Progress and Challenges in Primocane-Fruiting Blackberry Breeding and Cultural Management

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Abstract

The University of Arkansas blackberry breeding program began to focus on primocane-fruiting (PF) breeding in the mid 1990s, and has expanded this effort since then. Cultivars released since then include 'Prime-Jan'® ('APF-8'), 'Prime-Jim'® ('APF-12') in 2004 and 'APF-45' in 2009. Immediate challenges in breeding were seen, the most significant was heat damage to primocane flowers and fruits in Arkansas, along with development of commercially acceptable fruit size, quality, and plant productivity. One of the most striking observations made in the early 2000s was that the selections 'APF-8' and 'APF-12' performed much better in the more moderate climate of the Willamette Valley of Oregon. They had larger, more plentiful fruits, and overall plant performance was superior in Oregon to that in Arkansas. Fruiting began later compared to Arkansas, with mature fruits present from early September to late October. This striking environmental effect indicated that advances in PF breeding could benefit from multi-location testing and breeding. Expanded locations for PF genotype trials have further supported this observation. Near the time of release of 'Prime-Jim'® and Prime-Jan'®, it was evident that innovative cultural management of these genotypes would be required to provide for commercially acceptable yields. The initial studies conducted by Oregon State University indicated that tipping of primocanes was required to manage cane height and increase yields. Subsequent work evaluated tipping heights, mowing of canes to adjust the fruiting season, and high tunnel production and resulted in substantial yield increases and extension of the fruiting season. The combination of research in breeding, testing in diverse climates and locations, and development of cultural management systems has resulted in the beginning of commercial PF blackberry production in the USA. Further research and expanded commercial acreage will likely enhance precision timing of extended-season and off-season production.

INTRODUCTION

Plants in the genus *Rubus*, which include blackberries (*Rubus* subgenus *Rubus* Watson) and red raspberries (*R. idaeus* L.), have a perennial root system with biennial canes. Primocanes, or first-season canes, are usually vegetative. Floricanes, or second-season canes, are the same canes that then become reproductive and produce fruit the following season. Primocane-fruiting types are capable of fruiting on both primocanes and floricanes. In red raspberry, primocane- and floricane-fruiting cultivars have

substantial commercial value. In blackberry, floricane-fruiting has been the basis of all production and primocane-fruiting cultivars did not exist prior to the release of 'Prime-Jim'® and 'Prime-Jan'® by the University of Arkansas in 2004 (Clark et al., 2005).

Primocane fruiting has several advantages including: 1) potential of two crops on the same plant in the same year (floricane followed by primocane); 2) later-season (autumn) fruiting; 3) the possibility of scheduling fruit production using primocane management systems; 4) reduction in pruning costs by mowing of canes (primocane crop only); 5) avoidance of winter injury; and 6) production of fruit in an extended geographic area (such as low- or no-chill environments). The potential value of primocane fruiting depends primarily on the growing environment and fruit marketing opportunities. One period little blackberry fruit is available in the USA is September to November, a time when most of the summer production in the US is complete, but before substantial Mexican imports have begun. This is also a time of higher fruit prices and potential grower profitability (Carvalho et al., 2009). Primocane-fruiting is beginning to play a role in filling this market window.

Winter injury is a major concern in the mid-western to northern USA, and prevents reliable fruiting of floricane-fruiting blackberries. Since canes of primocane-fruiting types do not need to overwinter, the opportunity exists to grow blackberries in areas where canes are usually winter killed. In areas with inadequate chilling for floricane-fruiting blackberries, primocane production has potential as the need for chilling is reduced or eliminated. This might be particularly valuable in Mexico where chemical manipulations of plants are required on floricane-fruiting cultivars.

