.80 b-f	2.80 ef	4.09
Metolius		3.74 c-g	4.17 cd	4.50 c-g	3.30 def	3.93
Black Diamond		3.82 c-f		3.70 fg	3.12 def	3.55
ORUS 1939-4		3.95 b-f	1.80 e	3.97 d-g	3.40 def	3.28
Marion	3.27 bcd	3.05 fgh		3.30 g	3.30 def	3.23
Primocane						
Prime-Jim	4.11 a-d	3.29 d-g	3.99 cde	4.95 b-e	5.08 bc	4.29
Prime-Jan	3.55 a-d	4.00 b-f	3.93 cde	4.70 c-f	4.91 bc	4.22
Analysis of Variance						
Cultivar	0.037	<0.001	<0.001	<0.001	<0.001	
Block	0.020	0.683	0.103	0.004	0.090	

Means separation was by the pdiff option in PROC GLM, with a $p < 0.05$

size (6.42 g/fruit) of all cultivars in the trial (Table 5). This fruit size is smaller than that reported in Arkansas (average 9.4 g/fruit across locations) (Moore and Clark, 1996). However, 'Kiowa' tended to have the lowest total yields of the semi-erect and erect types. 'Triple Crown' had the second largest fruit size, 5.58 g/fruit, which was less than the 7.6 g fruit size previously reported by Strang et al. (2003) and Galletta et al. (1998b). 'Illini Hardy', 'Navaho', and 'Chester Thornless' tended to have the smallest fruit of any cultivars in the study, averaging less than 3 g/fruit.

Conclusion

Harsh winter conditions in the U.S. Intermountain West, including severe drops in temperature without adequate acclimating conditions, as well as late spring and early fall freezes, limit the blackberry cultivars that can reliably produce adequate yields. Semi-erect cultivars Triple Crown, Doyle's Thornless, and Hull had the highest average yield of the 19 cultivars and 2 numbered selections tested. The highest yielding erect cultivar Illini Hardy, had lower yields than all but one semi-erect cultivar, Loch Ness. Trailing type blackberries have particularly low winter survival and overall produced the lowest yields of the trial. None of the trailing cultivars included in the study had a reliability index > 0. The two primocane fruiting cultivars tested, Prime-Jim and Prime-Jan, did not have adequate season length to reach full production before a killing freeze occurred. Further research is needed to determine whether high tunnel protection or advancing growth in the spring with high tunnels or row covers could lengthen the growing season sufficiently to make the use of primocane-fruiting cultivars economically viable in the U.S. Intermountain West.

Footnotes

Funding was provided by grants from the Western Sustainable Agriculture Research and Education (SARE) program, the Utah Dept. of Agriculture and Food Specialty Crop Black Grant Program, and the Utah Agricultural Experiment Station - Utah State University (journal paper number 8930).

Disclaimer

Use of trade names does not imply an endorsement of the products named or criticism of similar ones not named.

Literature cited

Black, B.L., T. Lindstrom, R. Heflebower, B. Hunter, S. Olsen, and D.G. Alston. 2013. Adaptability of primocane raspberry cultivars to a high-elevation arid climate. J. Amer. Pomol. Soc. 67:47-56.

Clark, J. R. 2008. Primocane-fruiting blackberry breeding. HortScience 43:1637-1639.

Clark, J.R. and J.N. Moore. 1999. 'Apache' thornless blackberry. HortScience 34:1291–1293.

Clark, J.R. and J.N. Moore. 2005. 'Ouachita' thornless blackberry. HortScience 40:258-260.

Clark, J.R., J.N. Moore, J. Lopez-Medina, C.Finn, and P. Perkins-Veazie. 2005. 'Prime-Jan' ('APF-8') and 'Prime-Jim' ('APF-12') Primocane-fruiting Blackberries. HortScience 40:852-855.

Crandall, P.C. 1995. Bramble production: the management and marketing of raspberries and blackberries. Food Products Press, an imprint of The Haworth Press, Inc. Binghamton, NY.

Dana, M. and B. Goulart.1989. Bramble biology. In: Northeast Regional Agricultural Engineering Service (NRAES-35). Cooperative Extension. Cornell University. Ithaca, New York, p. 9-18.

