Susceptibility of Highbush Blueberry Cultivars to Larval Infestation by *Rhagoletis mendax* (Diptera: Tephritidae)

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ABSTRACT Eighteen highbush blueberry, *Vaccinium corymbosum* L., cultivars were evaluated for larval infestation by the blueberry maggot fly, *Rhagoletis mendax* Curran. Most cultivars were evaluated during 3 field seasons. Significantly fewer maggots were found in berries of early-ripening cultivars, 'Earliblue' and 'Bluetta', than in later maturing cultivars such as 'Bluehaven', 'Coville', 'Darrow', 'Elizabeth', and 'Lateblue'. The oviposition period of *R. mendax* is synchronized with the ripening dates of mid-season cultivars (late July to early August) in Rhode Island. This results in more oviposition and higher larval infestations in mid- and late-season susceptible cultivars. Among the mid- to late-season cultivars, 'Northland' and 'Herbert' berries had consistently fewer maggots than other cultivars. These cultivars, along with Bluetta and Earliblue appear to be good candidates for inclusion into integrated pest management programs.

KEY WORDS blueberry maggot fly, highbush blueberries, cultivars, oviposition

THE BLUEBERRY MAGGOT FLY, *Rhagoletis mendax* Curran, is a major pest of blueberries *Vaccinium* L. spp. in eastern United States and Canada (Smith and Prokopy 1981). Adults emerge when blueberries begin to ripen and females are attracted to ammonia (Liburd et al. 1998). Female flies are apparently seeking a protein source that may be important in egg maturation. Flies become sexually mature within 1–2 wk of emergence, mate on the host plant, and females oviposit into ripe or ripening berries (Lathrop and Nickels 1932, Smith and Prokopy 1981). Larvae feed inside the fruit and cause major destruction of the tissues. Processing plants may reject total shipments of berries even if only a few maggots are found (Dixon and Knowlton 1994). Infested berries may also be restricted from moving across national boundaries (Prange and Lidster 1992). Growers may apply 3–5 insecticide applications to prevent oviposition into fruits regardless of whether flies are present. Visual traps, including Pherocon AM boards (Prokopy and Coli 1978) and colored spheres (Liburd et al. 1998), have been used to monitor flies and time insecticide applications. Growers may also be able to better time insecticide applications based on ripening dates and cultivar susceptibility.

Host plant use by *R. mendax* is somewhat obscure. Blueberries (*V. corymbosum* L. and *V. angustifolium* Aiton) and huckleberries (*Gaylussacia* Humboldt, Bonpland, and Kunth spp.) are the 3 primary ericaceous hosts in the northeastern United States (Bush 1966). Smith and Prokopy (1981), however, found uninfested *V. angustifolium* growing only 30 m from heavily infested *V. corymbosum* plants in Massachusetts. In the south, Payne and Berlocher (1995a, b) reported that *V. stamineum* L. (deerberry) was the principal host, and in many of the sites they sampled, *R. mendax* did not infest any of the available species of *Gaylussacia* or other species of *Vaccinium*. They suggested that the pattern of host plant infestation by *R. mendax* may be related to its inflexible diapause phenology that restricts it to infesting host species during the short period when adults are active.

Although Diehl and Prokopy (1986) and Frey and Bush (1990) observed distinctive host selection behaviors between *R. mendax* and the sibling species *Rhagoletis pomonella* (Walsh), it is generally assumed that the factors affecting host plant detection by *R. mendax* are similar to those observed for *R. pomonella* (Geddes et al. 1987). Foliage color and bush shape and size may play a role in attracting *R. mendax* flies to its host. Fruit size and oviposition-deterring pheromones also influence oviposition in blueberries (Prokopy et al. 1976, Diehl and Prokopy 1986).

In *R. pomonella* (a pest of apples *Malus domestica* Borkhausen), Dean and Chapman (1973) measured 20 apple varieties and their associated ripening dates. They found that the time of ripening and the chemical and physical characteristics of the fruit were principal factors affecting the susceptibility of apple varieties to *R. pomonella*. For *R. mendax* in Maine, Lathrop and Nickels (1932) showed that the majority of maggots emerged in August but they did not report a relationship between time of ripening and level of susceptibility to *R. mendax*.

In North America, commercial highbush blueberry plantings are composed of artificially hybridized cultivars (Hancock and Draper 1989) and there is no

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quantitative data relating ripening dates to cultivar susceptibility to *R. mendax*. In addition, there are no studies that integrate blueberry phenology into *R. mendax* management strategies. The objectives of this study were to evaluate susceptibility of various commercial highbush blueberry cultivars to larval infestation by *R. mendax* and to integrate information on cultivar susceptibility into management strategies.