PRIMOCANE-FRUITING BREEDING, SELECTION TESTING, AND CULTURAL MANAGEMENT RESEARCH

Early Primocane-Fruiting Breeding in Blackberries

The first recorded occurrence of a primocane-fruiting blackberry that the authors are aware of was a wild plant found by L.G. Hillquist of Ashland, VA, USA. Mrs. Hillquist provided this genotype to the New York State Agricultural Experiment Station (Geneva) in 1949 (USDA, 2006). There is no taxonomic classification of the species of this plant. There is no evidence that this genotype was ever officially named, but likely was assigned the cultivar name 'Hillquist' as a designation in New York. This plant was noted to have a "rudimentary" level of primocane fruiting in Geneva (USDA, 2006). 'Hillquist' is a diploid (Thompson, 1995). There is no record of breeding with this plant until J.N. Moore obtained it in the mid-1960s while he accumulated germplasm for the University of Arkansas breeding program. Fortunately, 'Hillquist' is erect-caned, and this contributed to it being used in crossing in Arkansas. Moore made a cross of 'Brazos' × 'Hillquist' in 1967, and a selection made from this population in 1970 was designated Ark. 593. It was assumed that 'Hillquist' produced an unreduced male gamete to combine with the female gamete of 'Brazos' (a tetraploid plant as all University of Arkansas blackberries). Based on its success as a parent, Ark. 593 was determined to be a tetraploid selection. Ark. 593 did not express the primocane-fruiting trait, but was used in subsequent crossing mainly due to its early floricane fruit ripening. In the late 1980s, J.R. Ballington of North Carolina State University obtained plants of Ark.593, self-pollinated this selection, and recovered primocane-fruiting offspring. Ballington and Moore (1995) released the germplasm selection NC 194. Ballington and Moore hypothesized that the primocane trait was recessive. In the early 1990s, Moore's last graduate student, J. Lopez-Medina, undertook a formal study of the inheritance of this trait. His work proposed that the trait is controlled by a recessive allele at a single locus (Lopez-Medina et al., 2000).

The first primocane-fruiting selections in the University of Arkansas breeding program were made in September 1997. It was very exciting to identify primocane fruiting for the first time in blackberry seedlings, but was disappointing in that fruit quality was less than optimal. The fruits lacked size and quality compared to existing floricane-fruiting cultivars. Crossing of these new selections was officially begun at the

University of Arkansas Fruit Research Station (west-central Arkansas, lat. 35°47'N and long. 93°48'W) in 1999. Evaluations of primocane-fruiting selections and resulting seedlings further verified fruit size and quality concerns, and this was thought to be due to high temperatures during flowering and fruit maturity during late July to early September in Arkansas.

Testing of Primocane-Fruiting Genotypes in Oregon

Two selections, 'APF-8' and 'APF-12' (later named 'Prime-Jan'® and 'Prime-Jim'® respectively; Clark et al., 2005) were sent to Aurora, OR USA for trial by C.E. Finn, US Dept. of Agric. - Agric. Research Service (USDA-ARS) at the Oregon State University North Willamette Research and Extension Center (OSU-NWREC; lat. 45°17'N, long. 122°45'W) in 2000. The fruiting performance of these selections in Oregon was first observed in September and October 2001. These selections had primocanes with larger berries (8-10 g) than in Arkansas, (5-6 g and 3 g on floricanes and primocanes, respectively), many ripe, green and red fruit, plus many flowers and flower buds. It was obvious that these genotypes fruited much better in the cooler Oregon environment compared to the higher heat of Arkansas.

Based on the Oregon performance, 'Prime-Jan'® and 'Prime-Jim'® were released in the USA primarily for the home-garden market and limited commercial trials. Fruit quality, even in optimum conditions, was not thought to be entirely suitable for commercial markets and yield variations were substantial depending on where these were grown.

Early Research on Cultural Management of Primocane-Fruiting Blackberries

Strik et al. (2008) tested 'Prime-Jan'® and 'Prime-Jim'® in field plantings from 2003 to 2005. In 2005, the cultivars had similar primocane yields. However, soft-tipping canes at 1.0 m increased yield compared to un-tipped primocanes (Table 1) in both cultivars (5.7 vs. 2.2 t/ha,). Thompson et al. (2007), studied 'Prime-Jan'® and 'Prime-Jim'® in the same field and found that tipped primocanes developed twice as many flowers as un-tipped canes. They further found that canes soft-tipped at 1.0 m developed an average of three lateral branches, which flowered and fruited uniformly. Branches of un-tipped canes usually terminated in a single inflorescence, but did not always flower uniformly. In another study, row covers advanced bloom 14 d (24 June) compared to un-tipped canes, and increased yield compared to un-tipped, non-covered treatments (Strik et al., 2008).

