

# Response of Potted Red Raspberry Cultivars to Double-cropping under High Tunnels

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**Abstract.** Red raspberry cultivars that produce fruit on current-season canes (primocanes) can produce additional fruit the following year as second-year floricanes, termed double-cropping. The purpose of this study was to compare raspberry cultivars for double-cropping potential in a potted growing system under high tunnels in southwest Michigan. The cultivars Encore (floricanes fruiting only), Imara, Josephine, Kwanza, Kweli, Nantahala, Nova, and Prelude were grown for 3 years in 11-L pots under a high tunnel. ‘Imara’, ‘Kweli’, and ‘Prelude’ produced the greatest total yields, averaging 2.7 kg/plant during the last 2 years. ‘Imara’ and ‘Kweli’ also produced large fruit that retained high fruit quality after storage. ‘Prelude’ was the earliest to ripen floricanes fruit, and ‘Encore’, ‘Josephine’, and ‘Nantahala’ were the latest. The start of primocane fruit harvest varied by year, but ‘Prelude’ was consistently one of the earliest. Overall, maintaining potted plants for multiple years reduced the cost of annual replacement, but older plants managed for floricanes and primocane fruit production required additional pruning and training to control vigor.

During the past 10 years, fresh red raspberry (*Rubus idaeus*) production has increased dramatically as a result of improvements in production methods and year-round consumer demand for fresh, high-quality fruit. In U.S. markets alone, fresh raspberry movement from both foreign and domestic sources nearly tripled from 98 million pounds in 2010 to 281 million pounds by 2014 (Agriculture Marketing Service, U.S. Department of Agriculture, 2018). Part of the demand is likely related to the fruit chemical components associated with improved human health (DeSouza et al., 2014). To meet consumer demand, various systems for improving yield and expanding the season of berry production have been developed (Sønsteby et al., 2013). Substrate pot culture of raspberries grown in high tunnels has the potential for greater yields than traditional in-ground soil production (Qiu et al., 2016; Sønsteby et al., 2013). In addition, pot culture provides a means of manipulating the timing of fruit production by keeping plants in cold storage

until the desired production time (Dale et al., 2005; Pritts, 2008). Furthermore, growing plants in pots in soilless media avoids soil limitations such as pathogens, which may be present in any given field location.

The potential benefits of container culture are tempered by the costs associated with pots, media, complex irrigation requirements, and additional labor. Plants in some container systems are replaced each year, which increases annual costs further (Heiberg et al., 2008; Opstad et al., 2012; Pritts et al., 2017). However, some techniques have been tested that decrease production cost while maintaining yield, including reducing pot size and spacing (Sønsteby et al., 2013). Double-cropping is a practice during which current-year canes of primocane-fruiting cultivars are retained over winter so that a second crop is produced on floricanes the following summer. In short-season regions, double-cropping of in-ground plants has been shown to increase total yield compared with primocane fruiting alone (Hanson et al., 2019; Pritts et al., 2017). However, double-cropping has not been studied fully with potted plants in short-season areas. Selection of the best cultivars likely depends on the length of the growing season, because plants need to mature primocane fruit early enough to harvest acceptable volumes before harvest concludes with cold autumn weather.

In this study, the yield potential, fruit quality, and fruiting times of several primocane-fruiting raspberries were compared when managed for double-cropping in containers under a high tunnel. The goal was to identify cultivars suitable for production in regions with a relatively short growing sea-

son. We also maintained plants for 3 years to determine whether growers could realize cost savings by retaining plants for more than 1 year.

## Materials and Methods

This study was conducted in a 7.3 × 61 × 4.3-m (width × length × height) high tunnel (Haygrove Tunnels, Inc., Redbank, Ledbury, UK) at the Southwest Michigan Research and Extension Center in Benton Harbor, MI (lat. 42.1°N, long. 86.4°W) using similar production methods described by Hanson et al. (2018). The tunnel was oriented north to south, and was covered with Luminance THB polyethylene (BPI Visqueen Horticultural Products, Stockton-on-Tees, UK) from early May to late October or early November. The plastic was bundled and stored over winter in the gutter between adjacent tunnel bays. During warm periods in June, July, and August, the tunnel sides and ends were open and the plastic was pushed up onto the hoops to increase ventilation. The tunnel sides and ends were enclosed in plastic for the last 5 weeks of the season to retain heat. Temperatures in the tunnels were not monitored, but those outside the tunnels were recorded by an automated weather station (<https://enviroweather.msu.edu/>) located about 100 to 200 m from the tunnel.

