

Great Lakes Fruit, Vegetable & Farm Market EXPO

December 9-11, 2008

DeVo Place Convention Center, Grand Rapids, MI



Brambles I

Tuesday morning 9:00 am

Where: Grand Gallery (lower level) Room E-F

Recertification credits: 1 (1C, PRIV CORE)

CCA Credits: PM(0.5) CM(1.0)

Moderator: Susan Lynn, Sand Hill Berries, Mt Pleasant PA

- 9:00 a.m. Grower Spotlight: Blackberry Production in the Far North
- Gary Bardenhagen, Lake Leelanau, MI
- 9:20 a.m. Breeding Exceptional Blackberries
- John R. Clark, Horticulture Dept., Univ. of Arkansas
- 9:50 a.m. North American Bramble Growers Foundation Research Reports
- 10:30 a.m. Midwest Bramble Insects in the Field and Under Tunnels
- Rufus Isaacs, Entomology Dept., MSU
- 10:50 a.m. New Developments in Bramble Disease Control
- Mike Ellis, Plant Pathology (Wooster), Ohio State Univ.
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BLACKBERRY PRODUCTION IN THE FAR NORTH

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Our 180-acre farm is located northwest of Traverse City in Leelanau County. My son Steve and I grow strawberries, sweet and tart cherries and blackberries.

We first became interested in blackberries in 1988 because it was such a good fit with strawberries and sweet cherries which are handpicked for the wholesale fresh market. We proceeded to plant 2.5 acres of thornless blackberries, 1/3 Chester and 2/3 Thornfree variety. The plants were spaced 6 feet apart and rows were 12 feet apart. A simple 2-wire trellis system was used and 6 canes were trellised for each plant.

Eventually we went to pinching out the tips on the primocanes when they are about knee-high to reduce the cane diameter which causes the canes to be more flexible for trellising. We soon learned that our major insect pest would be tarnished plant bug – the same insect we deal with in our strawberries. It feeds on the developing berries shortly after bloom and results in small and/or misshapen fruit. We spray twice during bloom to control this pest along with fungicide for control of grey mold.

We found out that there is a lot of production on 2 ½ acres of blackberries – more than we could market locally. We eventually connected with a fresh fruit marketer at the Detroit Eastern Market who would buy all the blackberries we couldn't sell locally.

We continued harvesting this blackberry planting for 5 years up through 1993. In 1994 we removed the planting because nearly all the bearing canes were killed by the winter of 1993/94.

For the next ten years we stayed out of the blackberry growing business primarily because we had too many irons in the fire and lacked the time.

Then in 2004 we started a new planting. We once again felt we had the time for it and felt it was still a good fit for our operation. This time we planted just one acre. One third was planted to Chester and two thirds to Cacanska B. This time we used 5' x 14' spacing and stayed with the same trellis. The migrant workers who harvest the blackberries also trellis the canes in the spring, and later tie the primocanes out of the way for harvest. Weeds are controlled primarily with straw mulch. Trickle irrigation was installed also, with plans to use it for fertilizer injection in addition to water.

We soon ran into our old enemy, namely cold injury. It was much more severe in the Chester variety than the Cacanska. The Cacanska variety proved to be very productive. The berries were large and beautiful. However, all was not good. We found that the berries became soft as soon as they began to sweeten up. We tried to pick them a little early which helped with the softness, but caused some complaints because a number of our customers felt they were too tart. Also, it was difficult to avoid getting some soft berries in the pack. Cacanska also has a problem with red drupelets. Numerous drupelets turn red shortly after picking. The Chesters produced berries that were smaller than the Cacanska, but they were firmer even after acquiring some sweetness which resulted in greater customer satisfaction. We have averaged about 5900 pints each of the last 3 years.

So that was our quandary. Cacanska was more productive and quite winter hardy and Chester was not winter hardy and less productive, but had superior quality.

We decided to gradually phase out of the Cacanska. This spring we planted ½ acre of Triple Crown and a few Loch Ness. We expect the Triple Crown will be similar to Chester in terms of winter hardiness and that is a problem.

We have come to the conclusion that we need to address the winter injury problem head on if we are going to be able to grow the varieties that have the quality that our customers prefer. Therefore, we have decided to switch to the RCA tipping trellis as designed by Dr. Fumi Takeda. We talked to Dr. Takeda at the NABGA Annual Meeting in Hershey, PA last February, and have maintained contact via email.

With tipping trellises, one can manage the fruiting shoot growth so that all fruit ends up on one side of the trellis. This makes for a more efficient harvest plus more shading for the fruit. In addition, Dr. Takeda's trellis can be tipped to the ground for the winter season, making it easier to cover the canes with snow or with plastic row cover. Trellis Growing Systems LLC of Indiana is currently working on a prototype of Dr. Takeda's trellis and we hope to be able to test it on our Triple Crown next year.

