A Comparison of Nine Primocane Fruiting Raspberry Cultivars for Suitability to a High-Elevation, Arid Climate

Sheriden Hansen*, Brent Blackb, Diane Alstonc, Thor Lindstromb, and Shawn Olsena

*Utah State University, Davis County, Kaysville, Utah, USA; bPlants, Soils and Climate Department, Utah State University, Logan, Utah, USA; cBiology Department, Utah State University, Logan, Utah, USA

ABSTRACT
A replicated trial, planted in 2011, compared nine primocane-fruiting raspberry cultivars for suitability to commercial production in the U.S. Intermountain West. Factors evaluated included annual yield, fruit size, fruiting season, consumer preference, leaf chlorophyll content, and cane infestation by raspberry horntail, a common insect pest of raspberries in northern Utah. ‘Joan J’ was the highest yielding cultivar, averaging 3.32 kg per row meter, followed by ‘Polana’, ‘Autumn Bliss’, and ‘Dinkum’ with 2.53, 2.01, and 1.34 kg·m⁻¹, respectively. ‘Autumn Bliss’ and ‘Joan J’ were the earliest to fruit with a harvest midpoint 4 and 2 days before ‘Polana’, respectively. Leaf chlorophyll concentration (CCI) was highest in ‘Joan J’ and ‘Autumn Treasure’, averaging 30.9 and 27.0 CCI, respectively. All cultivars exhibited similar susceptibility to raspberry horntail, with differences in infestation rates related to the location in the field. A survey of farmers’ market customers found the highest consumer preference for ‘Autumn Bliss’, ‘Dinkum’, and ‘Vintage’. Only the earliest cultivars gave commercially viable yields for the high elevation valleys of the Intermountain West region of the U.S.

KEYWORDS
Rubus; fruiting season; raspberry horntail; alkaline soil tolerance

Introduction
In the Intermountain West region of North America, raspberries are a popular crop for small-scale local production often associated with seasonal tourism. Conditions in the region present challenges to growing raspberries due to an arid, high-elevation (>1,300 m) continental climate. The climatic conditions are characterized by cold winter and hot summer temperatures, and growing seasons limited by late-spring and early-fall freeze events. Additional production limitation factors include a lack of in-season rainfall, irrigation water quantity and quality, and alkaline soils. New cultivars, selected in other regions, may be poorly adapted to these conditions. Cropping on summer-bearing cultivars is often limited due to winter injury of the floricanes (Black et al., 2015). Many fall-bearing cultivars fruit too late in the season to provide commercially viable yields before production is terminated by the first fall freeze.

The fall-bearing cultivar ‘Heritage’ has traditionally been grown in Utah and in similar temperate climates (Dale, 1992). Previously, Black et al. (2013) identified several productive primocane-fruiting cultivars suited to the climate and conditions of the Intermountain West including ‘Joan J’, ‘Polana’, ‘Caroline’, and ‘Polka’. Identification of additional earlier producing primocane-fruiting cultivars with acceptable commercial fruit quality could support production expansion and diversification in the region.

The primary insect pest of raspberries in the region is the raspberry horntail, Hartigia cressonii (Kirby), a cane boring wasp that is prevalent in both home garden and commercial plantings throughout northern Utah (Alston et al., 2009). Young larvae tunnel in the cambium of primocanes, and move...
into the pith of the growing point, causing cane wilting, dieback, and reduced yield. Raspberry horntail has been found in multiple western states, including California, Colorado, Idaho, Montana, Nevada, and Washington (Middlekauf, 1969). Literature on its biology and management is scarce, and it is uncertain if cultivar resistance occurs. Previously, Black et al. (2013) reported variation in horntail damage, but incidents varied more among years and with cane vigor than among evaluated cultivars.

The objective of this research was to determine the suitability of primocane-fruiting cultivars for field production in the arid high-elevation valleys of the Intermountain West. Early fruiting is critical in these environments, high-elevation production as fall freezes often limit yield potential. Other selection criteria were fruit size, consumer acceptance, susceptibility to raspberry horntail, and tolerance to alkaline soil.