Dormant rooted suckers were planted in May 2015 in 11-L white polyethylene growbags (Hydro-Gardens, Colorado Springs, CO) filled with a medium of 70% composted pine bark (size, <2.2 cm) and 30% Canadian sphagnum peat. Five primocane-fruiting cultivars (Imara, Josephine, Kwanza, Kweli, and Nantahala) and three floricanes-fruiting cultivars (Encore, Nova, and Prelude) were planted in May 2015. Cultivars were replicated in three rows (blocks) that were 2 m apart in a randomized complete block design with each plot containing four plants that were 0.4 m apart. To minimize border effects, plant rows began and ended at least 6 m from the ends of the tunnel, and each row began and ended with at least one border plant.

Plants were pruned after planting in 2015 so that no floricanes fruit were produced. When plants were dormant in Dec. 2015, all canes were removed except the two healthiest per plant. Terminal nodes that had fruited that fall were removed and canes were further shortened if needed to 1.5 m and retained for floricanes fruit production in the subsequent season. The plants were then stacked in bins and held during the winter in a dark cold storage room at 0 to 3 °C. Plants were returned to the tunnel in late April, after greater than 3500 chilling hours, and arranged as in 2015. After floricanes harvest concluded in July or August, the spent floricanes were removed. Most cultivars produced excessive numbers of primocanes, so these were thinned once or twice between June and August so that each plant contained only three to five primocanes. After primocane harvest concluded, plants were stored and managed in the same way in 2017.

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Plants were secured to a tensioned metal wire 1.5 m above each row that was attached to metal conduit posts inserted into the ground every 3 m down the row. When plants were returned to the tunnel in early May 2016 and 2017, floricanes were secured to the metal wire. Developing primocanes were contained within the row by multiple lines of plastic twine running the length of the row and woven in between the conduit posts. Additional twine was added as the primocanes grew in height. The goal was to keep the plant row less than 1 m wide while allowing adequate air circulation within the canopy.

Each plant was irrigated using a 1.9-L-h<sup>-1</sup> emitter (Netafim USA, Fresno, CA) that ran for 15 to 30 min twice per day early in the season and up to eight times per day late in the season when temperatures were warmer and the plant canopy was large. Nutrition was supplied as 45 g Osmocote 17–5–11 fertilizer (The Scotts Company, Marysville, OH) each April. Plants also received 100 mg N/L continually through the irrigation using a 21–7–7 soluble fertilizer with micronutrients (JR Peters Inc., Allentown, PA) in May and June, and a 21–5–20 soluble fertilizer with micronutrients (JR Peters Inc.) when fruit were maturing from July to October. Plants received four to eight insecticide sprays between July and October to control spotted wing drosophila (*Drosophila suzukii*), but no fungicides were applied.

Berries were harvested from floricanes (2016, 2017) and primocanes (2015–17). Harvest intervals varied from every 2 to 5 d (average of 10 harvest dates for floricanes and 22 dates for primocanes). The total weight and berry number were recorded and used to calculate average berry weight. Relative earliness of harvest was calculated by determining the date on which the cumulative yield from a plot exceeded 10% of the seasonal total yield. Dates were expressed as the number of days after the earliest harvest date, so that day 1 was 20 June for floricanes and 1 Aug. for primocane harvest.

Berry quality and shelf life were compared by collecting samples on selected dates when sufficient fruit was available from at least one of the replicate plots of each cultivar. Floricane fruit were sampled on four dates in 2016 and 2017, and primocane fruit were sampled on five (2016) or six (2017) dates. Samples were placed in half-pint clamshell containers, enclosed in sealed black plastic bags, and held for 1 to 2 d at 2 °C and then at 18 °C for 24 to 36 h. Each container was then opened and rated for appearance on a numerical scale of 1 (not salable), 2 (possibly salable but poor quality), 3 (salable but with significant defects), 4 (good quality, only minor/subtle defects), or 5 (excellent quality, no significant defects). Characteristics that detracted from quality included visible mold or juice, small or variable size, variable color, and a dull rather than glossy surface. The total number of fruit and number with visible mold were recorded.