BREEDING EXCEPTIONAL BLACKBERRIES

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INTRODUCTION

Formal breeding of blackberries is nearing its 100th anniversary, since the first public program was started at Texas A&M University in 1909 (Darrow, 1937). Since that time, breeding has been conducted by various public, and more recently, private organizations in the world. In the process of domestication, excellent genotypes with many improved characters have been developed. In 2008, interest in cultivar improvement may be at its all-time high. Reasons for this include: 1) blackberries are a new crop to many areas of the world, 2) they share many similarities to red raspberry and as raspberry production develops in an area, blackberries often follow, 3) blackberries are less expensive to produce than red raspberries because they do not have to be replanted as often and commonly do not have as many pest control inputs, 4) improved cultivars have been developed that ship better, ripen earlier, ripen later, taste better, are thornless, etc., and 5) the growing awareness of the nutraceutical value of blackberries; other than black raspberries, blackberries have higher levels of anthocyanins than most other widely available fruits.

A total of 61 blackberry cultivars were released from 1985-2007 by public and private breeding programs. Many important current cultivars were released during this time, including 'Chester Thornless', 'Loch Ness', 'Navaho', and 'Tupy'. However, some older cultivars such as 'Thornless Evergreen' (1926), 'Boysenberry' (1935), 'Marion' (1956), and 'Brazos' (1959) continue to be important in various locations in the world. Each of these cultivars has had new releases targeted to serve as their replacements; time will tell if these new genotypes will supplant the older mainstays. The good news is that the substantial number of new cultivars released has strengthened the foundation for expanded blackberry production.

Fueled by an improved set of parents and traits to utilize and an increased interest among growers and consumers, blackberry breeders are in a great position to breed "exceptional" new cultivars.

CURRENT BREEDING EFFORTS

Breeding programs are active in several locations in North America. The two largest efforts are conducted by the University of Arkansas (active since 1964; directed by John R. Clark) and the United States Dept. of Agriculture – Agriculture Research Service (USDA-ARS-Oregon) (the oldest continuous program in the world, active since 1928; directed by Chad E. Finn). Other public programs underway include North Carolina State University, USDA-ARS-Mississippi, and Agriculture and Agri-Foods Canada in Nova Scotia. New public programs have been very limited in recent years, as the general trend in fruit breeding programs has been a decline or termination of efforts.

Private programs underway include those of Driscoll Strawberry Associates in California and Five Aces Breeding (associated with the University of Maryland). There are the beginnings of additional private blackberry breeding efforts underway at various locations in the world also, though the details of all of these activities are not publicly available.

EXCEPTIONAL BLACKBERRIES: TRAITS/CHARACTERS OF FOCUS

What exactly is an “exceptional” blackberry? Like many experiences in life, exceptional is much like the idea of “perfect” which means it is a quantitative situation (not clear cut). What one considers perfect or exceptional another might find only average, mediocre, or even undesirable. When one throws in other factors such as environmental effects and local custom and preferences, the equation is much more complicated.

Breeding an exceptional blackberry is an exciting proposition to me. However, I have learned that what I think is exceptional (or not) may prove itself differently when growers or consumers use the development. I have experienced two such instances of contrast in my career evaluating selections for release that resulted in different than expected outcomes. Back in 1998, I was evaluating data from several advanced blackberry selections, and one, A-1798, was simply outstanding. It had berries about twice as large as ‘Navaho’, an exceptional thornless plant, fabulous quality and handling ability, and high yields. When this cultivar was released as ‘Apache’ I thought it was a spectacular advancement. I remember thinking that for government work this was too much of an advance over what already was available (the thinking that the improvements should be more incremental so progress would not be made too fast). ‘Apache’ was embraced quickly in the marketplace, and even today is a good seller for local markets. Soon after release it showed susceptibility to an unknown tip dieback disease. Fortunately this disease was not seen again and never became an issue for growers as far as I know. But, in a year or two I began to get comments about the occurrence of white drupelets on ‘Apache’ berries. I wondered what had happened: why had I not spotted this problem? I have never fully answered that question. The white drupelet problem greatly diminished the interest in ‘Apache’, especially for the shipping market. The bottom line is my “exceptional” did not really turn out that way at all.