Materials and Methods

In 1995, experiments were conducted at 2 highbush blueberry plantings in Rhode Island. One site was located at the University of Rhode Island, East Farm Experimental Station in Kingston, RI. A 2nd site was located at a commercial blueberry grower's farm located in Coventry, RI. In 1996 and 1997, only the Kingston site was sampled. At the Kingston site, 17 cultivars were planted in blocks of 5 bushes per cultivar. Blocks were randomized completely within the planting. Blueberry plants were spaced 1.5 m between plants and 2.4 m between rows. In Coventry, blueberries were planted in rows of 15 bushes per cultivar. There were 3 rows each of 'Bluecrop', 'Coville', 'Berkley', and 1 row of 'Jersey' within the experimental area, with plants spaced 2 m apart within rows and 3 m between rows. Because cultivars have different ripening dates, 3 samples of berries were taken from each cultivar 1 wk apart, spanning the intervals before, during, and after peak ripeness (based on taste and when the majority of berries had turned blue around the stem end). Adult flies were monitored at both sites in 1995 with 4 green spheres (Great Lakes IPM, Vestaburg, MI) coated with Tangle-Trap (Tanglefoot, Grand Rapids, MI) based on previous studies that showed green spheres were attractive (Liburd et al. 1998). In 1996, flies were monitored using 4 green spheres and 4 Pherocon AM yellow boards (Great Lakes IPM). In 1997, only 4 Pherocon AM yellow boards were used for monitoring flies. All monitoring traps were unbaited to determine if there is a shift from boards (attraction to leaf mimics for food foraging) to spheres (attraction to oviposition mimics) as flies mature. Insects were counted and removed from traps 3 times per week and traps were changed after 3 wk.

Cultivar Sampling in 1995. Thirteen hybrid cultivars ('Bluecrop', 'Bluehaven', 'Bluetta', 'Bluejay', 'Blueray', 'Collins', 'Darrow', 'Earliblue', 'Herbert', 'Meader', 'Northland', 'Patriot', and 'Spartan') with different ripening dates (Eck et al. 1990) were evaluated at the Kingston site. In Coventry, 3 midseason (26 July to 5 August) cultivars that included Berkeley, Bluecrop, and Jersey and 1 late-season cultivar (Coville) (ripening after 5 August) were evaluated.

Three samples of 2,500 berries per sample were harvested weekly for 3 wk from each cultivar at both sites in 1995. Samples were weighed and temporarily placed into labeled plastic bags before being placed on trays (62 by 45 cm) with 0.5-cm mesh hardware cloth (G. F. Wright Steel and Wire, Worchester, MA). Boxes were then covered, labeled, and stored at room temperature in the laboratory for 14 d. Larvae exiting the berries fell through the mesh screen into clear plastic boxes (58 by 42.5 by 15 cm) (Rubbermaid, Wooster, OH).

Cultivar Sampling in 1996 and 1997. Thirteen cultivars were evaluated in 1996 including 12 from 1995 and a new cultivar, 'Lateblue'. Spartan was inadvertently eliminated from the study during 1996. In 1997, 17 cultivars (with different ripening dates) including the 14 evaluated in 1995 and 1996, and 3 additional cultivars, Berkeley, Coville, and 'Elizabeth', were evaluated.

Two 450-g poly-lined food containers (Sherri Cup, Kensington, CT) were used in the evaluation studies during 1996 and 1997. Containers were nested one inside the other with the bottom of the upper container removed and replaced by 0.50-cm mesh erosion netting (Bemis, St. Louis, MO). Twenty samples of 50 berries per cultivar were harvested weekly for 3 wk (1,000 berries per week) from each cultivar (5 bushes) and placed directly into food containers with netting. Ethylene glycol solution (75 ml) was placed in the bottom food container to collect emerged maggots. Food containers containing berries were covered and labeled before placing them into clear plastic boxes. The boxes were then covered and left in the laboratory at room temperature for 14 d. During 1996 and 1997, 50 berries from each cultivar were weighed and the diameter of each berry was measured.

Enumeration of Maggots and Flies. Plastic boxes and food containers were checked 3 times per week for 14 d and larvae and pupae from each cultivar were counted and removed from containers and trays. Traps for monitoring flies were hung 1 July in 1995, 3 July in 1996, and 2 July in 1997, and were checked 3 times per week for 6 wk, starting 5 July of each year. Flies were sexed once per week in the field.