In a comparison of yields on floricanes, 'Prime-Jan'® had a significantly higher yield than 'Prime-Jim'® (6.1 vs. 4.0 t/ha), but a smaller berry size (4.0 g vs. 4.6 g; $P \leq 0.01$). However, for primocane-fruiting blackberry in the western coastal USA climate, the primocane crop is more desirable than the floricane crop. It was also found that the fruiting season for these cultivars in the open-field was too late to harvest a significant portion of the crop prior to cool temperatures and rainfall, and thus tunnel production was recommended (Strik et al., 2008).

In a study comparing open-field and tunnel production of 'Prime-Jan'®, fruit harvest began on 12 September in both systems, but lasted about 3 weeks longer in the tunnel, ending on 16 November (Thompson et al., 2009) In the tunnel, cumulative yield of double-tipped primocanes (main cane and branches tipped) averaged 10.7 t/ha in 2006 (data not shown) and 19.3 t/ha in 2007 (Table 1), a 267 and 159% increase compared to plants with primocanes tipped once at 0.5 m, respectively. In 2007, harvest was delayed by 2 weeks and 4 weeks when primocanes were cut at 0.25 m and 0.5 m, respectively, compared to un-cut treatments. Primocanes that were double-tipped produced heavier fruit than other treatments (Table 1). In addition, plants growing under the tunnel tended to produce heavier fruit (32%, on average) than those grown in the open field (data not shown).

Current Status and Future Outlook in Primocane-Fruiting Breeding

In the early years of primocane-fruiting blackberry breeding, it was obvious that this was a crop with a substantial genotype × environment interaction. The most substantial observation was that the high summer heat (over 30°C) in Arkansas during primocane bloom and fruit development negatively influenced berry development, size, and quality. The heat effect on two primocane-fruiting cultivars was confirmed in work by Stanton et al. (2007). This research was done using growth chambers to provide differing conditions for plant development. They reported that 'Prime-Jim'® and 'Prime-Jan'® flower components were adversely affected by high temperatures, with the greatest impact at 35°C. Crossing and selection in Arkansas has continued in high-temperature conditions, and progress has been made in enhancing fruit set and berry quality. However, challenges still remain in further improving heat tolerance to achieve reliable primocane-fruiting performance in high-heat conditions.

Based on the observed limitations of making full progress in breeding primocane-fruiting blackberries in Arkansas, diverse locations were identified to grow seedlings and test selections. Expanded testing in the USA, including the very moderate climate of coastal California, was undertaken and revealed very good performance of primocane-fruiting genotypes there. Further, cooperative breeding activities between the University of Arkansas and private entities were established in the mid-2000s in the UK, Mexico, Chile, and Australia. These activities are providing a much broader expression of the primocane-fruiting trait in diverse environments that should enhance the use of this type of plant in many areas of the world. One primocane-fruiting cultivar, 'Reuben', was commercialized from these efforts in 2010 by Hargreaves Plants in Lincolnshire, UK, although still being evaluated for its commercial potential (Rupert Hargreaves, pers. commun.).

A major limitation seen when testing 'Prime-Jan'® and 'Prime-Jim'® in New York and Minnesota in the northern USA was the late date of ripe primocane fruit. Usually the first berries on these genotypes ripened about 1 September, leaving a short window for fruiting before frost (J.J. Luby and C.A. Weber, pers. commun.). Development of genotypes with earlier ripening date, similar to that done with red raspberry (Slate and Watson, 1964), is needed. This issue is being addressed by intercrossing the earliest primocane-blooming selections in Arkansas, and growing seedlings in Arkansas, Minnesota, and New York. Although this effort is still rather new, it appears that progress is being made to select more adapted genotypes for a shorter growing season region.

'Prime-Jan'® and 'Prime-Jim'® have fruit quality similar to the softer-fruited thorny cultivars from Arkansas, and the fruits are usually not considered firm enough for commercial shipping. However, both 'Prime-Jim'® and 'Prime-Jan'® have been grown commercially to some success in coastal California. Also, flavor is not as good as the thornless cultivars from Arkansas. Flavor can vary greatly with time of ripening, and primocane fruits developing in the heat of the summer in Arkansas often have poor flavor. Double and otherwise misshapen fruit have been seen on primocane fruiting selections. These traits are believed to be associated with high heat during flower bud, flower, and fruit development. The cultivar 'APF-45' (marketed as 'Prime-Ark® 45') was released in 2009 and has substantially improved fruit quality over prior releases with post-harvest potential for shipping similar to the thornless genotypes from Arkansas (Clark and Perkins-Veazie, 2011). Fruit firmness and improved flavor are being emphasized heavily when parents are selected for crossing and seedling evaluations in Arkansas and at cooperative breeding locations.