**Materials and Methods**

**Planting and Establishment**

A replicated raspberry cultivar trial was planted 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 first fall freeze on 13 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 2011, raspberry plants of six primocane-fruiting cultivars were selected for evaluation: ‘Autumn Bliss’ (Keep, 1989), ‘Autumn Britten’ (Daubeny, 1997), ‘Dinkum’ (McGregor, 1996), ’Joan J’ (Jennings, 2008), ‘Polana’ (Danek and Pasiut, 1991), and ‘Vintage’ (Finn, 2014). A previous cultivar trial at the same location (Black et al., 2013) found ‘Joan J’ to be the top performer, and it was again included for comparison. Plants were obtained from commercial nurseries and planted in four replicate plots arranged in a randomized block design with blocking by location in the field. Due to delayed plant availability, three additional cultivars: ‘Brice’ (Okie, 2004), ‘Josephine’ (Swartz et al., 2001), and ‘Autumn Treasure’ (Knight, 2008) were added in the early spring of 2012 to plots left vacant in the original design. Each plot was 7.3 m long, with 0.6 m between plots in the row and 3.35 m between rows. Experimental design and management were similar to the previous study (Black et al., 2013).

**Cultural Practices**

The space between plots within the row was covered with landscape fabric (5 oz., Dewitt, Sikeston, MI, USA) to suppress weed growth and maintain the separation of raspberry cultivars. Alleyways were planted in a perennial ryegrass (*Lolium perenne* L.) and creeping red fescue (*Festuca rubra* L.) 1:1 mixture at a seeding rate of 56 kg·ha⁻¹. In-row weed control was a combination of annual applications of a pre-emergent herbicide (1.9 to 2.8 L·ha⁻¹ Surflan, Southern Agric. Insecticides, Plametto, FL, USA) and hand weeding. The alleyway grass was mowed at ~3-week intervals, and the edges of the alleyway were cultivated 1 to 2 times per season to prevent grass from spreading into the raspberry row.

Plant nutrient needs were supplied with fertilizer applications of 135 kg·ha⁻¹ of 16–16–16 NPK applied in mid-April and again in early June, banded in the raspberry row. All canes in each plot were pruned to ground level in the late fall. Canes were supported with a trellis system consisting of a single twine on each side of the row, supported by t-shaped rebar posts.

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, USA), was installed in the center of each row at planting. The system was designed to supply 1.9 mm·h⁻¹ of water to the 90 cm-wide root zone, with approximately 46 mm applied per week. An overhead irrigation system was also installed to maintain the grass cover crop in the alleyways, provide cooling of fruit during heat events, and reduce the risk of spider mite infestation. The overhead system consisted of mini sprinklers (2.38 mm orifice, mini-Wobbler®, Senninger Irrigation, Inc. Clermont, FL, USA) set at 2.4 m heights,
placed every third row at 9.1 m in-row spacing, designed to supply 3.38 mm·h⁻¹. Irrigation scheduling was based on crop and cover crop need, with approximately 25 mm per week applied through the overhead system or approximately 35% of the total irrigation needs during mid-summer.

Data Collection
In the 2012–2014 growing seasons, plots were evaluated for total fruit yield, fruit size, and timing of the production season. Ripe fruit in each plot was harvested three times per week, from mid-July until the first fall freeze, and total ripe fruit, both marketable and cull fruit, weighed for each plot. For one harvest per week, mean fruit weight was determined on a 10-fruit sub-sample. To better compare the production season among cultivars, cumulative yield curves were generated, and the date at which 20% (early season) and 50% (season midpoint) of the total season crop had been harvested was calculated for each plot. Early-season and mid-season dates were then used to compare cultivars over multiple seasons.

Unmarketable fruit was removed from total fruit samples, weighed, and recorded (data not shown). The most common cause for culled fruit was sunburn. Soft fruit and inadequate fruit size were other common issues. Soft fruit was most commonly found when the harvest interval was more than 2 days, such as after the weekend or a rain event that prohibited harvest.