A few years later selection A-1905 was being evaluated closely in the program. It looked nice, not as large as ‘Apache’ but still very good with high yields and excellent quality. The plants were fine, although I saw some upward curling of leaves. This concerned me, and I held off advancing this selection to release. After another year or two, this selection was again looked at closely but still had the curled leaves at times. I was concerned that this might be powdery mildew, and if released it would be the first truly powdery mildew-susceptible North American blackberry. I did not want the honor of being known for white drupelets *and* powdery mildew susceptibility! I was visiting with an Arkansas grower one day in 2002, and mentioned that I had this selection (A-1905) that ripened between ‘Arapaho’ and ‘Navaho’, but was not sure it had value since it would overlap some with both (I also mentioned the curled-leaf concern). This grower told me that he badly needed a cultivar that ripened in this time period since sometimes ‘Arapaho’ fruited for a limited amount of time and was done prior to ‘Navaho’ beginning substantial harvest; his labor force had little to do during this period. That key piece of information encouraged me to release A-1905 as ‘Ouachita’. I hoped it would work out, and I would not be the king of blackberry defects in a couple of years! As of the end of 2008, ‘Ouachita’ has been the most exciting and quickly successful cultivar from the Arkansas program. Some would call it “exceptional”. I was not sure of that characterization until I saw the realization of this in grower fields.

In the following discussion, I comment on a few areas of focus required to produce an “exceptional” blackberry cultivar.

Fruit Quality. It is a common belief that improvement in fruit quality is the most important characteristic for focus of current breeders. Regardless of whether fruit is processed or used fresh, there are a number of quality traits of primary interest in breeding including fruit flavor (sweetness, acidity, astringency, aromatic components, etc.), color, firmness, ease of removal of the fruit at harvest, and seediness (size and mouth feel during consumption).

A few years ago I wrote that “the most important opportunity for improving the consumption of eastern U.S. blackberries is to enhance the sweetness of berries along with reduced acidity and astringency levels” (Clark, 2005). I still believe strongly in this idea. Higher soluble solids levels of 10-12% can be found in cultivars such as ‘Navaho’ and ‘Ouachita’. Further enhancements to 15% or more are possible by crossing among high soluble solids parents and selecting desired progeny. Most trailing blackberry cultivars, including ‘Boysenberry’, have high soluble solids levels (11-13%) compared to ‘Chester Thornless’ (8%) and in some years can range to greater than 15% (Fan-Chiang, 1999; Siriwoharn et al., 2004). However, simply having high soluble solids is not adequate since sweet berries with very low acidity can have a “flat” flavor (Hall, 1990). In the Arkansas program there are several selections that I consider “low acid” in that they have reduced acidity even prior to being fully ripe. As I entertained visitors to the program at Arkansas (particularly in 2008), I carefully observed impressions of this type. Comments were all over the place, ranging from “wow this is great”, to “this has no flavor”. This tells me that low-acid berries likely will not be preferred by all. Of course the same could be said of apples as the contrast in sweet/tart flavor between a ‘Gala’ and ‘Granny Smith’ is quite substantial. Flavor enhancement is a top priority in most breeding programs today and possibly a range of flavors addressing different preferences might be developed in future cultivars.

Postharvest quality is determined by how a genotype responds to storage and/or handling practices from the time the fruit ripens on the plant until it is in the consumers’ hands. Parameters examined in past and ongoing postharvest evaluations of cultivars and selections for fresh market in the University of Arkansas (and prior with the USDA-ARS/Oklahoma) effort include appearance, firmness, and flavor. Limitations such as presence of decay, leakage of juice, obvious mushiness of fruit, or presence of substantial red drupelet color limit consumer appeal while shiny, fully black berries are desired (Perkins-Veazie and Clark, 2005). Multi-year evaluations have been essential to fully determine the postharvest potential of new genotypes. A major finding in this work is that firmness evaluation in the field is not a full indicator that the harvested fruit will store well. Postharvest evaluations in the Arkansas program are a routine protocol for advanced selections, and the use of the technique developed by Dr. Penelope Perkins-Veazie for evaluations has been and is a key component in determining which selections get moved forward or sent to the glyphosate happy hour.

Recent work has evaluated nutraceutical/antioxidant levels in blackberry genotypes (Clark et al., 2002; Moyer et al., 2002; Cho et al., 2004; Siriwoharn et al., 2004; Connor et al., 2005). Substantial variation was found among cultivars from Arkansas with two to four-fold differences in oxygen radical absorbance capacity (ORAC) depending on year (Clark et al., 2002). We also found year-to-year variation for some genotypes. Cho et al. (2004) found variation among cultivars for ORAC along with differences in anthocyanin and flavanol contents. Currently, programs often measure ORAC, anthocyanin, or other compound levels in advanced selections, though breeding specifically for increased antioxidant levels is not common. The further evaluation of new developments for antioxidant content should be done along with the promotion of this potential health benefit to consumers.