Doyle, T.E. 1977. Doyle's blackberry. US PP4094 P. https://www.google.com/patents/USPP4094

Finn C.E., F.J. Lawrence, B.C. Strik, B.Yorgey, and J. DeFrancesco. 1999. 'Siskiyou' Trailing Blackberry. HortScience 34:1288-1290.

Finn, C.E., B.C. Strik, B. Yorgey, R.R. Martin, and M.M. Stahler. 2010. 'Newberry'Trailing Blackberry. HortScience 45:437-440.

Finn, C.E., B.M. Yorgey, B.C. Strik, H. K. Hall, R.R. Martin, and M.C. Qian. 2005a. 'Black Diamond' thornless blackberry. HortScience 40:2175-2178.

Finn, C.E., B.M. Yorgey, B.C. Strik, and R.R. Martin. 2005b. 'Metolious' Trailing Blackberry. HortScience 40:2189-2191.

Finn, C.E., B.M. Yorgey, B.C. Strik, R.R. Martin, and C. Kempler. 2005c. 'Obsidian' trailing blackberry. HortScience 40:2185-2188.

Galletta, G.J. 1981. 'Hull Thornless' blackberry. HortScience 16(6):796.

Galletta, G.J., A.D. Draper, J.L. Maas, R.M. Skirvin, A.G. Otterbacker, H.J. Swartz, and C.K. Chandler. 1998a. 'Chester Thornless' Blackberry. Fruit Var. J. 52:118–122.

Galletta, G.J., J.L. Maas, J.R. Clark, and C.E. Finn. 1998b. 'Triple Crown' thornless blackberry. Fruit Var. J. 52:124-127.

Kataoka, S. 1963. A stochastic programming model. Econometrika 31:181-196.

Moller, A.L. and Gillies, R.R., 2008. Utah Climate, 2nd Edition. Utah Climate Center, Utah State University. http://climate.usu.edu.

Moore J.N. 1997. Blackberry, p. 161-173. In: The Brooks and Olmo register of fruit and nut varieties, third edition. ASHS Press, Alexandria, VA.

Moore, J.N. and J.R. Clark. 1989. 'Navaho' thornless blackberry. HortScience 24:863–865.

Moore, J.N. and J.R. Clark. 1993. 'Arapaho' Erect, Thornless Blackberry. HortScience 28:861-862.

Moore, J.N. and J.R. Clark. 1996. 'Kiowa' Blackberry. HortScience 31:286-288.

Skirvin R.M. and A.G. Otterbacher. 1993. Blackberry plant named Illini Hardy. US PP8333 P. http://www.google.com/patents/USPP8333

Strang, J., A. Satanek, J. Snyder, C. Smigell, D. Archbold, P. Bush, D. Lowry, and D. Slone. 2003. Evaluation of thornless semi-erect and erect Blackberry training systems and varieties for Kentucky – 2001 & 2002. Univ. of Kentucky, College of Agr. http://www.uky.edu/Ag/CCD/blackberriesLex02.htm

Strik, B.C., J.R. Clark, C.E. Finn, and G. Buller. 2012. Management of primocane-fruiting blackberry: Impacts on yield, fruiting season, and cane architecture. HortScience 47:593–598.

Takeda, F., D.M. Glenn, and T. Tworkoski. 2013. Rotating cross-arm trellis technology for blackberry production. J. Berry Res. 3:25-40.

Thompson E., B. C. Strik, C.E. Finn, and J. R. Clark. 2009. High tunnel versus open field: management of Primocane-fruiting blackberry using pruning and tipping to increase yield and extend the fruiting season. HortScience 44:1581-1587.

Utah Climate Center. 2016. Utah Temperature Resource and Alerts for Pests, Kaysville USU Farm. Utah Climate Center,Utah State University. http://climate.usurf.usu.edu/traps/

Warmund, M.R. and M.F. George. 1990. Freezing survival and super-cooling in primary and secondary buds of *Rubus* spp. Can. J. Plant Sci. 70:893-904.

Wytsalucy, R., T. Maughan and B. Black. 2015. High Tunnel Blackberry Production for Northern Utah. USU Ext. Publ. Hort./High Tunnel/2015-01pr.