To compare fruit quality and consumer preference among cultivars, a simple non-written evaluation was devised and conducted as previously described (Black et al., 2013, 2015). In brief, fruit samples were presented at a local farmers’ market. One clamshell container of each cultivar was placed on a table with a small coin bank placed directly behind each container, and market attendees were asked to taste and evaluate fruit from each of the cultivars available. Participants were given 10 coins and instructed to taste berries from each container. Participants could ‘vote’ by placing all 10 coins into one bank or spreading their coins out among banks based on their preferences. Preference surveys were carried out on 12 Sep 2013, 7 Aug 2014, and 4 Sep 2014 with 605, 596, and 530 total votes cast, respectively.

Iron chlorosis is a common issue of raspberries grown on alkaline soils. Measurements of leaf chlorophyll can be useful in quantifying genetic differences in adaptability to alkaline soils (Black et al., 2021). Nondestructive leaf chlorophyll measurements were taken on seven mid-shoot leaves per plot on 31 Jul 2014 with a chlorophyll content meter (CCM-200 chlorophyll content meter, Opti-Science, Inc. Hudson, NH, USA). During the 2014 growing season, plots were assessed for raspberry horntail infestation on 24 Jun, 1 Jul, 8 Jul, and 18 Jul. Primocanes with wilted tips were suspected of infestation, removed, and dissected to confirm presence of horntail larvae. The number of horntail infestations or ‘strikes’ were recorded per plot.

A weather station located within 250 m of the plots recorded air temperature, humidity, wind speed, precipitation, and solar radiation. Data were archived by the Utah Climate Center, Utah State University, USA, and are publicly available (www.climate.usu.edu).

Statistical Analysis
The three years of data for yield, fruit size, and soluble solid content were analyzed as repeated measures [GLM procedure in the SAS software package (version 9.1, Cary, NC)], independently for each year when significant treatment × year interactions were detected. Horntail infestation data were analyzed as cumulative infestations for the observed season.

Results and Discussion
Yield
Selection criteria to determine primocane-fruiting cultivars suitable for field production included yield, fruiting season, fruit size, consumer acceptance, susceptibility to infestation with the raspberry horntail, and alkaline soil tolerance.
Across the three harvest seasons, ‘Joan J’ consistently produced the highest yields, followed by ‘Polana’. The lowest yielding cultivars were ‘Josephine’ and ‘Autumn Treasure’ (Table 1). Productivity is often correlated with earliness as early fall frosts limit the productivity of fall raspberries (Goulart and Demchak, 1999; Nonnecke and Luby, 1992), and yields in this trial followed this trend (Table 2). ‘Polana’ was found to be consistently high-yielding and early-producing cultivar, reaching 20% of total harvest on average by 21 Aug, 3 days later than ‘Autumn Bliss’ and 2 days later than ‘Joan J’. In contrast, ‘Brice’, ‘Vintage’, ‘Josephine’, and ‘Autumn Treasure’ consistently produced low yields, with harvest midpoint 2 to 3 weeks later than ‘Polana’. Yields for ‘Joan J’ were relatively consistent with those previously reported for the same location (Black et al., 2013).

Harvest season varied by year, likely due to variation in weather conditions. The first significant primocane harvest occurred on 3 Aug 2012, 7 Aug 2013, and 11 Jul 2014. The length of the fruiting season and the rate at which the season progressed were relatively similar among cultivars. In all years, fruit harvest continued until the first fall freeze which occurred on 5 Oct 2012, 7 Oct 2013, and 8 Oct 2014. The historical average (1948–2007) first fall freeze for this location is 13 October (Moller and Gillies, 2008). Total season yields showed a significant cultivar × year interaction (Table 1) in cultivars planted in 2011. Yields were correlated with the length of the growing season, with the highest yields in the long 2014 season and lowest in the initial 2012 season. Cultivar and year were found to be significant factors in the harvest season, with the earliest harvest midpoint occurring in 2014 (Table 2). The harvest mid-point for ‘Polana’ was 3 Sept 2012, 10 Sept 2013, and 19 Aug 2014. The 2014 growing season was characterized by unusually warm spring temperatures compared to 2012 and 2013. Early warming spring temperatures initiated cane growth and bud formation earlier in 2014 than 2012 or 2013. Interestingly, Yao and Rosen (2011) previously reported that ‘Joan J’ was later than ‘Polana’ in a high tunnel planting in Minnesota. By contrast, ‘Joan J’ fruiting season was similar to or slightly earlier than ‘Polana’ at this location.

