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Adaptability of Primocane-fruiting Raspberry Cultivars to a High-elevation Arid Climate

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Abstract

Early-ripening, high-yielding cultivars with good consumer acceptance and few production problems are critical to the economic viability of growing primocane-fruiting raspberries for local consumption in high elevation arid climates. A replicated trial was planted in 2006 to evaluate 10 primocane-fruiting cultivars for suitability to commercial production in the US Intermountain West. Factors evaluated included annual yield, fruit size, fruiting season, consumer preference, incidence of fruit sunburn, and cane infestation by raspberry horntail, the most common cane-boring insect pest in northern Utah. The highest yields were for 'Joan J', averaging 3.58 kg per row meter, followed by 'Polana', 'Caroline' and 'Polka' with 2.59, 2.40 and 2.35 kg·m^{-1}, respectively. 'Polka' and 'Joan J' were the earliest fruiting with a harvest midpoint 21 and 18 days before 'Heritage', and consequently gave the highest yield reliability index. Panels and surveys showed highest consumer preference for 'Anne', 'Polka' and 'Joan J'. 'Jaclyn', 'Polana', and 'Joan J' fruit had the least sunburn. There was no difference among cultivars in susceptibility to raspberry horntail; the range was 1.1 to 3.1 infested canes per row meter. The cultivars 'Joan J' and 'Polka' give the best combination of yield reliability, reasonable fruit size, good consumer acceptance, and relatively low incidence of sunburn.

Raspberries have become a popular option for pick-your-own and pre-picked direct sales near urban centers throughout the U.S. In some areas of the Intermountain West, fresh local raspberries have become closely associated with the summer tourism industry, presenting an important market opportunity for small-acreage farms. Some of these areas have challenging growing conditions associated with arid high elevation (> 1,300 m) environments. These challenges include alkaline soil, limited irrigation water that is often alkaline, cold winter temperatures, and growing seasons limited by frequent late-spring and early-fall freezes. Producers in these areas have come to rely heavily on older floricane-fruiting cultivars that have shown reasonable winter cold hardiness. With the exception of 'Heritage', primocane-fruiting cultivars have not been tested extensively in these areas, but present the opportunity to expand the production window and to avoid the frequent yield losses associated with winter cane injury in floricane-fruiting cultivars. Obtaining commercially viable yields has been difficult with 'Heritage', and finding earlier cultivars with commercially acceptable fruit quality may overcome a primary limiting factor in adoption of primocane-fruiting production systems in this and other temperate regions (Dale, 1992; Nonnecke and Luby, 1992; Swartz et al., 1992).

Additional problems that are common to raspberry production in the Intermountain West include fruit sunburn due to hot summer days and high light intensity, and cane-boring insect pests. The raspberry horntail, *Hartigia cressonii* (Kirby), is the most common cane-borer in commercial and home garden raspberry production in northern Utah (Alston

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et al., 2009). It is known in other western states, including California, Colorado, Idaho, Montana, Nevada and Washington (Middlekauff, 1969), but literature on its biology and management is scarce. There is no published information on the susceptibility of different raspberry cultivars to the caneborer.

The objective of this research was to evaluate primocane-fruiting cultivars for suitability to field production in the high elevation valleys of the Intermountain West. The cultivars selected for trial were 'Anne' (Swartz et al., 1998a), 'Caroline' (Swartz et al., 1998b), 'Himbo Top®', 'Jaclyn' (Swartz et al., 2005), 'Joan J', 'Polana' (Danek and Pasiut, 1991), 'Ruby™' (Sanford and Reich, 1989) and 'Summit'. 'Heritage' (Ourecky, 1969), was included as a standard. Selection criteria were yield, fruiting season, fruit size, consumer acceptance, and susceptibility to the two primary problems in the region, fruit sunburn and infestation with the caneborer, raspberry horntail.