Fruit Size. Fruit size advancement has been substantial in blackberry breeding. Most programs have attained large size in selections and/or cultivars released, and exceptional-sized parents are usually available for breeding. In fact, excess fruit size has surfaced as a concern in recent years (Clark, 2005). The thornless ‘Apache’ produces fruit of up to 10 g, and the thorny ‘Kiowa’ up to 15 g. Berries this large can be at a disadvantage as they can have difficulty fitting in or making product weight in clamshell containers. This has created a shift from breeding for “larger the better” to a size of 7-8 g for shipping in the Arkansas program (Clark, 2005). However, the newest release from Arkansas, ‘Natchez’, has berries in the area of 10 g. But, the berries are long and slender in shape and are envisioned to be easier to pack than round berries. Although fruit size is still very important in breeding, excellent size has been attained in parents for breeding and is much easier to achieve in progeny than in years past.

Thornlessness. This trait has had substantial attention for many years, and the number of thornless cultivars is on the increase. Most blackberry producers agree that thornlessness is desired, although it is of greatest concern for pick-your-own marketers and mechanically picked berries for processing. Advances in thornless breeding have been made in most programs, using either the recessive ‘Merton Thornless’ source (Scott and Ink, 1966), the dominant thornless in ‘Austin Thornless’ (Lawrence, 1986), or non-chimeral, dominant-thornless Loganberry type (Hall et al., 1986). With these and other sources of thornless genes and the resulting increase in thornless parents for breeding, it is expected that a higher proportion of new cultivars will be thornless in the future. In fact, I am not sure there will be any further thorny, florican-fruiting cultivars released from the Arkansas program.

Plant Adaptation and Habit. In the past, environmental adaptation in blackberry breeding has largely focused on winter hardiness, with lesser emphasis on reduced chilling requirement and other traits. Moore (1984) indicated that lack of winter hardiness was a major limitation to the expansion of production in much of North America, and this limitation continues today. The release of ‘Illini Hardy’ by the University of Illinois and ‘Chester Thornless’ by the USDA-ARS provided two of the hardiest cultivars of recent times. However, breeding for winter hardiness has largely been discontinued in the U.S. Primocane-fruiting is another approach to addressing winter injury (see primocane-fruiting section).

Blackberry production in reduced-chill environments (generally 300 hours or less below 7°C during the “dormant” season) has greatly increased in recent years, predominantly in Mexico and, to a lesser extent, Guatemala and southern Spain. Cultural manipulation is often used in these environments, including defoliation, pruning, and growth regulator applications to force plants to flower and encourage high yields of quality fruit (J. Lopez-Medina, personal commun.). Currently, breeding in a low-chill environment is very limited if done at all in the U.S.

Another trait getting attention in the category of adaptation is resistance to sunburn on fruit, which is seen as the appearance of few to many white drupelets on the fruit which render the fruit to be worthless for most markets. There appears to be adequate resistance to sunburn to achieve progress for this trait. One can rest assured I spend a substantial amount of time focusing on this trait!

Important components of plant habit include the growth habit of canes along with time of flowering and ripening of fruit. Blackberries are usually classified using three cane types; trailing, semi-erect, and erect. Genetically there is a continuum of cane types and not distinct classes as mentioned here; however, for production guidelines these groupings have utility. Efforts continue for all cane types. The Arkansas program has stressed erect canes coupled with the incorporation of thornlessness, and substantial success has been achieved. In general, fresh-market growers tend to prefer erect canes.

Time of fruit ripening varies substantially, and is a trait that is of primary importance to most blackberry breeders. Early ripening is often of high priority, and cultivars such as ‘Choctaw’, ‘Metolius’, ‘Obsidian’, ‘Siskiyou’, ‘Arapaho’ and ‘Natchez’ were released primarily for their early fruit maturity. Later ripening is also of importance where fruiting season extension is desired, and several of the thornless, semi-erect cultivars have later ripening times as do primocane-fruiting types. The expansion of the ripening season is a common goal in current breeding programs. The Arkansas program has developed a strong focus on later ripening florican-fruiting genotypes, although it will take a while to achieve late-ripening, high quality objectives due to the program being focused mainly on early ripening material in its first 40 years.

Primocane Fruiting. The development of flower buds and fruit on first-season canes, or primocanes, has been of substantial commercial importance in red raspberry. This fruiting habit has recently gained attention among blackberry breeders and in the coming years primocane-fruiting cultivars will become important in commercial production. Primocane fruiting has several advantages including: 1) later-season (fall) fruiting period, 2) the potential to schedule production based on primocane management, 3) potential of two crops on the same plant in the same year (florican followed by

primocane), 4) reduction in pruning costs by mowing of canes (primocane crop only produced), 5) avoidance of winter injury, and 6) avoidance of rosette/double blossom occurrence (primocane crop only produced).

Identified sources of the primocane-fruiting trait for blackberry include red raspberry and the wild blackberry selection referred to as 'Hillquist' and cultivars and selections with 'Hillquist' in their backgrounds. Each of these sources has been used in breeding investigations in recent years.