The yield threshold for economic viability depends on product pricing, marketing strategies, and individual farm production costs, which is beyond the scope of this study. Several published enterprise budgets for raspberry suggest that single-season (excluding establishment costs) break-even yields for established commercial plantings range from 2.8 to 4.2 Mg·ha⁻¹ (Cornell University, 2014; Nonnecke and Nonnecke, 2010; Safley et al., 2009). Safley et al. (2009), used Mg·ha⁻¹ as the target yields for a mature primocane-fruited system in North Carolina. With the row spacing used in this study, 8.4 Mg·ha⁻¹ would correspond to 2.56 kg·m⁻¹. Our recommendations would be that yields would need to be above 1.7 kg·m⁻¹ to be economically viable.

Table 1. Marketable yields over three seasons for primocane-fruiting raspberries at the Kaysville Research Farm. Yields are expressed as kg of fruit per m of row. Based on the row spacing used here, 1 kg·m⁻¹ is equivalent to 3.28 Mg·ha⁻¹.

| Cultivar        | 2012  | 2013  | 2014  | Mean  |
|-----------------|-------|-------|-------|-------|
| Joan J          | 2.38  | a     | 4.17  | a     |
| Polana          | 2.33  | a     | 3.08  | b     |
| Autumn Bliss    | 1.73  | b     | 2.47  | bc    |
| Dinkum          | 1.14  | c     | 1.66  | cd    |
| Autumn Britten  | 1.30  | d     | 1.56  | de    |
| Brice           | 1.73  | de    | 1.60  | d     |
| Vintage         | 1.12  | de    | 1.23  | d     |
| Josephine       | 0.49  | ef    | 1.53  | de    |
| Autumn Treasure | 0.11  | f     | 0.72  | e     |

Analysis of variance

| Cultivar | Block | Year | Cultivar×Year |
|----------|-------|------|---------------|
|          | 0.001 |      | <0.001        |
|          | 0.002 |      | 0.007         |

*Data not available due to late planting date of cultivars.
**Table 2.** Harvest season as indexed by early harvest and harvest midpoint. Cumulative yields were calculated with the early harvest and midpoint representing the mean date at which cumulative yield reached 20% and 50% of the season total, respectively. The relative date is earliness relative to ‘Polana’.

| Cultivar      | 2012      | 2013      | 2014      | mean     | relative date |
|---------------|-----------|-----------|-----------|----------|---------------|
| Autumn Bliss  | 16-Aug    | 1-Sep     | 7-Aug     | 18-Aug   | b             |
| Joan J        | 17-Aug    | 3-Sep     | 7-Aug     | 19-Aug   | b             |
| Polana        | 21-Aug    | 3-Sep     | 7-Aug     | 21-Aug   | b             |
| Dinkum        | 20-Aug    | 4-Sep     | 8-Aug     | 21-Aug   | 0             |
| Autumn Britten| 22-Aug    | 4-Sep     | 7-Aug     | 22-Aug   | b             |
| Vintage       | 29-Aug    | 8-Sep     | 15-Aug    | 28-Aug   | a             |
| Brice         | –*        | 7-Sep     | 22-Aug    | 30-Aug   | 9             |
| Autumn Treasure| –*       | 19-Sep    | 27-Aug    | 7-Sep    | 18            |
| Josephine     | –*        | 15-Sep    | 4-Sep     | 10-Sep   | 29            |
| mean          | 21-Aug    | 6-Sep     | 12-Aug    | 25-Aug   |               |