Materials and Methods

Planting. A replicated raspberry 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 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 2006, raspberry plants of nine primocane-fruiting cultivars were obtained from commercial nurseries and planted in four replicate plots arranged in a randomized block design with blocking by location within the field. The cultivar 'Polka' (Danek, 2002) was added in April 2007 in plots left vacant in the original design. Each plot was 3.66 m long, with 2.44 m space between plots in the row, and 3.05 m between rows. Each plot initially consisted of 6 nursery plants spaced 0.6 m apart within the row.

*Cultural practices.*The space between plots within the row was covered with landscape fabric (5 oz., Dewitt, Sikeston, MI) to suppress weeds and inhibit the raspberry cultivars from growing together. 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-emergence 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, and the edges of the alleyways were cultivated ~ three times per season to prevent grass from spreading into the raspberry row.

Plant nutrient needs were supplied with fertilizer applications of 135 $kg \cdot ha^{-1}$ of 16-16-16 NPK applied in mid April and again in early June, banded in the raspberry row. Only the primocanes were cropped, as all the canes in each plot were pruned to ground level at the end of each season. 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), 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 heights, placed every third row, at a 9.1 m in-row spacing, designed to supply 3.38 $mm \cdot h^{-1}$. Irrigation scheduling was based on crop and cover crop need, with approximately 25 mm per week applied through the overhead system and 17 to 25 mm per week applied by drip.

Data collection. In the 2008-2010 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, from late July until the first fall freeze, and total ripe fruit per plot weighed. For one harvest per week, mean fruit weight was determined on a 5-fruit subsample, and the largest mean fruit weight of the season was used to compare cultivars over the three seasons. Some plots produced a few ripe fruit sporadically for the first few weeks of harvest. This early production was likely the result of basal floricane buds that emerged near the soil surface. To better compare production season, 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 and season. These early-season and season-midpoint dates were then used to compare cultivars over the three seasons.

The amount of total fruit that was considered unmarketable was not recorded. The most common cause for unmarketable fruit was sunburn, followed by inadequate size, or the fruit becoming over ripe. Over-ripe fruit was most commonly found after the weekend, when the harvest interval was more than 2 days.

To compare fruit quality and consumer preference among cultivars, several evaluations were conducted. On 10 October 2008 and 10 September 2010, amateur taste panels were convened and instructed to taste fruit from each of the 10 cultivars and provide ratings for firmness, appearance, flavor and overall preference. Panels included 10 and 30 participants, respectively. During the 2011 growing season, yield and production season were no longer being evaluated, and all of the fruit from the planting was diverted for commercial sale, including at a local farmers' market. Harvested fruit was scored once each week for incidence of sunburn, and fruit taken to the farmers' market was used to conduct a consumer preference survey. The survey was open to any market attendee. From the preference panel carried out in 2010, it was determined that a written evaluation of multiple factors (firmness, appearance, and flavor) discouraged participation. A simple, non-written evaluation strategy was devised to increase participation and gauge overall preference of a wider population. One clamshell container of each cultivar was placed at the front of a display table with a small coin bank placed directly behind each clamshell. Each participant was then provided with 10 pennies and instructed to taste berries from each container and then 'vote' their preferences by placing pennies into the corresponding coin bank. Participants could place all 10 pennies in one bank, or distribute their 10 votes among the coin banks according to their preferences. Preference surveys were carried out on 8 Sept. and 22 Sept. 2011, with 29 and 63 participants, respectively.

Approximately weekly during June to August in 2009 to 2011, the number of canes with wilted tips and suspect for infestation with raspberry horntail were collected from each plot. Suspect canes were cut open and the presence of raspberry horntail larvae was determined.

A weather station located ~ 150 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 Orchard Weather Data network (http://climate.usu.edu, listed under "Plant Management Tools").

Data for yield, fruit size, harvest season, and raspberry horntail infestation for the three years were analyzed as repeated measures using the GLM procedure in the SAS software package (version 9.1, Cary, NC). Because yield showed such a strong cultivar × year interaction (P = 0.0035), a yield reliability index was calculated according to Kataoka (1963). Briefly, a reliability index is used to compare yields across 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 percent of the time. Sunburn incidence in 2011 was scored as a percent of the harvested fruit with bleached drupelets. Logit-transformed data were analyzed as repeated measures over five harvest dates.