Economical yield is critical to commercial success and therefore yield is a major area of focus in primocane blackberry improvement. Breeding for yield improvement is location specific, and emphasis on single- (primocane only) vs. double-cropping (floricane and primocane crop) may affect evaluation of seedlings. A key issue in increasing yield is to increase flowering on primocanes. This is where cultural management has been shown to have a tremendous impact on yield (Strik et al., 2008; Thompson et al., 2009). Yield components that are important are primocane lateral bud

break, flower number per lateral and per inflorescence, and the amount or degree of primocane flowering. The first four primocane-fruiting cultivars are thorny, but thornlessness has been readily incorporated in primocane-fruiting selections in the Arkansas and Arkansas-related programs. The thornlessness source is the recessive 4*x* source derived from *R. ulmifolius* Schott., used in all Arkansas thornless cultivars and many others including 'Chester Thornless'. Thornless primocane-fruiting cultivars will be released in the near future, and these will eventually become standard.

Outlook for Expanded Cultural Management in Primocane-Fruiting Blackberries

Research on primocane management using row covers to advance the crop, single-tipping of the primocanes to improve yield (Strik et al., 2008; Strik and Thompson, 2009), and cutting primocanes to delay growth along with single or double-tipping (Thompson et al., 2009) has shown great promise for improvement of yield, quality, and altering the fruiting season. In warmer climates, primocane-fruiting blackberries may be field-grown; however, in temperate climates this crop may require a tunnel to protect against rain and allow fruit harvest into late autumn.

Future investigations into primocane-fruiting blackberry management will include fertility studies, as nutrition standards currently do not exist. Economic studies are also needed to evaluate whether intensive management of primocanes, to increase yield and berry weight, are worthwhile for the relatively short window when fruit will likely be marketed (August through November in the northern hemisphere). In hot climates, such as the southeastern USA, future studies may include the use of shade cloth or UV-reflecting plastic to protect flowers during bloom and thereby improve fruit set. As new cultivars are released, further primocane management studies will be needed to determine their optimal fruit production methods and to schedule harvests more precisely.

CONCLUSIONS

We feel that primocane fruiting in blackberry will have substantial impact on fresh-market blackberry production in the world, hopefully similar to the tremendous expansion of the primocane-fruiting red raspberry industry in the past 20 years. The expanded geographic potential for production, variation in time of fruit ripening, and cultural management opportunities are substantial to exploit the genetic potential of this type of blackberry.

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Tables

Table 1. The effect of primocane management system on yield (per 3 m plot) and fruit size of 'Prime-Jan'®, in 2005 and 2007 at the Oregon State University's North Willamette Research and Extension Center[z,y].

Primocane management	Yield (kg/plot)	Berry weight (g)
2005 (field-grown)[z]		
Un-tipped primocane	1.9 c	5.7
+ Rowcover, un-tipped primocane	5.5 a	5.5
Primocane tipped at 1.0 m (T1.0 m)	4.0 b	5.8
Significance[x]	***	ns
2007 (grown in tunnel)[y]		
C0.25 m/T0.5 m[w]	4.4 c	6.9 c
C0.5 m/T0.5 m	4.9 c	7.5 b
T0.5 m/Tb0.5 m	17.9 a	8.1 a
T0.5 m	6.9 b	6.5 c
Significance	***	**

[z] from: Strik et al., 2008.
[y] from: Thompson et al., 2009.
[x] NS, **, ***=non-significant or significant at P≤0.01, or 0.001, respectively, within tunnel or field. Means followed by the same letter within year and culture are not significantly different (P>0.05).
[w] C0.25 m/T0.5 m: all primocanes cut to the ground when 0.25 m tall, then later emerging primocanes soft-tipped at 0.5 m; C0.5 m/T0.5m: all primocanes cut to the ground when 0.5 m tall, then later emerging primocanes soft-tipped at 0.5 m; T0.5 m/Tb0.5 m: all primocanes soft-tipped at 0.5 m tall, then subsequent lateral branches soft-tipped at 0.5 m long; and T0.5 m; control: all primocanes soft-tipped at 0.5 m.