**Harvest midpoint (50%)**

| Cultivar     | 2012      | 2013      | 2014      | mean     | relative date |
|--------------|-----------|-----------|-----------|----------|---------------|
| Autumn Bliss | 28-Aug    | 9-Sep     | 15-Aug    | 28-Aug   | –4            |
| Joan J       | 28-Aug    | 10-Sep    | 18-Aug    | 29-Aug   | –2            |
| Polana       | 3-Sep     | 10-Sep    | 19-Aug    | 1-Sep    | 0             |
| Dinkum       | 1-Sep     | 9-Sep     | 30-Aug    | 3-Sep    | 3             |
| Autumn Britten| 4-Sep     | 11-Sep    | 28-Aug    | 4-Sep    | 4             |
| Vintage      | 11-Sep    | 16-Sep    | 16-Sep    | 14-Sep   | 14            |
| Josephine    | –*        | 21-Sep    | 16-Sep    | 18-Sep   | 18            |
| Brice        | –*        | 15-Sep    | 24-Sep    | 19-Sep   | 19            |
| Autumn Treasure| –*       | 21-Sep    | 20-Sep    | 21-Sep   | 21            |
| mean         | 2-Sep     | 12-Sep    | 1-Sep     | 7-Sep    |               |

**Analysis of variance**

| Cultivar | Early | Midpoint |
|----------|-------|----------|
| Block    | 0.272 | 0.616    |
| Year     | <0.001| <0.001   |
| Cultivar×Year | 0.108 | <0.001   |

*Data not available due to late planting date of cultivars.*

**Fruit Size and Soluble Solid Content**

Peak fruit size was the average weight of an individual fruit at peak production. Fruit size was significantly related to cultivar, with ‘Josephine’ consistently producing the largest and ‘Autumn Treasure’ producing the smallest berries (Table 3). Variation in fruit size may be attributed to crop load, where the size of individual berries is inversely related to the number of fruit per cane (Gundersheim and Pritts, 1991). In our study, low yielding ‘Josephine’ fruit size at peak harvest was 3.76 g per fruit, compared to 3.37, 3.05, and 3.06 g per fruit for the higher yielding ‘Joan J’, ‘Autumn Bliss’, and ‘Polana’, respectively. Three of the nine cultivars included in this study (‘Autumn Britten’, ‘Autumn Bliss’, and ‘Polana’) were also compared in southwest Michigan (Hanson et al., 2005). The size of fruit in Utah was slightly larger than reported for the Michigan study for all three cultivars. Fruit size reported here for ‘Autumn Bliss’ and ‘Polana’ was much larger than found in a study conducted in Serbia, where the average fruit size was 1.2 g and 1.3 g, respectively (Milivojević et al., 2010). ‘Josephine’, ‘Brice’, and ‘Autumn Treasure’ were not included in the means separation due to the late planting date.

Soluble solids content of fruit was determined by refractometry and was the average soluble solids in a random sample of 10 fruits collected weekly from each plot throughout the harvest season. ‘Vintage’ averaged the highest soluble solids at 11.9% followed by ‘Josephine’, ‘Dinkum’, and ‘Autumn Treasure’ measuring 11.6%, 11.4%, and 10.8%, respectively. Previous studies comparing these cultivars did not report soluble solids, but these values are similar to previous reports for common North American (Daubeney and Kempler, 1995) and European cultivars (Heiberg et al., 2002).
Table 3. Fruit size and soluble solid content of primocane-fruiting cultivars over three seasons at the Kaysville Research Farm. Mean is average over the season weighted for yield. The peak is the largest mean fruit size during the season. The soluble solid content was determined by refractometry on a pooled sample of 10 fruits from each plot, measured at weekly intervals during the 2014 season.

| Cultivar     | Fruit Size | Soluble solids content |
|--------------|------------|------------------------|
|              | Mean (g/fruit) | Peak (%) |
| Josephine    | 3.12       | 3.76                  | 11.60 a |
| Joan J       | 2.72       | a                     | 3.37 a  | 10.23 cd |
| Autumn Britten | 2.43     | b                     | 3.12 a  | 9.58 e  |
| Autumn Bliss | 2.42       | b                     | 3.05 a  | 10.02 de |
| Polana       | 2.34       | b                     | 3.06 a  | 9.95 de  |
| Brice        | 2.22       |                     | 3.35    | 10.22 cde|
| Dinkum       | 2.12       | c                     | 2.59 b  | 11.37 ab |
| Vintage      | 1.89       | d                     | 2.28 b  | 11.86 a  |
| Autumn Treasure | 1.71   |                      | 2.38    | 10.78 bc |