Results and Discussion

Yield and harvest season were compared over three years, 2008 to 2010. The date of first fruit harvest was remarkably similar among years. The first fruit ripened on 23 July 2008, 24 July 2009 and 28 July 2010. These early fruits were primarily from short shoots that appeared to originate from basal floricane buds near the soil surface. The first significant primocane fruit harvest occurred on 1 August 2008, 3 August 2009 and 2 August 2010 (data not shown).

While the start of fruit harvest was similar across years, the length of the fruiting season and rate at which the season progressed, differed significantly among cultivars. In 2008 and 2009, fruit harvests continued until the first fall frosts, which occurred on 10 Oct. 2008 and 2 Oct. 2009. By contrast, fruit production in 2010 was markedly reduced by mid October with the last harvest on 21 October and the first freeze on 27 October. The average date of first fall freeze for this location is 13 October (Moller and Gillies, 2008). Total season yields showed a significant cultivar × year interaction (Table 1), but were not correlated with the length of the harvest season, as yields were generally the highest in the relatively short 2009 season and lowest in the long 2010 season. Clearly, fruit harvest progressed more quickly in 2009 than in 2008 or 2010. Although both the early-harvest and harvest-midpoint dates showed significant cultivar × year interactions (Table 2), both of these measures indicated a more rapid harvest progression in 2009. For example, in the case of 'Caroline' the harvest midpoint was 1 September in 2009, but did not occur until 23 and 29 September in 2010 and 2008, respectively. The reason for the difference in season progression is not clear, but may be due to weather conditions. Temperature effects on crop development are

Table 1. Total fruit yield over three seasons of 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 $kg \cdot m^{-1}$ is equivalent to 3.28 $Mg \cdot ha^{-1}$.

Cultivar	2008	2009	2010
		($kg \cdot m^{-1}$)	
Joan J	4.79 a	3.58 a	2.37 a
Polana	3.29 ab	3.35 ab	1.14 de
Caroline	2.39 bcd	2.97 abc	1.82 bc
Polka	2.51 bc	2.30 cd	2.25 ab
Summit	2.24 bcde	2.70 bcd	1.40 cd
Ruby	1.22 cde	2.03 d	0.95 def
Heritage	0.72 de	2.15 d	0.90 defg
Jaclyn	1.46 cde	1.36 e	0.71 efg
Himbo Top	0.93 cde	1.11 e	0.56 fg
Anne	0.63 de	1.17 e	0.39 g
Mean	2.02	2.27	1.25
Analysis of variance			
Cultivar	<0.001		
Rep	0.001		
Year	<0.001		
Cultivar*Year	0.004		

typically quantified based on accumulation of heat units such as growing degree hours or days. However, heat unit models don't always account for super-optimal temperatures or high temperature limits to growth. Black et al. (2008) found that the base and optimum temperatures for floral development in blackberry were 6 and 25°C, respectively, based on a linear model, but were unable to clearly define a maximum critical temperature. Fernandez and Pritts (1994) reported that photosynthetic rate of 'Titan' floricane-fruiting raspberry reached a maximum between 19 and 22°C and dropped dramatically at higher temperatures. However, Stafne et al. (2000) reported that only two of five raspberry cultivars, some with adaptation to warmer climates, had significant reductions in photosynthesis as air temperatures increased from 20 to 30°C. Average daily air temperatures in northern Utah in August and September often exceed 22°C, with daytime maxima exceeding 30°C. These super-optimal temperatures may partially account for annual differences in the progression of the crop, and the significant cultivar × year interaction. Air temperatures during the month of August were typically cooler in 2009, than in 2008 or 2010, with average temperatures of 22.1, 24.0 and 22.9°C, respectively. Total daily solar radiation during August was also lower in 2009 than in 2008 or 2010. Determining the degree to which these light and temperature conditions account for differences in growth rate, floral development, and fruit ripening would require more complex growth models than are currently available.