There is no record of breeding with 'Hillquist' until James N. Moore of the University of Arkansas used it as a parent in a 1967 cross. Though no primocane-fruiting progeny were derived in the first-generation 'Hillquist' progeny, a later evaluation of 'Hillquist'-derived plants determined that primocane fruiting was a recessive trait (Lopez-Medina et al., 2000). From seedlings produced in Lopez-Medina's inheritance study, 'Prime-Jan'® and 'Prime-Jim'® were released (Clark et al., 2005).

Subsequent breeding in this area in the last five years in Arkansas has been very exciting. The limitation of damaging heat effects on primocane flowering and fruit set/quality continue to manifest, but some progress is being made in selecting more heat-tolerant genotypes. Substantial effort continues on this objective. Fruit quality advances beyond 'Prime-Jan'® and 'Prime-Jim'® have been achieved, and the first shipping-quality primocane fruiting selections are in place. One of these is tentatively planned for release in 2009.

Another promising area of advance, particularly in 2006-2008, has been the selection of a number of thornless primocane-fruiting plants. These have increased fruit size over prior plants of this type, and early indications are that some appear to have postharvest quality suitable for the shipping market. These traits have moved along somewhat more quickly than envisioned a few years ago. It is hoped that in 2-4 years that the first primocane-fruiting thornless blackberry will hit the market.

Many are aware of the major differences in performance of the primocane types in more moderate summer and early fall temperature areas compared to Arkansas. The best adaptation is seen in western states, particularly in coastal California where 'Prime-Jan'® and 'Prime-Jim'® have been tested, along with some of the newer selections from the Arkansas program. Excellent yields, large fruit size, and good plant health are seen on primocane cultivars in coastal climates. Evaluations of primocane-fruiting blackberries in high tunnels in the East have not been reported, but it is hoped that this approach to fall production can be achieved.

Most believe that primocane fruiting holds great potential for furthering blackberry production in the world. This trait will likely get substantial attention in the coming years and could revolutionize production worldwide.

Pest Resistance. Blackberries are remarkably free of serious disease and insect pest problems in much of their range. In commercial settings where the crops are grown intensively in a monoculture, fungicide applications are a standard management practice. Insecticides/acaricides are often applied only for specific problems. There is a range of pest species that impact blackberry production, though I am not aware of any programs that routinely screen for pests other than through normal field screening and rouging of susceptible genotypes. However, a few advances in pest resistance have been achieved in recent years, while other concerns have not been addressed or loom as potential problems.

Double blossom/rosette is a serious disease in the southeastern U.S. In general, the Arkansas thornless cultivars have resistance to double blossom and this has allowed the expansion of production in the southern U.S.; thorny cultivars all show some degree of susceptibility (Buckley et al., 1995). Downy mildew can be a problem in all regions, particularly in cool, moist climates similar to California and New Zealand where heavy sporulation coincides with flowering, and it is increasingly seen in Mexico (J. Lopez-Medina, personal commun.). This disease could become a

major problem based on recent observations in these locations. There is much to be learned concerning sources of resistance to this disease.

Finally, while viruses have long been known in *Rubus*, particularly red raspberry, they were generally considered to be asymptomatic in blackberry (Converse, 1987). In the late 1990s, as new tools for identifying and characterizing viruses began to be used on viruses in small fruits, a number of viruses were newly identified as occurring specifically in blackberry (Guzmán-Baeny, 2003; Martin et al., 2004; Susaimuthu et al., 2007). The concern for viruses in the South is increasing as planting area of blackberries expands. *Blackberry yellow vein associated virus* and *Blackberry virus X* are two of the emerging viruses that are gaining attention (Y. Tzanetakis, personal commun.) Breeding for virus resistance has not been specifically undertaken, although activities such as testing parents used in crosses and selections prior to release has become routine. The latter practices contribute to the lessening of spread of viruses rather than direct resistance breeding.

CONCLUSIONS

This is a grand time for blackberry breeding. The most important factor is the increasing interest in blackberries worldwide. This interest is inspiring expansion in some existing programs (such as USDA-ARS and University of Arkansas) while new private endeavors are being considered. Genetically this is also a very good time, with many advances for characteristics such as fruit quality, thornlessness, plant adaptation, and primocane fruiting available for breeding with the potential for substantial improvement. The next twenty years holds great promise for this berry to accelerate in production and consumption. Exceptional blackberries, if not already here, are certainly on the way!

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MIDWEST BRAMBLE INSECTS IN THE FIELD AND UNDER TUNNELS

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This talk will be presented in two halves. The first will review the primary insect and mite pests that affect bramble crops in the Great Lakes region and the currently-available tools for controlling these pests in brambles. The second half will report on some recent studies that have explored the effect of high tunnels on bramble insect pests in this region, with a focus on the dramatic reductions in pest pressure from Japanese beetles and potato leafhopper when brambles are grown under tunnels. These trials have also provided some insight into the relative susceptibility of raspberry cultivars to these two pests. If time permits, I will also discuss some of the issues growers should think about related to pollination of bramble crops grown under tunnels.