Analysis of variance

| Cultivar | Block | Year | Cultivar×Year |
|----------|-------|------|---------------|
|          | <0.001| 0.044| 0.217         |
|          | <0.001| 0.009| 0.772         |

Consumer Preference

Consumer preference was evaluated on three dates, one time in each year. There was some variation in cultivar ranking among dates, which may be attributed to fruit quality variability from early to late harvests. Consumer preference did not appear to be correlated with soluble solids (data not shown). The three highest ranked cultivars were ‘Autumn Bliss’, ‘Dinkum’ and ‘Vintage’ and the three lowest ranked cultivars were ‘Brice’, ‘Polana’, and ‘Autumn Treasure’ (Table 4). Although it is not possible to statistically analyze flavor preference data collected here, it is of interest to note that both ‘Dinkum’ and ‘Vintage’ ranked high in taste preference as well as soluble solid percentage. Factors other than soluble solids are linked to taste preference in raspberries. A 2013 taste preference study found that consumer preference for fresh raspberries was linked to several factors including high color uniformity, raspberry aroma, raspberry flavor, floral aroma, green flavor, bitterness, astringency, and aftertaste all of which increased acceptability, whereas high color intensity and green aroma were associated with negative drivers of preference (Villamor et al., 2013).

Table 4. Consumer preference ratings of primocane-fruiting raspberries. Ratings were based on votes cast at a farmers’ market (10 votes per participant). Values are presented as the percent of votes cast on that day.

| Cultivar      | 12-Sep-13 | 7-Aug-14 | 4-Sep-14 | Average (% of votes) |
|---------------|-----------|----------|----------|----------------------|
| Autumn Bliss  | 26        | 13       | 11       | 16                   |
| Dinkum        | 19        | 13       | 12       | 15                   |
| Vintage       | 10        | 13       | 20       | 14                   |
| Autumn Britten| 6         | 18       | 15       | 13                   |
| Josephine     | 5         | 17       | 12       | 11                   |
| Joan J        | 9         | 10       | 12       | 10                   |
| Brice         | 10        | 5        | 11       | 8                    |
| Polana        | 7         | 10       | 7        | 8                    |
| Autumn Treasure | 8      | 5        | 6        | 6                    |

Since the preference of individual participants was not recorded, statistical analysis was not possible.
Leaf Chlorophyll

None of the cultivars showed visible chlorosis symptoms, but there were differences in leaf chlorophyll among cultivars (Table 5). Relative leaf chlorophyll is a good quantitative measure of chlorosis severity and is useful for determining genetic differences in tolerance to alkaline soils (Black et al., 2021). The Kaysville Research Farm soil has a native pH of 7.5 and is typically less prone to iron chlorosis than other soils in the arid Intermountain West. It is not clear if cultivar differences reported here are due to adaptability to alkaline soils or just genetic differences in leaf chlorophyll. It is interesting to note that ‘Vintage’ was found to have low yields in Utah despite a relatively early fruiting season. The leaf chlorophyll readings in this cultivar were significantly lower than almost all other cultivats at 19.8 CCl in contrast to ‘Joan J’ which had the highest yields and leaf chlorophyll readings of 30.9 CCl. Among the other cultivars tested, there was no correlation between yields and leaf chlorophyll. This suggests that the poor performance of ‘Vintage’ may indicate lower tolerance to alkaline soils, however, this should be tested on more alkaline soils typical of the region.