Among cultivars, 'Joan J' consistently had the highest yields and 'Anne' and 'Himbo Top' consistently had the lowest yields (Table 1). Because of the significant cultivar × year interaction for yield, a yield reliability index was calculated. In high elevation temperate climates where early fall frosts often limit the productivity of fall raspberries, total yields are typically correlated with earliness (Goulart and Demchak, 1999; Nonnecke and Luby, 1992). Figure 1 shows yield and

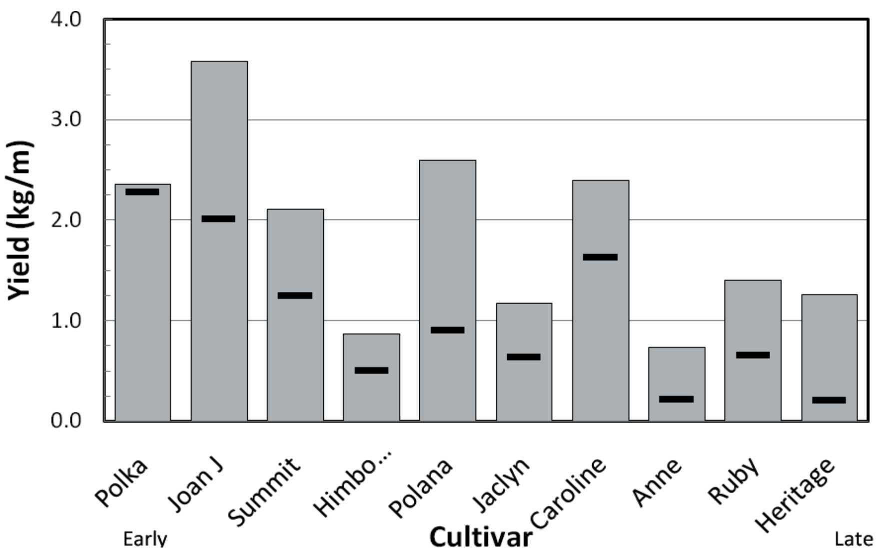

Fig. 1. Average yield and yield reliability index of 10 primocane-fruiting raspberry cultivars at the USU Kaysville Research Farm from 2008 to 2010. Yield reliability index (75%) is shown by the horizontal bars, and represents the minimum yields that could be expected in 75% of the years. Cultivars are listed from earliest to latest. Yields are reported as kg of fruit per row meter.

Table 2. Harvest season as indexed by early harvest and harvest midpoint. Cumulative yields were calculated with early harvest and harvest midpoint representing the mean date at which cumulative yield reached 20% and 50% of the season total, respectively. Relative date is expressed as earliness relative to 'Heritage'.

