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High Tunnel Performance of Seven Primocane Red Raspberry Cultivars in Western NY

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Abstract

Seven primocane fruiting red raspberry (*Rubus idaeus* L.) cultivars ('Autumn Britten', 'Caroline', 'Heritage', 'Himbo Top', 'Jaclyn', 'Joan J' and 'Polka') were cultivated under high tunnels to assess their relative performance in a protected agriculture system in western New York. 'Joan J' had the highest yield over three seasons averaging over 14 t·ha^{-1} per year while 'Autumn Britten' and 'Jaclyn' were the lowest yielding with mean annual yields of less than 7.5 t·ha^{-1} per year. 'Caroline', 'Himbo Top', 'Polka' and 'Heritage' produced intermediate yields similar to each other. 'Autumn Britten' had the greatest mean annual berry weight but was very similar to 'Jaclyn', 'Himbo Top', 'Joan J', and 'Polka'. 'Heritage' consistently had the lowest mean berry weight in all years. The beginning of harvest varied widely from season to season. It started as early as 23 July and as late as 11 Aug. in the earliest cultivar, 'Autumn Britten', with a similar range among the remaining cultivars. Harvest lasted for 6 to 9 weeks for individual cultivars depending on cultivar and approximately 10 weeks across all cultivars in a given season. The cultivars 'Joan J', 'Himbo Top', 'Polka' and 'Heritage' showed the best potential to produce high quality fruit over extended period using high tunnels in New York and regions of similar climate.

Red raspberry (*Rubus idaeus* L.) production in the eastern United States has a long history and was once concentrated in New York state with over 4,200 ha under cultivation in 1919 (Hedrick, 1925). That is greater than the area that was cultivated in California in 2016 (USDA-NASS, 2017) although the historical industry was primarily for processing berries using floricane cultivars, and productivity was considerably lower. Over the last 100 years, market conditions and production problems have reduced the eastern industry to hundreds of hectares across the region. The vast majority of U.S. production today is centered in California for fresh market sales and in Washington for frozen berries used whole or in processing (USDA-NASS, 2017). The increased availability of fresh raspberries in supermarkets made possible through improvements in production practices in combination with the adoption of primocane fruiting cultivars in warm climate production regions (Pritts, 2008) has also driven interest in local sources of fresh raspberries for farm-direct retail outlets and farmers' markets as well as regional wholesale outlets in the Northeast. Increased demand for locally grown fruit for use in local processing for the tourist trade has also provided more opportunities for growers in the temperate regions in the Midwest and Northeastern U.S. to market fruit directly.

The introduction of high tunnels for raspberry production has been instrumental in the expansion of the fresh market raspberry industry in the U.S. and around the world (Gaskell, 2004). Fruit quality improvements due to post-harvest handling advances combined with new cultivars enabled the widespread shipment of fresh raspberries from production areas in the west to the entirety of the U.S. This technology has also made widespread production in temperate regions more feasible and possibly competitive to

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California production of fresh raspberries, when all cost and productivity factors are considered. Multiple reports on performance of open field (Goulart and Demchak, 1999; Hanson et al., 2005; Weber et al. 2005) and high tunnel (Demchak, 2009; Hanson et al., 2011; Yao and Rosen, 2011) trials with primocane cultivars in temperate climate conditions have been published. However, many of the cultivars that were evaluated are not currently grown widely and information on the performance of some newer cultivars is unavailable to growers.

The goal of this project was to compare the performance of seven currently available commercial primocane fruiting raspberry cultivars in a high tunnel production system to aid in evaluating their suitability for the system and to demonstrate the potential for fresh red raspberry production in New York. Yield components and fruit quality observations were made to evaluate the potential of the cultivars for NY production and their utility for use in the Cornell berry breeding program for the development of improved cultivars for protected production in temperate climate regions.