Raspberry Horntail

Field position was found to be the most significant factor when assessing raspberry horntail strikes. There was a significant correlation with the plot (P = .0237), with higher infestation levels in plots on the east side of the planting (data not shown). These results are similar to those of a previous primocane-fruiting cultivar study (Black et al., 2013). This response to field location may be due to adult horntails moving into the trial from nearby home gardens, the closest of which was located less than 100 m Northeast of the plots. A comparison of floricanes-fruiting cultivars at the same location found cultivars with high winter hardiness and cane vigor were least susceptible to raspberry horntail (Black et al., 2015). An additional observation noted in the floricanes study was that the cane-borers preferred thicker, sturdier canes as compared to thin, flexible ones. This observation aligns with the horntail’s biology where a thin cane may not support the overwintering larval hibernaculum within the pith. Additionally, the cutting of primocanes in spring removes overwintering larvae as compared to floricanes where horntail larvae complete their development within the standing canes and emerge as adults the following season. Although raspberry horntail continues to be a problem in Utah, no preference among primocane-fruiting cultivars was identified in this or the previous study (Black et al., 2013).

Conclusion

The top yielding cultivar in this study was ‘Joan J’, similar to the previous study at this location. This cultivar also had among the largest fruit size and the highest leaf chlorophyll content.

### Table 5. Leaf chlorophyll measured on seven mid-shoot primocane leaves per plot on 31 July 2014.

| Cultivar      | Leaf Chlorophyll (CCI) |
|---------------|------------------------|
| Joan J        | 30.9                   |
| Autumn Treasure | 27.0                  |
| Brice         | 26.2                   |
| Dinkum        | 26.0                   |
| Autumn Britten | 23.4                   |
| Autumn Bliss  | 22.9                   |
| Josephine     | 22.3                   |
| Polana        | 21.3                   |
| Vintage       | 19.8                   |
| **Analysis of variance** | **<0.001** |
| **Cultivar**  | **0.004**              |


indicating good adaptation to local conditions. Unfortunately, consumer flavor preferences ranked 'Joan J' in the middle of the tested cultivars. Other cultivars with economically viable yields were 'Polana' and 'Autumn Bliss'. 'Autumn Bliss' was the highest ranked cultivar in the flavor preference comparison. 'Autumn Bliss', 'Joan J', and 'Polana' were the three earliest-fruiting cultivars, confirming previous results that in the high-elevation valleys of the Intermountain West, early fruiting is essential to the viability of primocane cropping cultivars. Conversely, the later fruiting cultivars of 'Josephine', 'Vintage' and 'Autumn Treasure' produced yields that were not commercially viable.

**Acknowledgments**

The authors gratefully acknowledge the technical assistance of Casandra Collard, Harlie Hutchinson, and Elizabeth Winters.

**Funding**

This project was supported by the Utah Department of Agriculture and Food Specialty Crop Block Grant Program; and by the Utah Agriculture Experiment Station, Utah State University, and approved as journal paper UAES #9389.

**References**

Alston, D., B. Black, and M. Murray. 2009. Raspberry horntail [*Hartigia cressonii* (Kirby)]. Utah State University Extension Fact Sheet ENT-132-09, Logan.

Black, B.L., T. Lindstrom, R. Heflebower, B. Hunter, S. Olsen, and D.G. Alston. 2013. Adaptability of primocane-fruiting raspberry cultivars to a high-elevation arid climate. J. Am. Pom. Soc. 67(1):47–56.

Black, B.L., T. Lindstrom, B. Hunter, S. Olsen, R. Heflebower, D.G. Alston, and T. Maughan. 2015. Adaptability of floricane-fruiting raspberry cultivars to a high-elevation. Arid Climate. J. Am. Pom. Soc. 69(2):74–83.

Black, B.L., I.S. Minas, G.L. Reighard, and T. Beddes. 2021. Alkaline Soil Tolerance of Rootstocks included in the NC-140 ‘Redhaven’ Peach Trial. J. Am. Pom. Soc. 75(1):9–16.

Cornell University. 2014. Raspberries (Floricane summer bearing) – Returns to risk and management. Cornell Fruit Resources, New York. 24 Sep. 2020. [https://blogs.cornell.edu/berries/productions/berry-budgets/](https://blogs.cornell.edu/berries/productions/berry-budgets/).

Dale, A. 1992. Raspberry cultivars in eastern Canada. Fruit Var. J. 46(4):222–225.

Danek, J., and Z. Pasiut. 1991. Polana primocane fruiting raspberry cultivar. Fruit Sci. Rep. 18(3):103–105.