Statistical Analysis. Data on percent infestation from the 3 weekly samples were averaged and subjected to analysis of variance (ANOVA) and the least significant difference (LSD) test was used to show infestation differences among the cultivars ($P = 0.05$) (SAS Institute 1989). Data from the 4 monitoring traps were averaged for each monitoring period (1 wk). In 1996, data from Pherocon AM boards and green spheres were log transformed ($x + 1$) to stablize variances and subjected to ANOVA. Means were separated by LSD.

Results

1995. At the Kingston site, we collected significantly ($F = 4.5$; df = 12, 24; $P < 0.01$) fewer maggots from berries of early-season cultivars (Bluetta and Earliblue) than from Patriot, Bluehaven, Blueray, and Darrow (Table 1). The number of flies caught on green spheres at this site was low (Fig. 1). Peak fly capture occurred on 19 July (Fig. 1).

At Coventry, peak fly captures on green spheres also occurred on 19 July 1995. There were no significant differences ($F = 1.6$; df = 3, 6; $P > 0.05$) in the number of maggots collected from the 4 cultivars tested.

Table 1. Infestation percentages of *R. mendax* in various highbush blueberry cultivars in Kingston, RI (1995, 1996, and 1997)

Cultivar	Avg ripening date in Rhode Island	Mean ± SEM		
		1995	1996	1997
		Early-Season		
Earliblue	8 July	1.0 ± 0.2d	1.4 ± 0.8d	0.3 ± 0.3d
Bluetta	16 July	1.3 ± 0.0cd	2.1 ± 0.4d	1.1 ± 0.9d
		Early-Midseason		
Collins	21 July	3.7 ± 0.3bcd	5.5 ± 1.1bcd	2.0 ± 2.0d
Meader	24 July	2.1 ± 1.0cd	7.0 ± 1.2abcd	1.4 ± 0.7d
Patriot	24 July	6.6 ± 2.0ab	5.3 ± 1.7bcd	4.8 ± 1.9bcd
Spartan	24 July	3.5 ± 0.3bcd	—	4.4 ± 1.7bcd
		Midseason		
Northland	28 July	0.6 ± 0.3d	3.2 ± 0.0cd	1.2 ± 0.3d
Bluecrop	29 July	4.8 ± 2.3abc	4.1 ± 0.7cd	2.3 ± 1.4cd
Bluejay	29 July	1.6 ± 0.4cd	9.1 ± 2.2abcd	2.3 ± 0.3cd
Blueray	29 July	7.1 ± 1.0ab	3.4 ± 2.4cd	6.7 ± 0.8bcd
Berkeley	30 July	—	—	3.8 ± 1.6bcd
Bluehaven	2 Aug.	7.0 ± 3.1ab	10.2 ± 5.0abc	8.9 ± 2.0ab
		Late season		
Coville	10 Aug.	—	—	8.5 ± 1.5abc
Darrow	10 Aug.	8.4 ± 2.7a	13.2 ± 5.9ab	14.8 ± 6.5a
Herbert	10 Aug.	1.3 ± 0.6cd	5.9 ± 1.3bcd	4.4 ± 1.3bcd
Elizabeth	12 Aug.	—	—	8.6 ± 3.5ab
Lateblue	20 Aug.	—	14.7 ± 5.4a	14.5 ± 3.6a

Means in the same column followed by the same letter are not significantly different ($P = 0.05$, LSD test).

Mean ± SEM percent berry infestation over the 3-wk period was 9.8 ± 4.5, 10.0 ± 7.1, 17.2 ± 11.2, 14.7 ± 6.9 for Bluecrop, Jersey, Berkeley, and Coville, respectively.

1996. Significantly ($F = 2.2$; df = 12, 24; $P = 0.05$) fewer maggots were collected from berries of early-season cultivars (Bluetta and Earliblue) than from Bluehaven, Darrow, and Lateblue (Table 1). Flies were first observed on Pherocon AM boards on 5 July 1996 (Fig. 2). Fly captures peaked 12–19 July and declined to nearly zero by 8 August (Fig. 2). Green spheres caught significantly ($F = 11.0$; df = 1, 3; $P < 0.05$) more flies than Pherocon AM boards from 26 July–8 August (Fig. 3). The highest mean ± SEM number of flies caught (9.0 ± 4.2) occurred on green spheres on 26 July (Fig. 3). During that same period, more females than males were caught (Fig. 4).

1997. Significantly ($F = 4.0$; df = 16, 32; $P < 0.01$) fewer maggots were collected from berries of early-season cultivars (Bluetta, Earliblue) than from Bluehaven, Coville, Darrow, Elizabeth, and Lateblue (Table 1).