Materials and Methods

A trial of seven primocane fruiting red raspberry cultivars was established in a randomized complete block design at Cornell University's New York State Agricultural Experiment Station (NYSAES) in Geneva, NY (lat. 42°8'N, long. 77°0'W). The cultivars included 'Autumn Britten', 'Caroline', 'Heritage', 'Himbo Top' (cv. 'Rafzaqu'), 'Jaclyn', 'Joan J' and 'Polka', which represent standard and newly introduced cultivars in the region from multiple breeding programs around the world (Weber, 2013). Bare root canes of each cultivar were sourced from commercial nurseries and planted in 30.5 cm high raised beds in a Honeoye loam soil with less than 3% slope in a 3-bay (7.32 m width) high tunnel structure (Haygrove Ltd., Ledbury, UK). Each bay was treated as a block in a randomized complete block design with one 6-plant plot (5.49 m per plot) of each cultivar randomly located in each block (bay). Initial in-row spacing was 0.9 m within row and 2.44 m between row centers with 3 rows in each bay.

A three-level V-trellis with a width of 46 cm at the base and 60 cm at 1.5 m height was installed after planting and drip irrigation was provided to deliver approximately 25 mm of water per week after the tunnels were covered prior to bloom and approximately 51 mm of water per week during the fruit development period through harvest after which the tunnel covers were removed for the winter. Fertilization was based on recommendations for high tunnel (Heidenreich et al., 2012) and field production practices (Bushway et al., 2008) and was applied through the drip irrigation. Weed barrier fabric (GreenhouseMegastore, International Greenhouse Co., Danville, IL) was applied between the rows and supplemental hand weeding was utilized within the rows. Predator mites (*Phytoseiulus persimilis*) (Biobest USA, Inc., McFarland, CA) were released prophylactically three times each summer to suppress two-spotted spider mite (*Tetranychus urticae* Koch) populations. To ensure good pollination, a quad-hive of bumble bees (*Bombus impatiens* Cresson) (Biobest USA, Inc., McFarland, CA) was placed at the end of the tunnel at the beginning of bloom each year.

Fruit was harvested for the same 2 m of row within each block for three seasons after the establishment year for annual and cumulative yield calculations. The first harvest began approximately 14 months after planting. Yield was converted to $t \cdot ha^{-1}$ based 4099 m of $row \cdot ha^{-1}$ at the spacing stated above. Fruit were harvested on Mondays, Wednesdays and Fridays, for each plot throughout the harvest period. For mean fruit weight calculations, a random 10-fruit sample was taken at each harvest date per block per cultivar being harvested. Mean fruit weight values over the whole season were calculated for each year, and total mean fruit weight values across all three years were calculated. All mean yield

and fruit weight values for each cultivar were subjected to one-way analysis of variance (ANOVA) and mean separation by Duncan's multiple range test ($P \leq 0.05$) using Microsoft Excel software (Microsoft Corp., Redmond, WA) following the procedures of Gomez and Gomez (1984). Harvest began when any plot had ripe fruit and ended when the last plot had fruit. The date of first harvest, peak harvest, and last harvest were recorded each year for each cultivar with peak harvest being the date with the greatest 3-plot cumulative daily yield. Air temperature and rainfall measurements were recorded at the New York State Agricultural Experiment Station Research North Farm weather station approximately 1.5 km from the trial site to identify any gross differences in annual weather conditions between years that may have affected the trial results.

Results and Discussion

The performance of the cultivars in the trial under high tunnels compared very favorably to similar trials in open field conditions (Goulart and Demchak, 1999; Hanson et al., 2005; Weber et al., 2005; Yao and Rosen, 2011). Mean yield across the cultivars in the first season was over 89% higher compared to an open field trial previously conducted in a nearby field at the NYSAES (Weber et al. 2005) and 48% higher than first season yields in Michigan (Hanson et al., 2005). Yields in subsequent seasons were similarly higher. While these studies cannot be compared directly because they were completed in different years and with a different cultivar mix, they were completed under similar conditions with several of the same cultivars. These same cultivars showed similar yield differences between trials as the overall mean comparisons, suggesting that the comparison between high tunnel and open field systems provides a good estimate of predicted performance.

Mean yields across the cultivars in this trial were highest in harvest seasons one and two, at over 10 $t \cdot ha^{-1}$ but with wide differences among the cultivars (Table 1). This is less than that achieved by Demchak (2009) in Pennsylvania and by Yao and Rosen (2011) in Minnesota but still double or more

Table 1. Yield of seven primocane red raspberry cultivars in a high tunnel field trial at Geneva, NY over three harvest seasons. Field spacing was equivalent to 4099 m of $row \cdot ha^{-1}$ at 3.44 m center to center row spacing.