Daubeny, H. 1997. Raspberry, p. 635–662. In: Brooks and Olmo register of fruit and nut varieties. 3rd ed. ASHS Press, Alexandria, Va.

Daubeny, H.A., and C. Kempler. 1995. ‘Qualicum’ red raspberry. HortSci 30(7):1470–1472. doi: [10.21273/HORTSCI.30.7.1470](https://doi.org/10.21273/HORTSCI.30.7.1470).

Finn, C. 2014. Red raspberry plant named 'Vintage'. Patent 24,198, USA.

Goulart, B.L., and K. Demchak. 1999. Performance of primocane fruiting red raspberries. J. Am. Pom. Soc. 53(1):32–40.

Gundersheim, N.A., and M.P. Fritts. 1991. Pruning practices affect yield, Yield Components, and Their Distribution in ‘Royalty’ Purple Raspberry. J. Am. Soc. Hort. Sci. 116(3):390–395.

Hanson, E., S. Berkheimer, A. Schilder, R. Isaacs, and S. Kravchenko. 2005. Raspberry variety performance in southern Michigan. J. Am. Soc. Hort. Sci. 15(3):716–721.

Heiberg, N., R. Standal, and F. Máge. 2002. Evaluation of red raspberry cultivars in Norway. Acta Hort. 585:199–202. doi: [10.17660/ActaHortic.2002.585.31](https://doi.org/10.17660/ActaHortic.2002.585.31).

Jennings, D.L. 2008. Raspberry plant named 'Joan J’. Patent 18,954, USA.

Keep, E. 1989. Raspberry plant – Autumn Bliss cultivar. Patent 6,597, USA.

Knight, V.H. 2008. Raspberry plant named 'Autumn Treasure'. Patent 20,769, USA.

McGregor, G. 1996. Raspberry plant named ‘Dinkum’. Patent 9,477, USA.

Middlekauf, W.W. 1969. The cepheid stem borers of California. Bulletin of the California Insect Survey. Vol. 11. University of California Press, Berkeley.

Milivojević, J.M., M.D. Nikolić, J.J. Dragišić Maksimović, and D.D. Radivojević. 2010. Generative and fruit quality characteristics of primocane fruiting red raspberry cultivars. Turk. J. of Agric. For. 3:289–296.

Moller, A.L., and R.R. Gillies. 2008. Utah climate. 2nd ed. Utah Climate Center, Utah State University, Logan, Utah.

Naeve, L., and G. Nonnecke. 2010. Enterprise budget: Raspberries. Iowa State University Extension and Outreach. 24 Sep. 2020. [https://store.extension.iastate.edu/product/Enterprise-Budget-Raspberries](https://store.extension.iastate.edu/product/Enterprise-Budget-Raspberries).

Nonnecke, G.R., and J.J. Luby. 1992. Raspberry cultivars and production in the Midwest. Fruit Var. J. 46(4):201–212.
Okie, W.R. ed. 2004. Register of new fruit and nut varieties, list 42. HortSci. 39(6):1509–1523. doi:10.21273/HORTSCI.39.6.1509.

Safley, C.D., G.E. Fernandez, and D. Inhen. 2009. Cost of producing, harvesting and marketing primocane-fruiting raspberries in North Carolina: Estimated costs for a five acre commercial operation. North Carolina State University Extension. 24 Sep. 2020. <https://rubus.ces.ncsu.edu/rubus-blackberry-and-raspberry-budgets-pricing/>.

Swartz, H.J., J.A. Fiola, H.D. Stiles, and B.R. Smith. 2001. Raspberry plant named 'Josephine'. Patent 12,173, USA.

Villamor, S.S., C.H. Daniels, P.P. Moore, and C.F. Ross. 2013. Preference mapping of frozen and fresh raspberries. J. Food Sci. 78(6):911–919. doi: 10.1111/1750-3841.12125.

Yao, S., and C.J. Rosen. 2011. Primocane-fruiting raspberry production in high tunnels in a cold region of the upper Midwestern United States. HortTechnology 21(4):429–434. doi: 10.21273/HORTTECH.21.4.429.