EFFICACY OF PREHARVEST FUNGICIDE APPLICATIONS AND COLD STORAGE FOR POSTHARVEST CONTROL OF BOTRYTIS FRUIT ROT (GRAY MOLD) ON RED RASPBERRY

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Abstract

Applications of the fungicides Elevate 50WG and Switch 62.5WG to red raspberry prior to harvest were evaluated for postharvest control of fruit rot, caused by *Botrytis cinerea*. Fungicides were applied three times during bloom only, three times preharvest (postbloom) only, or six times full season (bloom through harvest), and symptomless fruit (at harvest) were incubated for 8 days in either cold storage (4°C) or at room temperature (23°C). Without fungicide, between 6 and 29% of the fruit had rot symptoms after 2 days of storage at room temperature over the 2 years of testing; after 8 days, 74 and 85% of the fruit had symptoms at room temperature. Zero and 12% of fruit had symptoms with 2 days of cold storage when plants were not treated with fungicide, and rot incidence increased to 9 and 60% at 8 days of cold storage over the 2 years. All fungicide treatments significantly reduced postharvest fruit rot compared to control (six water sprays). Applications of fungicide only at bloom generally had higher fruit rot incidence than found for the preharvest and full season fungicide programs. Results indicate that preharvest (post-bloom) fungicide sprays are beneficial for control of postharvest *Botrytis* fruit rot, especially when coupled with cold-temperature storage.

Introduction

One of the major constraints to increased raspberry production and marketing worldwide is *Botrytis* fruit rot or gray mold, caused by the fungus *Botrytis cinerea*. The raspberry is an aggregate fruit composed of about 100 drupelets. Its morphological characteristics contribute to its high susceptibility to fruit rots. The lack of effective postharvest control of gray mold is the most important single factor limiting the sale of fruits on distant markets. In Ohio, almost 100% of raspberry fruits are marketed as pick-your-own or direct retail in farm markets. Growers that market harvested berries often need to hold them in cold storage for at least 2 to 3 days for marketing purposes; however, many growers experience 100% loss of fruit in cold storage within 48 to 72 h due almost exclusively to rot caused by *B. cinerea*.

B. cinerea also causes gray mold of strawberry. Epidemiological studies have demonstrated that the majority of fruit infections on strawberry occur during bloom. Studies on raspberry have had similar results. Williamson et al. reported that inoculation of flowers with dry conidia greatly reduced the shelf life of fruit after harvest. They also found that most fruits are symptomlessly infected via flower parts prior to harvest. Jarvis reported that mycelium infecting floral parts can invade the proximal end of both strawberry and raspberry receptacles. This mycelium generally remains quiescent (latent) until fruit begin to ripen, at which time the fungus becomes active and rots the fruit. Even under relatively dry environments, conidia can germinate in stigmatic fluid and symptomlessly colonize styles that remain attached to fruits at maturity.

Due to the importance of flower infections, fungicide applications for gray mold control on strawberry and raspberry are currently targeted primarily during the bloom period. On strawberry, bloom applications have been very effective for gray mold control in perennial production systems. In perennial matted row strawberry production systems, there is a limited bloom period that makes it relatively efficient to protect the blooms with fungicides. Currently in Ohio, most strawberry growers apply

fungicides for Botrytis fruit rot control during bloom, and discontinue spraying after bloom through harvest. This approach has provided excellent control on strawberry. On raspberry, bloom occurs over a much longer period of time and considerable bloom can be present during harvest. Many Ohio growers make applications to raspberry similar to those made on strawberry during the primary bloom period and generally stop sprays as harvest approaches. Although this approach works very well on strawberry, our observations suggest that preharvest sprays on raspberries may be beneficial for post harvest control of gray mold. Dashwood and Fox suggested that multiple-spray programs on raspberry were essential to prevent both the early symptomless infection of fruit, as well as later surface contamination. The use of cold storage to aid in the reduction of postharvest fruit rot is a clearly established and widely used cultural practice. The objective of this study was to evaluate the effects of fungicide timing and cold storage on postharvest fruit rot caused by *B. cinerea* in raspberry.

Fungicide Timing and Postharvest Storage Trials

Fungicide evaluations were conducted in a 3- year-old commercial red raspberry planting at Moreland Fruit Farm, Moreland, OH, initially in 2003. Plants of the cultivar 'Nova' were grown in trellised rows on 3.6-m (12- ft) centers. Individual plots consisted of 4.6-m (15-ft) long sections of row. An untreated section of row was left between each treated section of row. Treatments were arranged in a completely randomized design with four replications per treatment. Fungicides were applied in 935 L of water per ha (100 gal of water per acre) using a handgun at 1724 kPa (250 psi) pressure. All treatments were applied to runoff. The fungicides Elevate (fenhexamid) and Switch (cyprodinil plus fludioxonil) were applied in a one or two-spray alternating program, with the first application for each timing period being Elevate and the last application being Switch. Switch has provided good control of postharvest fruit rots on other crops (16); therefore, Switch was targeted for use in the last application before harvest.