Data were analyzed using SAS v9.4 (SAS Institute Inc., Cary, NC). The effects of treatments on growth, development, yield, and postharvest fruit quality were analyzed by analysis of variance using PROC MIXED. When variances were unequal (based on Levene's test and plots of residuals), a model with heterogenous variances was fit. When interactions were significant, tests of simple effects were carried out by slicing. Means separation was accomplished using Tukey's honestly significant difference. All statistical tests for significance were conducted at  $\alpha = 0.05$ .

## Results

Significant interactions occurred between primocane, floricane, and total yield and year, so yearly cultivar means are presented (Table 1). The three cultivars producing the most total primocane fruit were 'Imara', 'Kweli', and 'Prelude'. Together, these cultivars produced an average primocane yield of 0.20, 1.57, and 1.74 kg/plant in 2015, 2016, and 2017, respectively. 'Kwanza', 'Kweli', and 'Imara' had the greatest floricane yields, with a combined average yield of 1.43 g in 2016 and 0.87 g in 2017. 'Kweli' and 'Imara' had the greatest total yields (primocane plus floricane), averaging 2.94 and 2.69 kg, respectively, over 2 years.

The average berry weight was consistent across years so multiple-year means are presented in Table 2. 'Kwanza', 'Encore', 'Josephine', and 'Nantahala' produced the heaviest floricane berries; 'Kwanza', 'Imara', 'Josephine', and 'Kweli' had the heaviest primocane berries. The order of ripening of floricane berries (earliest to latest) was 'Prelude' and 'Kweli', 'Imara' and 'Kwanza', followed by 'Nova', 'Josephine', 'Nantahala', and 'Encore' (Table 2). The earliness of primocane harvest varied by year (Table 2). Primocane fruit harvest began late in the 2015 planting year (average across all cultivars, 27 Sept.) compared with 2016 (11 Aug.) or 2017 (11 Sept.). 'Prelude' was one of the earliest to ripen primocane fruit; 'Nova' was one of the latest. Other cultivars were intermediate and/or were not consistent across years.

After undergoing a simulated commercial storage and handling period, floricane berries had low incidences of mold (1% across cultivars and years) that did not vary among

cultivars (Table 3). Primocane fruit had a greater average incidence of mold across years and cultivars (6%), and mold varied significantly among cultivars, ranging from 0.9% for 'Kweli' to 18.4% for 'Nantahala'.

Floricane fruit appearance varied by cultivar in 2016 and 2017. In 2016, 'Nova' had the highest appearance rating (5.0), which differed significantly from that of all other cultivars except 'Kweli' (4.5). In 2017, appearance ratings ranged from 4.9 for 'Imara' to 3.0 for 'Encore'. Examples of common reasons for lower ratings included the lack of a glossy surface and variable berry size ('Nantahala', 'Josephine'), and variable color and size ('Encore'). Primocane fruit of 'Kweli', 'Imara', 'Kwanza', and 'Nova' were rated highest in appearance; those of 'Nantahala' and 'Prelude' were rated lowest. Primocane fruit on 'Nantahala' were often rated lower because of greater mold incidence and a dull fruit surface, whereas small size and variable fruit color detracted from 'Prelude' fruit appearance.

Average growing season temperatures (May–October) outside the tunnels were 18.6, 20.2, and 18.0 °C in 2015, 2016, and 2017, respectively. Average monthly temperatures outside the tunnels were 15.3, 20.8, 22.3, 21.8, 20.2, and 13.1 °C in May, June, July, August, September, and October, respectively.

## Discussion

'Imara' and 'Kweli' appeared to be the best-suited cultivars for the conditions and management approaches used in this study. Each produced high primocane and floricane yields, with large berries that rated high in appearance with little mold after storage. Andrianjaka-Camps et al. (2016) also found 'Kweli' performed well when double-cropped in pots. 'Prelude' also produced high total yields, but the small size of floricane and primocane fruit reduced harvest efficiency.

Primocane fruit need to ripen early enough to harvest high yields before cold weather concludes production, so earlier maturing primocane cultivars are best for shorter growing seasons. As an example, 'Nova' produced low primocane yields (Table 1) because fruiting began too late in the fall (Table 2). However, very early primocane-fruited types tend to produce shorter primocanes because growth ceases

Table 1. Primocane, floricane, and total fruit yield (measured in kilograms per plant) from potted raspberry cultivars grown under high tunnels in Benton Harbor, MI.