Cultivar	Mean yield[z] ($t \cdot ha^{-1}$)[y]			Total cumulative Yield[x] ($t \cdot ha^{-1}$)[y]
	Year 1	Year 2	Year 3	
Joan J	14.9 a	15.6 a	12.5 a	43.0 a
Caroline	11.6 b	12.3 ab	8.9 ab	32.8 b
Himbo Top	9.8 bc	10.7 ab	9.4 ab	29.9 bc
Polka	11.6 b	9.4 bc	8.1 b	29.2 bcd
Heritage	8.4 c	10.8 ab	8.6 b	27.8 bcd
Jaclyn	11.7 b	4.8 c	6.0 b	22.5 cd
Autumn Britten	7.6 c	7.2 bc	5.8 b	20.6 d
Mean[w]	10.8	10.1	8.5	

[z] Means (n=3) within columns followed by common letters are not significantly different by Duncan's multiple range test at $P \leq 0.05$.

[y] Multiply $t \cdot ha^{-1}$ by 890 for equivalent $lb \cdot ac^{-1}$.

[x] Mean for all cultivars.

Table 2. Mean fruit weights of seven primocane red raspberry cultivars over three harvest seasons at Geneva, NY.

Cultivar	Mean fruit weight [z] (g)			Three-year mean fruit weight [z,y] (g)	Maximum 10-fruit mean weight (g)			Minimum 10-fruit mean weight (g)		
	Yr1	Yr2	Yr3		Yr1	Yr2	Yr	Yr1	Yr2	Yr3
Autumn Britten	3.09 a	3.03 a	3.03 a	3.05 a	3.8	3.9	3.6	2.3	2.0	2.2
Jaclyn	3.09 a	2.87 a	2.87 ab	2.95 a	3.9	3.8	3.3	2.3	2.4	2.6
Himbo Top	3.01 a	2.99 a	2.81 ab	2.93 a	4.5	3.9	3.4	2.1	2.2	2.3
Joan J	2.90 ab	3.05 a	2.72 ab	2.89 a	5.0	4.0	3.7	1.9	2.2	2.0
Polka	2.63 bc	2.96 a	2.95 ab	2.84 a	3.4	4.0	3.4	1.9	2.2	2.2
Caroline	2.53 c	2.63 a	2.50 bc	2.55 b	3.4	3.8	3.5	1.7	1.7	1.8
Heritage	2.10 d	1.82 b	2.28 c	2.07 c	3.0	2.8	2.0	1.6	1.0	1.2
Mean[x]	2.76	2.76	2.74							

[z] Means (n=3) within columns followed by common letters are not significantly different by Duncan's multiple range test at $P \leq 0.05$.
[y] Mean across all three harvest seasons.
[x] Seasonal mean across all cultivars.

than some field trials (Goulart and Demchak, 1999; Yao and Rosen, 2011). Overall yield in harvest season three was lower than in the first two seasons and this was consistent among all cultivars except 'Jaclyn' where the lowest yield was in season two (Table 1). Over the three harvest seasons, 'Joan J' was consistently the highest yielding cultivar with 'Caroline' and 'Himbo Top' having similar yield in seasons two and three but significantly less cumulative yield over the three season period. Overall there was a 2-fold difference in cumulative yield among the cultivars over three harvest seasons (Table 1).

Additionally, mean fruit weight was higher in this trial compared to some of the same cultivars in the open field trials, with the overall average of 2.8g per fruit in this trial compared to 1.7g in the first season of the open field trial in NY (Weber et al., 2005). This trend of larger/heavier fruit was consistent over subsequent seasons. The mean fruit weight of the cultivars was also consistent over the three harvest seasons (Table 2). 'Autumn Britten' consistently produced the largest fruit (though not significantly larger than most other cultivars in the trial) and 'Heritage' the smallest (Table 2). 'Jaclyn', 'Himbo Top', 'Joan J' and 'Polka' were all very similar to 'Autumn Britten' with 'Caroline' being intermediate. In the Michigan (Hanson et. al., 2005) and Minnesota trials (Yao and Rosen, 2011) the size difference between tunnel production and open field production was not as pronounced but the general trend was the same.