Cultivar	2008		2009		2010		Mean	Relative date
Early harvest (20% of cumulative yield)								
Polka	30-Aug	ef	17-Aug	c	12-Aug	e	19-Aug	-27
Joan J	7-Sep	de	13-Aug	c	23-Aug	de	24-Aug	-22
Summit	5-Sep	de	16-Aug	c	5-Sep	c	28-Aug	-18
Himbo top	14-Sep	bcd	14-Aug	c	28-Aug	cd	28-Aug	-18
Polana	26-Aug	f	15-Aug	c	17-Sep	ab	29-Aug	-17
Jaclyn	13-Sep	cd	13-Aug	c	5-Sep	c	30-Aug	-16
Caroline	18-Sep	bc	26-Aug	ab	7-Sep	bc	6-Sep	-9
Anne	22-Sep	abc	22-Aug	b	17-Sep	ab	9-Sep	-6
Ruby	22-Sep	ab	30-Aug	a	22-Sep	a	14-Sep	-1
Heritage	28-Sep	a	27-Aug	a	23-Sep	a	15-Sep	0
Mean	12-Sep		19-Aug		6-Sep			
Harvest midpoint (50% of cumulative yield)								
Polka	18-Sep	d	25-Aug	c	29-Aug	f	3-Sep	-21
Joan J	22-Sep	cd	20-Aug	d	10-Sep	e	6-Sep	-18
Himbo top	25-Sep	bc	23-Aug	cd	13-Sep	de	9-Sep	-15
Jaclyn	22-Sep	bc	23-Aug	cd	19-Sep	cde	10-Sep	-14
Summit	20-Sep	cd	25-Aug	c	21-Sep	cd	11-Sep	-13
Polana	18-Sep	d	25-Aug	c	3-Oct	a	14-Sep	-10
Caroline	29-Sep	ab	1-Sep	b	23-Sep	bc	17-Sep	-7
Anne	30-Sep	ab	2-Sep	b	1-Oct	ab	20-Sep	-4
Heritage	5-Oct	a	4-Sep	b	5-Oct	a	24-Sep	0
Ruby	2-Oct	a	10-Sep	a	5-Oct	a	25-Sep	1
Mean	25-Sep		28-Aug		22-Sep			

Analysis of variance

	Early	Midpoint
Cultivar	<0.001	<0.0001
Rep	0.67	0.68
Year	<0.001	<0.0001
Cultivar*Year	<0.001	<0.0001

Within-year means separation by LSD. Cultivar means followed by the same letter are not significantly different at $P = 0.05$.

yield reliability index of the 10 cultivars, where cultivars are listed in order of earliness (Table 2). 'Himbo Top', 'Jaclyn' and 'Anne' were all consistently low yielding. Among the remaining cultivars, both yield and yield reliability appeared to be correlated with earliness (Figure 1). Interestingly, 'Joan J' was among the earliest cultivars in our study reaching 20% of total production 21 days earlier than 'Heritage', with 'Caroline' only 6 days earlier than 'Heritage'. By contrast Yao and Rosen (2011) found 'Joan J' to be later than 'Polana' and only slightly earlier than 'Caroline'. Over the three years, yields for 'Caroline' ranged from 1.82 to 2.97 $kg \cdot m^{-1}$ which at this row spacing is equivalent to 5.97 to 9.73 $Mg \cdot ha^{-1}$. This is somewhat higher than previous reports for this cultivar of 6.3 Mg·ha^{-1} in Pennsylvania (Goulart and Demchak, 1999), 6.07 Mg·ha^{-1} reported for Michigan (Hanson et al., 2005), and 4.51 Mg·ha^{-1} reported for field production in Minnesota (Yao and Rosen, 2011).

Of particular interest is the comparison between the two earliest cultivars 'Polka' and 'Joan J'. Averaged over the three years, yields for 'Joan J' were much higher than for 'Polka' at 3.58 and 2.35 kg·m^{-1}, respectively. However, yields for 'Polka' were much more consistent from year to year, resulting in a very similar RI_{75} for both cultivars (2.28 and 2.01 kg·m^{-1} for 'Polka' and 'Joan J', respectively). While 'Polka' was the earliest of the cultivars, the smaller yield potential was realized in all of the three seasons. By comparison, 'Joan J' appeared to have higher yield potential, and had higher yields when weather conditions remained favorable.

Fruit size showed a significant year × cultivar interaction ($P = 0.010$), but 'Anne', and 'Ruby' were consistently among the cultivars with the largest fruit size, whereas 'Summit' and 'Heritage' typically had the smallest fruit (Table 3). Interestingly, both the largest and smallest average fruit sizes were from cultivars that did not yield well in this location. Five of the 10 cultivars included in this study ('Anne', 'Caroline', 'Heritage', 'Polana', 'Ruby') were also compared in Pennsylvania (Goulart and Demchak, 1999), and fruit sizes for these cultivars were very similar at both locations.