Cultivar	Primocane yield			Floricane yield		Total yield	
	2015	2016	2017	2016	2017	2016	2017
Encore	—	—	—	1.14 abcd	0.86 a	1.14 d	0.86 c
Imara	0.32 a <sup>z</sup>	1.33 abc	2.03 a	1.23 abc	0.80 ab	2.57 abc	2.83 a
Josephine	0.30 a	0.89 bc	0.96 b	1.01 bcd	0.60 bc	1.91 bd	1.56 bc
Kwanza	0.22 ab	1.32 ab	0.69 b	1.43 ab	0.87 a	2.75 ab	1.55 bc
Kweli	0.13 bc	1.90 a	1.39 ab	1.62 a	0.98 a	3.52 a	2.37 a
Nantahala	0.30 a	1.19 abc	0.74 b	0.65 d	0.48 c	1.84 cd	1.22 bc
Nova	0.04 c	0.52 c	0.57 b	1.24 abc	0.53 c	1.77 cd	1.09 bc
Prelude	0.16 ab	1.46 ab	1.80 a	0.84 cd	0.62 bc	2.30 bc	2.42 a

<sup>z</sup>Means within columns followed by common letters not significantly different ( $P < 0.05$ ).

Table 2. The average weight and earliness of harvest of primocane and floricanes berries from potted raspberry cultivars.

Cultivar	Berry wt (g) <sup>z</sup>		Earliness of harvest (day 10% of total yield exceeded) <sup>y</sup>			
	Floricanes	Primocane	Floricanes <sup>y</sup>	Primocane		
				2015	2016	2017
Encore	4.2 ab <sup>x</sup>	—	18 a	—	—	—
Imara	3.6 bc	3.6 ab	9 c	50 b	4 bc	40 ab
Josephine	3.9 abc	3.9 a	16 ab	60 b	5 bc	39 ab
Kwanza	4.2 a	4.1 a	11 c	53 b	18 a	42 ab
Kweli	3.6 c	3.8 ab	7 cd	61 ab	11 ab	49 a
Nantahala	3.7 ab	3.4 b	18 a	53 b	12 ab	47 a
Nova	3.4 cd	3.5 b	14 b	75 a	17 a	50 a
Prelude	2.8 d	2.9 c	2 d	51 b	2 c	30 b

<sup>z</sup>Data are means of 2016 and 2017 (floricanes) or 2015, 2016, and 2017 (primocane).

<sup>y</sup>Day 1 corresponded to 20 June for floricanes harvest and 1 Aug. for primocane harvest.

<sup>x</sup>Means within columns followed by common letters not significantly different ( $P \leq 0.05$ ).

Table 3. Mold incidence and appearance of floricanes and primocane fruit after a simulated commercial storage period.

Cultivar	Floricanes fruit			Primocane fruit	
	Mold (%) <sup>z</sup>	Appearance		Mold (%) <sup>z</sup>	Appearance <sup>z</sup>
		2016	2017		
Encore	2.1 a <sup>y</sup>	3.4 c	3.0 c	—	—
Imara	0.9 a	3.6 bc	4.9 a	2.4 b	4.2 ab
Josephine	0.6 a	3.4 c	3.7 bc	1.3 b	3.7 bc
Kwanza	2.3 a	3.9 bc	4.3 ab	2.2 b	4.2 ab
Kweli	0.7 a	4.5 ab	4.3 ab	0.9 b	4.4 a
Nantahala	3.1 a	3.2 c	4.1 ab	18.4 a	2.1 d
Nova	1.0 a	5.0 a	4.5 ab	12.4 ab	4.0 ab
Prelude	1.0 a	3.7 bc	3.7 bc	4.8 ab	3.1 c

<sup>z</sup>Data are means of 2016 and 2017 (floricanes) or 2015, 2016, and 2017 (primocane).

<sup>y</sup>Means within columns followed by common letters not significantly different ( $P \leq 0.05$ ).

early in the summer, subsequently resulting in less productive floricanes because canes are shorter with fewer nodes for floricanes fruiting (Hanson et al., 2019). With the exception of ‘Encore’, which fruits only on floricanes, the cultivars tested in our study are considered mid- to late-season primocane-fruited types (Bushway et al., 2008; Fernandez et al., 2009; Moore et al., 2018). ‘Nova’ and ‘Prelude’ have been described as floricanes-fruited cultivars that also produce some late-season primocane fruit (Bushway et al., 2008). These later primocane-fruited types may have yielded well in our study in part because they were in a high tunnel, which tends to accelerate plant development and prolong the fall fruiting season (Demchak, 2009).