The fruit in this trial was largest at the beginning of the season and dropped off in size as the season progressed, which also occurred in the Minnesota trial (Yao and Rosen, 2011). However, the lowest fruit weights in most plots were recorded at or just following the peak harvest date before rebounding towards the end of the season when the crop load was reduced. The rebound often lasted until the final harvests in the last week to 10 days. The decline in fruit size was as much as 64% in 'Heritage' in year 2, but the mean decline for 'Heritage' over all 3 seasons was only 36%. The greatest mean seasonal fruit weight decline over the 3 seasons was observed in 'Caroline' at 51%, followed closely by 'Joan J' (47%) and 'Polka' (44%). Growers will need to determine their own thresh-

old for when fruit weight and crop load make harvest uneconomical. Further research may be useful in determining if the observed fruit size reduction near peak crop load can be mitigated through more precise water management leading up to this period. The lowest mean fruit weight declines were recorded for 'Himbo Top', 'Autumn Britten' and 'Jaclyn' at 26%, 30% and 31%, respectively. This wide difference in fruit weight uniformity among the cultivars suggests a strong genetic effect on this character. Therefore, improving this uniformity is likely to be possible through breeding. Future trials with newer cultivars will determine if progress has been made and the potential for future improvements.

The length of the harvest season extended to several weeks for all cultivars, starting as early as 23 Jul. in year 1 and as late as 11 Aug. in year 2 for the early cultivars (Table 3) and lasted 10 weeks cumulatively each year for all the cultivars (Table 3). The late cultivars in this trial stretched the season into Oct. in each year (Table 3). The harvest ended each year not due to cold weather as is often observed in open field production but due to the fruit all being harvested. With the recent development of later producing cultivars, production using high tunnels could stretch well into Nov. in most years in central NY, possibly replacing 'Heritage' as the standard late season cultivar with a cultivar with larger fruit.

Overall, the performance of all seven cultivars under high tunnels was better than that observed in outdoor trials. Pest control requirements were also significantly reduced in the tunnels. No fungicides were used at

Table 3. Harvest dates for 7 primocane raspberry varieties grown under high tunnels over three harvest seasons in Geneva, NY.

Cultivar	Harvest Season	1st Harvest Date[z]	Last Harvest Date[y]	Peak Harvest Date[x]	Season Length (days)
Autumn Britten	1	Aug 11	Sept 28	Sept 1	49
	2	Jul 23	Sept 1	Aug 9	41
	3	Aug 3	Sept 30	Aug 24	59
Caroline	1	Aug 25	Oct 16	Sept 17	53
	2	Aug 9	Sept 24	Aug 20	47
	3	Aug 15	Sept 23	Aug 24	40
Heritage	1	Aug 28	Oct 16	Sept 18	50
	2	Aug 16	Oct 2	Aug 27	48
	3	Aug 17	Oct 11	Sept 12	56
Himbo Top	1	Aug 18	Oct 16	Sept 4	60
	2	Jul 30	Sept 17	Aug 25	53
	3	Aug 3	Sept 26	Aug 30	55
Jaclyn	1	Aug 17	Oct 12	Sept 9	57
	2	Jul 30	Sept 20	Aug 13	53
	3	Aug 8	Sept 23	Sept 6	47
Joan J	1	Aug 17	Oct 16	Sept 9	61
	2	Jul 26	Sept 20	Aug 18	56
	3	Aug 8	Sept 26	Aug 29	50
Polka	1	Aug 18	Oct 8	Sept 16	52
	2	Jul 23	Sept 20	Aug 18	60
	3	Aug8	Sept 30	Aug 22	54
Whole Planting	1	Aug 11	Oct 16		67
	2	Jul 23	Oct 2		72
	3	Aug 3	Oct 11		70

[z] Date when any plot had ripe fruit.
[y] Date when the last fruit from any plot was harvested.
[x] Date with the highest total yield.

any time in the trial and only minimal hand weeding was needed for weed control within the rows. Even without fungicide treatments, no appreciable fruit rots were observed. However, spotted winged drosophila (*Drosophila suzukii*) has become a serious pest in raspberry production in most if not all production regions in the U.S. including NY. A diligent insecticide spray program rotating recommended chemical classes (Pritts et al., 2015) or complete exclusion with netting (http://blogs.cornell.edu/swd1/2016/04/19/exclusion-netting-against-swd/) is currently required to control this pest in order to have marketable fruit.