Fungicide, rates and timing for each treatment in 2003 are provided in Table 1. Fruits were harvested from all treatments on three dates, 24 June, 29 June, and 4 July. At each harvest, 50 apparently healthy (symptomless) fruit (marketable fruit, red ripe) were hand harvested directly into 0.24-liter (2 pint) plastic clam shell containers. Fruits were picked carefully to avoid physical damage. Fruits were in contact with each other and all fruit could be observed without opening the container and moving the fruit. Two containers (each containing 50 fruit) were harvested from each replication, treatment, and harvest date. Containers were kept on ice in a cooler and within 1 h were immediately transported to the laboratory where one container per replication and treatment was placed on a laboratory bench at room temperature (23°C) and the other container was placed in cold storage at 4°C and 95% relative humidity. On days 2, 4, 6, and 8 of storage, the contents of each container were inspected for incidence of Botrytis fruit rot. Decayed fruit were left in the clamshell containers to replicate commercial conditions and also to prevent fruit damage and spread of inoculum that would accompany excessive handling. Disease incidence was recorded for each observation based on the presence of white mycelium, or presence of fungal sporulation. Visual diagnosis was confirmed by examination of sporulation with a hand lens or by plating out representative samples of aerial mycelium on acidified potato dextrose agar.

The entire experiment was repeated in 2004, with the same fungicide treatments and storage conditions. Fungicides, rates and timing are presented in Table 2. Fruit were harvested from all treatments on 24 June, 29 June, and 4 July. Experimental procedures for harvesting, storage, and incubation of fruit were the same as described for 2003.

Postharvest Fruit Rot 2003

At 2 days after harvest at room temperature, 6% of the non-treated control fruit had gray mold symptoms, even though all fruit were symptomless when harvested. At 4 days after harvest at room temperature, 27% of the control fruit had symptoms and/or signs of visible mycelia. By 8 days after harvest, 85% of the control fruit had gray mold. At 2 days after harvest at room temperature, none of the fruit from plots treated with fungicide showed any gray mold symptoms. By 8 days at room temperature,

however, 30% of the fruit from the bloom-only treatment showed fruit rot symptoms. All fungicide treatments had significantly less Botrytis fruit rot than the untreated control at 8 days of room-temperature storage (Table 1). Moreover, the preharvest only (application after bloom) and full-schedule treatments had significantly less Botrytis fruit rot than the bloom only treatment, and there were no significant differences in means between the preharvest and full-schedule treatments. Fungicide treatment after bloom (i.e., preharvest) or the full-season fungicide regime resulted in only about 10% fruit rot after 8 days of storage at room temperature.

At 2 days of cold storage after harvest, there were no visible gray mold symptoms for any of the treatments, including the control. Even after 8 days, fruit from the treatments receiving any fungicide (bloom, preharvest, or full season) showed no symptoms, and 9% of the fruit from the control treatment had gray mold symptoms (Table 1). At 8 days, the mean for the cold-storage control was significantly less than the mean for the room-temperature control, and also less than the mean for the room-temperature bloom-only fungicide treatment (Table 1).

Postharvest Fruit Rot 2004

Post-harvest fruit rot incidence was initially higher in 2004 than in 2003, especially for the untreated fruit. Variability was also higher than in 2003. At 2 days after harvest at room temperature, 29% of the non-treated control fruit had gray mold symptoms. With 8 days of storage, 74% of the control fruit had gray mold symptoms. At 2 days, none of the fruit from the preharvest (post-bloom) or full-season fungicide treatments showed symptoms; however, 2% of the fruit from the bloom-only treatment had fruit rot symptoms. By 8 days of storage at room temperature, 18% of the fruit from the bloom-only treatment, but only 4.5% of the fruit from the preharvest treatment and 1.2% of the fruit from the full-season treatment showed symptoms. With 8 days of storage, fruit rot incidence was significantly greater for the control than for the other treatments (Table 2). Moreover, rot incidence for the full season treatment was less than for the bloom-only treatment.

At 2 days of cold storage, 12% of the fruit from the non-treated control treatment had Botrytis fruit rot symptoms; this is in contrast to 0% in 2003 for the same conditions. Incidence increased to 60% by day 8 for the cold-storage control. There were no fruit with gray mold at 2 days of cold storage for the three fungicide treatments. At 8 days of cold storage, fruit rot incidence for the fungicide treatments ranged from 1.2% (full-season) to 9% (bloom). Means for the fungicide treatments were all significantly ($P = 0.05$) less than for the control with cold storage (Table 2). Moreover, with the controls, the mean for cold storage was significantly less than the mean for room temperature at 8 days of incubation.