There were 3.5 times as many flies captured on Pherocon AM boards on 19 July in 1997 as in 1996 (Fig. 2). The 1st flies were caught 2 July, captures peaked on 18 July then declined to nearly zero by 8 August (Fig. 2). We noticed that >75% of the berries on Earliblue were ripe by 12 July 1996 and 10 July 1997. On those dates an average of 5.8 ± 1.8 and 7.5 ± 1.9 (mean ± SEM) flies, respectively, were counted on Pherocon AM boards for the monitoring period 5–12 July (Fig. 1).

Discussion

Our results show that early maturing cultivars (Earliblue and Bluetta) contained significantly fewer maggots than Bluehaven, Coville, Darrow, Elizabeth and

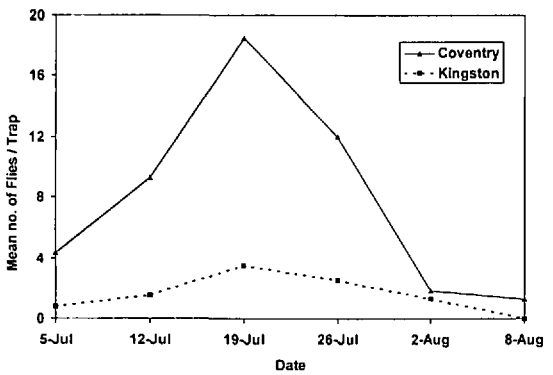

Fig. 1. Capture of *R. mendax* on unbaited green spheres in Coventry and Kingston, RI (1995).

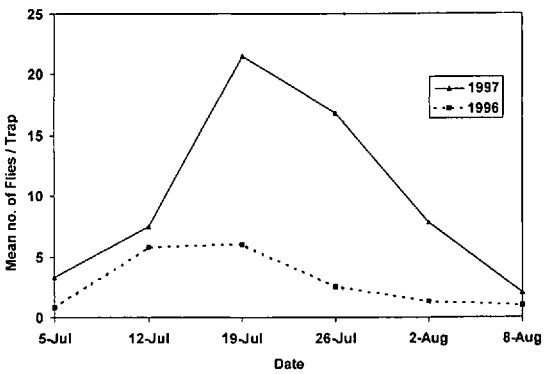

Fig. 2. Capture of *R. mendax* on yellow pherocon AM boards in Kingston, RI (1996 and 1997).

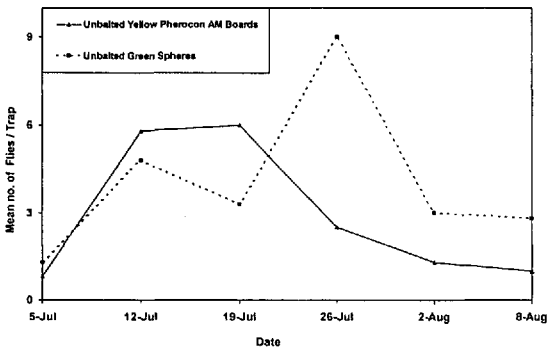

Fig. 3. Capture of *R. mendax* on unbaited green spheres and yellow pherocon AM boards in Kingston, RI (1996).

Lateblue. This is probably the result of the ripening and harvesting of berries from early-season cultivars before *R. mendax* reaches its ovipositional period. Lathrop and Nickels (1932) indicated that oviposition usually begins 10–15 d after the 1st fly has emerged. Based on monitoring trap data, the 1st flies emerged during the last week of June or during the 1st week in July. This suggests that oviposition will begin during the 1st or 2nd wk of July when >75% of Earliblue berries are ripe. If berries are harvested during this period, flies will be unable to oviposit into fruits. This may be the main reason why there was <2.1% infestation from berries of Earliblue and Bluetta (Table 1). In Europe, a shift to earlier producing and harvested cherry (*Prunus*) varieties significantly contributed to a reduction in *Rhagoletis cerasi* L. populations (Leski 1963).