Additionally, in the first year of production, there were symptoms associated with feeding by potato leafhoppers (*Empoasca fabae*), especially in the cultivars 'Polka' and 'Jaclyn'. These insects moved into the tunnel after the first mowing around the outside of the tunnels. Damage observed included stunted canes, twisted leaves and yellowing of the leaves similar to a nutritional deficiency or viral infection. Considerable damage was done to developing fruit at the time of infestation but, if yield was affected, the effects were marginal as new growth developed normally and overall yield was similar to unaffected cultivars (Table 1). The extent that the tunnel system exacerbated the leafhopper infestation or symptoms is not known but little leafhopper damage has been observed in open production trials at this location. In subsequent seasons, more careful management of the vegetation surrounding the tunnels kept leaf hopper damage to a minimum and yield for 'Polka' and 'Jaclyn' were in line with most of the other cultivars though tending to be in the lowest grouping (Table 1).

It is important to note that while all the cultivars tested performed very well compared to open field conditions, many displayed characteristics that may limit their suitability for some markets. Dark red fruit color, especially after storage was observed in many cultivars, especially 'Joan J', 'Polka' and 'Jaclyn', making them less than ideal for wholesale markets and some retail outlets. Fruit from 'Autumn Britten' and 'Caroline' could also be dark when overripe or after a few days of storage but were not as problematic as the former varieties. Dark red fruit was most problematic in 'Jaclyn' because this cultivar is very difficult to detach until it is completely ripe (when the fruit is darkest). The receptacle is elongated and thin and adheres tightly in the fruit cavity. This can cause damage when extra force is needed for picking. These fruit characteristics severely limit the usefulness of 'Jaclyn' even though it has superior flavor. The darker fruit color observed in many of these cultivars is often perceived by consumers as being overripe and having poor shelf life. This is especially problematic for red raspberries because of their relatively high cost and short shelf life compared to other fresh fruits. This is less problematic in local markets in which fruit is marketed soon after harvest and consumers can often obtain information from the grower concerning variation in cultivars and when the fruit was harvested.

'Himbo Top' had some of the best fruit quality with bright, shiny red, firm fruit with good flavor. However, the fruit was noticeably softer when temperatures at harvest were high, requiring immediate chilling to maintain fruit quality. Additionally, 'Himbo Top' canes are taller than the other cultivars tested. This, in combination with long fruiting laterals and a crop concentrated on the top third of the plant, makes them top-heavy and prone to weeping. Considerably more trellising is required compared to the other cultivars in order to keep the canes upright and easy to harvest. This greater cane height, however, does present the potential of double cropping the floricanes of 'Himbo Top' in the summer since considerable cane length for fruiting remains at the end of the fall (primocane) season. Managing this system can be done but was outside the scope of this study.

'Caroline' performed very well but was very vigorous and the thick foliage often obscured the fruit and slowed harvest. This led to un-

picked ripe fruit, which then became overripe fruit with poor shelf life in the next harvest and a target for spotted wing drosophila infestation. Careful and thorough harvest is required to best manage this cultivar. It may also benefit from primocane thinning and precise trellising to mitigate the problem. Conversely, 'Autumn Britten' was the least vigorous cultivar based on sucker production. It was the lowest yielding cultivar, mainly due to fewer canes for harvest. It had very good fruit quality in firmness and flavor, though it too could be dark. Higher initial plant density and careful attention to nutrition may be useful in increasing cane density to increase overall yield.

'Heritage', the standard primocane cultivar for the region, performed as expected with very good cane development and fruit numbers. The round shaped fruit was typically smaller than other cultivars, which reduced harvest efficiency and made it less desirable in the marketplace. However, fruit quality was consistent and local consumers did not object to the size. Overall, even with some shortcomings in the cultivars, none of the fruit was rejected by local wholesale buyers who reported that the fruit was acceptable for local markets. The use of high tunnels for raspberry production continues to be adopted by local producers as the benefits become recognized. Current cultivars can meet the immediate demand for local fruit, but improvements in size, color and yield are required for the industry to expand and take advantage of the expanding local market. Additional trials on more recently developed cultivars would also be useful to local growers.

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