Raspberries are well adapted to culture in pots (Dijkstra and Schultens, 1993) and several management approaches have been studied. Long-cane production is a common annual system in which plants with one floricanes are produced in nurseries, used for floricanes fruit production, then discarded (Heiberg et al., 2008; Pitsioudis et al., 2002; Sønsteby et al., 2013). Long-cane plants can also be retained for multiple seasons by allowing primocanes to grow for floricanes fruit production during the subsequent season. This does not appear to diminish yields (Palonen et al., 2016; Sønsteby et al., 2013) and may reduce plant costs for growers. Another approach is to grow primocane-fruited cultivars for multiple years to reduce plant replacement expenses. Primocane-fruited cultivars can be managed to produce primocane fruit only (Qiu et al., 2016; Hanson et al., 2018) or primocane and

floricanes fruit. These results and those of Andrianjaka-Camps et al. (2016) indicate that potted primocane-fruited raspberries can yield well when double-cropped in a high tunnel. The floricanes plus primocane yields in our study were similar to or greater than that of plants managed in a similar manner (Andrianjaka-Camps et al., 2016), and primocane yields were comparable to those of other cultivars grown in the same containers and media (Hanson et al., 2018).

Plants in our study were maintained for 3 years. It is not clear whether they would have remained productive for longer. Although average total yields across all cultivars were somewhat less in 2017 (1.7 kg/plant) than in 2016 (2.2 kg), perhaps indicating a decline in productivity with plant age, some cultivars (Imara, Prelude) had greater yields in 2017 than in 2016. Retaining plants for multiple years is desirable because primocane yields during the year of planting were less than half the levels of subsequent years (Table 1) (Hanson et al., 2018). However, retaining plants for more years may increase some management expenses. We noticed greater numbers of insect pests, such as scale and aphids, during the third growing season.

The quality of floricanes and primocane fruit from a given cultivar tended to rank similarly. For example, both floricanes and primocane fruit of ‘Prelude’ were very small whereas all fruit of ‘Kwanza’ were among the largest (Table 2). Both floricanes and primocane fruit of ‘Nantahala’ had high incidences of mold whereas ‘Kweli’ and ‘Imara’ had low incidences. This suggests that these character-

istics of floricanes and primocane fruiting are under genetic control and are likely to be consistent within a genotype. The very high variability in mold incidence on primocane fruit (Table 3) might have been the result of contamination of adjacent berries during storage. Fungi from one or two infested berries often spread to adjacent berries, resulting in much greater incidence percentages and high variation in the data.

The relative earliness of floricanes harvest was consistent across years. Respectively, ‘Prelude’ and ‘Encore’ are considered the earliest and latest of commonly grown floricanes-fruited cultivars in this region (Bushway et al., 2008), and the other types tested here generally fell between these extremes (Table 2). The earliness of primocane fruit harvest varied by year, but ‘Prelude’ was consistently among the earliest of the tested cultivars (Table 2). The late start of primocane harvest in 2015 was presumably because plants were started as dormant rooted suckers and took time to become established. The use of green plug plants rather than dormant suckers might have hastened and possibly increased primocane harvest during the planting year. The early harvest in 2016 reflected the warmer weather during that summer and fall.

The growing approach used here appears to have commercial potential. Total yields in the second and third seasons exceeded 2 kg/plant for several cultivars. In contrast, long-cane plants of floricanes-fruited cultivars have produced yields between 1 and 3 kg/plant (Heiberg et al., 2008; Opstad et al., 2012; Qiu et al., 2016; Sønsteby et al., 2013). The plants in our study contained two floricanes and up to five primocanes, which resulted in thick canopies that slowed harvest and may not have been optimized for production. Many plants produced 10 to 20 primocanes that required time to thin. Optimum cane numbers may differ with cultivar because cane height and branching vary. Retaining different numbers of primocanes or floricanes could alter the competition between canes for space and resources, but because cane numbers did not vary in this study, different cane numbers would need to be compared to determine how they affect overall yields. Floricanes numbers did not alter primocane yields of in-ground raspberries (Hanson et al., 2019). More work is needed to understand optimum plant spacing and cane number, which could be used to develop an improved training/trellising system that separates the cane types for better flower and fruit exposure.

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