Consumer preference was evaluated on four different dates, and using two different methods. With the exception of the 2010 panel rating, where three of the cultivars were not available for evaluation, preferences were remarkably consistent (Table 4). The cultivars 'Anne' and 'Polka' consistently ranked highest, whereas 'Summit', 'Himbo Top' and 'Caroline' typically showed the lowest levels of consumer preference.

Under the high light, high temperature and low humidity conditions typical of a high elevation arid climate, sunburned or bleached druplets are one of the most common limitations to marketability. While the problem is more typically associated with floricane-

Table 3. Average fruit size of primocane-fruiting cultivars over three seasons at the Kaysville Research Farm, Kaysville, Utah.

Cultivar	2008		2009		2010		Mean
			(g/fruit)				
Anne	3.10	ab	2.76	a	2.95	a	2.94
Ruby	3.45	a	2.09	bc	2.65	ab	2.73
Joan J	3.53	a	1.96	bcd	2.65	ab	2.71
Caroline	3.43	a	2.23	b	2.35	b	2.67
Polka	3.10	ab	2.28	b	2.47	ab	2.62
Himbo top	3.20	a	1.99	bcd	2.45	ab	2.55
Jaclyn	2.98	ab	1.96	bcd	2.30	b	2.41
Polana	2.63	b	1.90	bcd	2.20	b	2.24
Heritage	2.63	b	1.60	cd	2.15	b	2.12
Summit	1.53	c	1.46	d	1.55	c	1.51
Mean	2.96		2.02		2.37		
Analysis of variance							
Cultivar	<0.001						
Rep	0.049						
Year	<0.001						
Cultivar*Year	0.010						

Within-year means separation by LSD. Cultivar means followed by the same letter are not significantly different at $P = 0.05$.

Table 4. Fruit quality and consumer preferences ratings of 10 primocane-fruiting raspberries. Panel ratings were from amateur panels (10 October 2008, 10 Sept. 2010) that subjectively scored fruit for firmness, appearance and flavor, and then rated overall preference on a 1 to 5 scale, where 5 represented the most desirable. Consumer rating was based on votes cast at a farmer's market in 2011 (10 votes per participant).

	Panel rating (1-5)		Market survey (% of votes cast)	
Cultivar	Oct. 2008	Sept. 2010	8 Sept.	22 Sept.
Anne	4.4 a	--*	34.8	21.3
Polka	4.2 ab	3.39 b	22.7	18.4
Heritage	3.4 abc	--	9.4	11.0
Joan J	3.0 bc	3.85 a	9.4	10.3
Jaclyn	2.9 bc	3.44 b	7.0	7.7
Himbo Top	2.7 bc	3.59 ab	4.3	5.5
Polana	2.7 bc	3.84 a	3.9	5.7
Summit	2.6 c	2.98 c	2.0	5.2
Ruby	2.4 c	--	--	7.7
Caroline	2.3 c	3.33 b	6.6	7.2

Within-year means separation by LSD. Cultivar means followed by the same letter are not significantly different at $P = 0.05$.
*Ripe fruit of 'Anne', 'Heritage' and 'Ruby' were not available for the Sept 2010 taste panel.
Since the preference of individual participants in the market survey was not recorded, statistical analysis is not possible.

than primocane-fruiting raspberries, it still can result in significant loss of marketable yields. Significant differences were found among cultivar ($P = 0.006$) and harvest date ($P = 0.02$), with no significant cultivar × harvest date interaction (Table 5). 'Ruby' and 'Heritage' had the highest levels of sunburn, with 14.4 and 13.9% of fruit affected, respectively. The lowest levels of sunburn were found in 'Jaclyn', 'Polana' and 'Joan J'.

The average number of canes infested with raspberry horntail ranged from 1.1 to 3.1 per m of row, but was not significantly different among cultivars (Table 5). There was a significant influence of year on raspberry horntail infestation, where number of infested canes was more than 56% lower in 2010 and 2011 as compared to 2009, the first year of horntail monitoring. These results support the benefit of frequent pruning and removal of infested canes, such as was done with our sampling protocol. In addition, pruning back primocane-fruiting canes in the fall or following spring before adults emerge from overwintering chambers in the canes may reduce raspberry horntail infestation.