In this study, Bluehaven, Darrow and Lateblue were consistently heavily infested while Northland, a midseason cultivar was slightly infested. Northland matures between the 4th wk of July and 1st wk of August. This cultivar is highly prolific with many small fruits per bush, and has a prolonged ripening period. Among the 17 cultivars evaluated, Northland had the smallest berry in terms of its size and weight averaging ± SEM 13.1 ± 1.3 mm diameter and 0.8 ± 0.1 g per berry respectively (n = 50) versus Bluehaven (midseason)

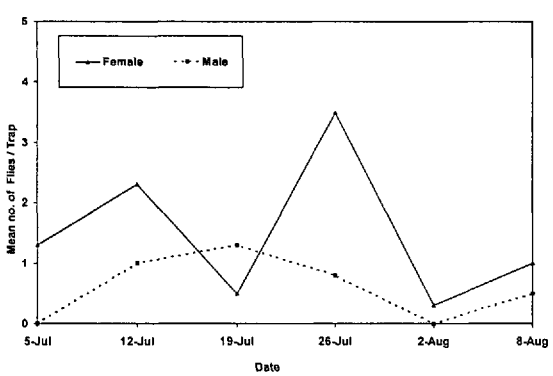

Fig. 4. Capture of male and female flies on unbaited green spheres in Kingston, RI (1996).

that averaged ± SEM 16.1 ± 1.0 mm diameter and 1.7 ± 0.3 g per berry.

Herbert consistently averaged higher infestation levels than Northland, but it was among the least infested late-season cultivars. Herbert yields moderately and has a prolonged ripening period. Fruits are average in terms of size and weight (15.8 ± 1.5 mm diameter,1.7 ± 0.3 g per berry) but the cultivar could be distinguished easily from the other 17 cultivars by its purplish-blue color. *Rhagoletis* flies are known to use shape, size and color as a basis for detecting fruits on host plants (Boller and Prokopy 1976). The reasons for the low infestation of Northland and Herbert may be the result of small fruit size and distinct color, however, this needs further research.

Pherocon AM boards provide a foliage-type stimulus that elicits host and food seeking behavior (Prokopy 1968, 1972). Because more flies were caught on boards than spheres between 12 and 19 July, it is presumed that flies caught during this period were in the host and food seeking behavioral state. Spheres are believed to be fruit mimics that elicit fruit seeking behaviors for oviposition by *Rhagoletis* species (Prokopy 1968). More flies were caught on spheres than boards from 26 July to 8 August. Flies caught on spheres are presumed to be searching for oviposition sites. Smith and Prokopy (1982) found that as the season progressed, and the flies matured, there was movement from foliage to fruit. Prokopy and Coli (1978) also found that blueberry maggot flies showed increasing preference for spheres over boards as the season progressed.

Peak trap captures on green spheres (fruit mimics) on 19 July 1995 and 26 July 1996 (Figs. 1 and 3) correspond with the availability of suitable fruit for oviposition in cultivars such as Bluehaven. This partially explains the higher percentages of maggots found in early-mid- and midseason cultivars. Lathrop and Nickels (1932) also collected the highest number of maggots from susceptible lowbush blueberries that ripened during the last week of July and the 1st wk of August.

A significantly higher percentage of maggots was collected from berries of late maturing cultivars (Coville, Darrow, Elizabeth, and Lateblue) as compared with early maturing cultivars (Earliblue and Bluetta). This may be caused by the susceptible state of the berries from late maturing cultivars. During the study, the percent of maggots consistently increased from the 1st to 2nd sample and then declined during the 3rd sample. Because the 3rd sample was taken when ≈100% of the berries were ripe, it appears that berries that are fully ripened are not in an optimum state of susceptibility or are unattractive to *R. mendax*. This corresponds to the findings of Reissig (1974) with respect to *R. pomonella* and apples. He reported that *R. pomonella* prefer to oviposit in apples that have not reached maturity. It also corresponds to the findings of Fein et al. (1982) who stated that extracts from ripe apples reduced the number of *Rhagoletis* flies that landed at the source in wind tunnel and olfactometer studies. Messina and Jones (1990) found that fruit

ripening phenology and hardness were important factors in oviposition by *R. pomonella,* but that these factors did not adequately explain why *R. pomonella* does not infest apples in Utah. Messina (1989) suggested an extremely low acceptance of apple relative to hawthorn or cherry, which was determined in laboratory assays. Other factors such as fruit size, color, and differences in the levels and composition of fruit volatiles may also affect the attractiveness of cultivars to *R. mendax.*

Our results show that early-season cultivars (Earliblue and Bluetta) incorporated into blueberry cropping systems may reduce the need for insecticide applications. Seasonal production of blueberries can be extended by including mid- (Northland) and late-season (Herbert) cultivars. Earliblue, Bluetta, and Herbert have moderate yields, are winter hardy, and are all suitable for mechanical harvest (Pritts and Hancock 1992). Herbert has excellent fruit flavor, whereas Earliblue and Bluetta are less flavorful (Pritts and Hancock 1992). Earliblue is suseptible to phomopsis canker and Northland fruit are of good quality but the bushes are difficult to prune (Gough 1994). Continued research on cultivar susceptibility may eventually allow control decisions to be based on plant phenology.

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