Implications for Control of Post Harvest Fruit Rot on Raspberry

Results for the control of postharvest Botrytis fruit rot of red raspberry were similar in 2003 and 2004. Without fungicide treatment before harvest, unacceptable levels of fruit rot were found after only 2 days of storage at room temperature, even though all fruit were symptomless at time of harvest. At room temperature, all fungicide treatments resulted in significantly less postharvest fruit rot than the untreated control. There also was a tendency for fruit rot incidence to be lower when fungicides were applied during preharvest (after bloom), or during bloom and preharvest (full season), compared to when fungicide was applied only during bloom. Even under the very extreme situation of 8 days of fruit storage at room temperature, less than 10% of the raspberry fruit showed symptoms of gray mold when fungicides were applied preharvest or for the full season.

Cold storage clearly reduced the incidence of fruit rot symptoms when plants were not treated with fungicides in the field. Cold-storage alone would not be adequate for controlling the disease postharvest, since in 2004 about 12% of the fruit showed gray mold symptoms after only 2 days of storage when plants were not treated with fungicide in the field. All fungicide treatments resulted in excellent control of postharvest Botrytis fruit in cold storage. At 2 days of cold storage, 0 or close to 0%

fruit rot was found; after 4 days of cold storage, no fruit with disease symptoms were found for the preharvest or full-season fungicide treatments during both years. After 8 days of cold storage, the highest fruit rot incidence for the treatments receiving fungicide over the 2 years was 9% (bloom only), and most treatments had incidence of 1% or less.

In summary, Elevate and Switch provided excellent postharvest control of *Botrytis* fruit rot in red raspberry in 2 years of studies. When fungicide treatments were combined with cold storage, disease control was enhanced. If growers intend to hold raspberries for as little as 2 days after harvest, the importance of maintaining good cold storage facilities cannot be over emphasized. However, even with good cold storage, fungicide use (especially during preharvest and possibly for the full season) appears to be beneficial for control of postharvest fruit rot. We need to emphasize that the results of our studies apply only to control of postharvest fruit rot by *B. cinerea*. In both years of testing very little fruit rot was observed in the controls at harvest in the field and only healthy (marketable) fruits were selected for use in storage studies. We do not intend to suggest that applications of fungicide during bloom are not important for control of *Botrytis* fruit rot, especially at harvest. Our data does suggest that preharvest applications of effective fungicides are beneficial for controlling postharvest fruit rot.

Table 1. Percentage of raspberry fruits with Botrytis fruit rot (gray mold) symptoms after 8 days of post-harvest incubation at either room temperature (23 C) or cold storage (4 C) in 2003

Treatment	Spray timing	Fruit rot (%) at 8 days	
		Room Temp.	Cold Storage
Application only at bloom	Elevate 50 WG at 1.68 kg on 22 (early bloom) and 28 May (50% bloom) (2 sprays); then Switch 62.5 WG at 980 g on 4 June (late bloom)	30.2 b ^z	0 d
Preharvest applications only	Elevate 50 WG at 1.68 kg on 14 June (green fruit present); then Switch 62.5 WG at 980 g on 21 (red fruit Present) and 28 June (1 day before second harvest)	9.7 c	0 d
Full season	All sprays in Bloom and Preharvest treatments (above)	9.5 c	0 d
Untreated control ^y	--	85.0 a	9.0 c

^zMeans followed by the same letter within or across columns for incidence of fruit rot are not significantly different.

Table 2. Percentage of raspberry fruits with Botrytis fruit rot (gray mold) symptoms after 8 days of post-harvest incubation at either room temperature (23 C) or cold storage (4 C) in 2004

Treatment	Spray timing	Fruit rot (%) at 8 days	
		Room Temp.	Cold Storage
Applications only at bloom	Elevate 50 WG at 1.68 kg on 15 (early bloom) and 22 May (50% bloom)(2 sprays); then Switch 62.5 WG at 980 g on 28 May (late bloom, green fruit)	18.3 c ^z	9.2 cd
Preharvest applications	Elevate 50 WG at 1.68 kg on 4 June (green fruit); then Switch 62.5 WG at 980 g on 12 (fruit beginning to ripen) and 19 June (1 day before first harvest)	4.5 cd	3.0 d
Full season	All sprays in Bloom and Preharvest treatments (above)	1.2 d	1.2 d
Untreated control ^y	--	74.0 a	59.8 b

^zMeans followed by the same letter within or across columns for incidence of fruit rot are not significantly different.