Growing raspberries in an arid continental climate above 1300 m elevation presents a number of challenges. However, opportunities for local direct sales of raspberries remain a strong incentive for diversified small-acreage operators. With the high risk of early fall frosts, early-fruiting cultivars present the best chance of obtaining consistent economic yields from primocanes. The fruiting season of the 10 cultivars included in this study differed from other published reports. Based on results presented here, 'Joan J' and 'Polka' give the highest level of yield reliability, reasonable fruit size, good consumer acceptance, and relatively low incidence of sunburn. Although no differences in raspberry horntail infestation were found among the 10 cultivars, this is the first published report comparing susceptibility of primocane-fruiting cultivars to this cane-boring insect pest. Reductions in infestation across the three years of the study support the value of pruning as a key cultural practice for management of raspberry horntail.

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Table 5. Incidence of two common problems, fruit sunburn and raspberry horntail infestation, in ten primocane-bearing raspberry cultivars growing at Kaysville, Utah. Sunburn damage was scored as the percent of fruit affected at each harvest, during the 2011 season. The average number of raspberry horntail infested canes per row m was determined approx. weekly from June through August in 2009 to 2011.

Cultivar	Sunburn (%)		Horntail incidence (#/m)
Ruby	14.4 a		2.2
Heritage	13.9 a		2.8
Caroline	11.9 ab		1.8
Himbo Top	11.9 ab		2.6
Anne	11.3 abc		3.1
Polka	9.3 abcd		2.1
Summit	8.3 bcd		1.9
Joan J	6.3 cd		2.2
Polana	6.0 d		1.1
Jaclyn	5.8 d		2.1
		2009	3.7 a
		2010	1.4 b
		2011	1.6 b
Analysis of variance			
Cultivar	0.006	Cultivar	0.5
Rep	0.22	Rep	0.58
Harvest	0.02	Year	0.009
Cult*Harv	0.081	Cult*Year	0.77

Means for cultivar and year followed by the same letter are not significantly different at $P = 0.05$, as determined by LSD.

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Disclaimer

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

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Approach to assess infrared thermal imaging of almond trees under water-stress conditions.

Introduction. Optimising agricultural water use implies the combination of physiological, technological and engineering techniques, especially those for continuously monitoring the water status of plants subjected to deficit irrigation. A methodology to estimate water stress of young almond trees from thermal images was developed based on assessing the physiological status of almond crops under limited water-supply conditions. **Materials and methods**. Two irrigation treatments were tested during the maximum evapotranspirative demand period (214th to the 243rd day of the year) in an experimental almond [*Prunus dulcis* (Mill) D.A. Webb, cv. Guara] orchard: a low-frequency deficit irrigation (LFDI) treatment, irrigated according to the plant-water status, and a fully irrigated treatment (C100) at 100% of crop evapotranspiration. Daily canopy temperature at midday (TC) was measured with an infrared camera, together with standard measurements of stem-water potential (Ψ_{Stem}) and stomatal conductance (g_s). The time course of these parameters and their relationships were analysed. **Results and discussion**. The time course of the parameters studied showed highly significant correlations among the differentials of canopy-air temperature (ΔT), Ψ_{Stem} and g_s. The methodological protocol for analysing thermal images allowed a time saving in processing information and additionally offered the possibility of estimating the Ψ_{Stem} and g_s values. **Conclusion**. Our results confirm that infrared thermography is a suitable technique for assessing the crop-water status and can be used as an important step towards automated plant-water stress management in almond orchards. Abstract from: Iván García-Tejero, Víctor Hugo Durán-Zuazo, Javier Arriaga, Almudena Hernández, Luisa Maria Vélez and José Luis Muriel-Fernández, 2012. Fruits 67(6):463-474.