Host Utilization and Phenology of Injury by Plum Curculio (Coleoptera: Curculionidae) in West Virginia[1]

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J. Entomol. Sci. 40(2): 149-157 (April 2005)

Abstract Host utilization by plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), among 8 species of tree fruit was tested under natural orchard conditions in eastern West Virginia. Cohorts of fruit on apricot, European plum, Japanese plum, peach, sweet cherry, sour cherry, pear and apple were examined periodically from just after fruit set to harvest for the appearance of oviposition injury. Percentage of dropped fruit with plum curculio oviposition also was recorded. Fruit also was harvested and evaluated for the presence of oviposition scars, adult feeding, and internal larvae. Apricot had the highest percentage of injury followed by Japanese plum, European plum, apple, peach, sweet cherry, sour cherry and pear. In plum, there was in increase in the percentage of fruit on the tree with oviposition injury from fruit set to harvest; whereas, with the other fruit the percentage of injury on the tree remained relatively constant beyond about a month after fruit set.

Key Words Plum curculio, *Conotrachelus nenuphar*, host utilization, phenology, apple, peach

Plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), is a serious pest of both stone and pome fruit (Quaintance and Jenne 1912, Racette et al. 1992) and blueberry (Mampe and Neunzig 1967) in eastern North America. In spite of the major pest status on multiple fruit crops, little is known of its specific host plant relationships (Racette et al 1992). Plum curculio can use at least 19 rosaceous plants as hosts, including a number of native *Amelanchier* spp. and *Prunus* spp. (Maier 1990). Quaintance and Jenne (1912) observed a host preference in the relative order, from most to least preferred, of plum, peach, cherry, apricot, apple, pear and quince. In Georgia, however, more fruit injury was found on peach than other *Prunus* spp. (Yonce et al. 1995). In areas where both stone and pome fruit are grown, peach is generally more preferred as a host than is apple (Chandler 1932, Armstrong 1958).

Effective monitoring and management of plum curculio depends on accurate knowledge of relative host preferences for the specific population being considered. Plum curculio is known to use host-produced volatiles to locate its hosts (Leskey and Prokopy 2001). However, the work of Leskey and Wright (2004) and Prokopy et al. (2004) regarding the presence of host trees on trap efficiency suggests that success in using traps will depend upon the host species composition of the surrounding environment. In the mid-Atlantic states of West Virginia, Virginia, Maryland, and surrounding areas, both apples and peaches are grown in close proximity, thus allowing

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plum curculio to freely choose among these hosts. This study was conducted to evaluate the relative degree of host utilization by a natural plum curculio population under natural conditions in West Virginia.

Materials and Methods

A research orchard designed to examine host relationships of plum curculio was planted in April 1997. The orchard was planted in a 4 × 4 Latin Square replicated 3 times. In each Latin Square there were 8 species of tree fruit, each replicated twice: apple (*Malus x domestica* Borkh, cultivars 'Granny Smith' and 'Empire'), pear (*Pyrus communis* L., cultivars 'Beurre Bosc' and 'Seckel'), peach (*Prunus persica* Batsch, cultivar 'Loring'), apricot (*Prunus armeniaca* L., cultivar 'Deatrick'), sour cherry (*Prunus cerasus* L., cultivar 'Montmorency'), sweet cherry (*Prunus avium* [L.], cultivars 'Ulster' and 'Emperor Francis'), European plum (*Prunus domestica* L., cultivar 'Stanley Prune'), and Japanese plum (*Prunus salincina* Lindl., cultivars 'Santa Rosa' and 'Formosa'). Trees were planted at a spacing of 6 m between trees in a row and between rows, with 12 m between Latin Square replicates. The orchard had unmanaged apple orchards (planted in 1984) to the east and west, a pear orchard to the north that received no insecticides in 2000 or in 2001, and a natural hedgerow to the south. A 3 m wide weed-free strip was maintained in the tree rows with regular use of paraquat. Peachtree borer (*Synanthedon exitiosa* [Say]; Lepidoptera: Sesiidae) and lesser peachtree borer (*S. pictipes* [Grote and Robinson]) were managed with mating disruption (Biocontrol Limited, Vancouver, WA). No other insecticides or fungicides were used prior to or during the study.

In 2000 and 2001, the orchards were monitored to record blossom phenology from mid-March until all cultivars had bloomed. Beginning on 16 May 2000 and 7 May 2001 fruit were monitored for plum curculio oviposition scars weekly until late June and then every 2 to 4 wks thereafter to evaluate the phenology of fruit injury. Two branches with fruit were selected on each tree for non-destructive sampling, with up to 175 fruit per branch. Branches were selected on opposite sides of the tree at 0.5 to 2.0 m above ground level, higher branches were sampled from a step ladder. The same branches were sampled at each visit, counting all fruit and determining the percentage that had oviposition scars. At each sample 50 dropped fruit under the tree, or as many as were available, were examined and the percentage with plum curculio oviposition scars was determined. After sampling dropped fruit, all drops were raked from beneath the tree so that only freshly dropped fruit were examined at the next sample.

To obtain an unbiased estimate of relative injury among host plants a random sample of fruit was evaluated at harvest. Fifty randomly selected fruit per tree, or all the fruit if there were less than 50 fruit on a tree, were harvested and evaluated for injury by plum curculio. The stone fruit were harvested 1 to 2 wks before maturity due to a high incidence of brown rot (*Monilinia fructicola* [G. Wint] Honey). Three measures of plum curculio injury were evaluated: oviposition scars, feeding injury by adults, and the presence of curculio larvae inside the fruit.

Overall seasonal differences in the development of fruit injury on sample branches and on dropped fruit were compared with a time series analysis mixed model ANOVA (SAS 1998). In reporting the results from the ANOVA, some degrees of freedom are not whole numbers due to the iterative nature of the analysis and calculation of estimated degrees of freedom. Data from evaluations of fruit injury at harvest were transformed with square root arcsine transformation and analyzed with a mixed model ANOVA with least square means multiple comparisons (SAS 1998).

Results

Host plant phenology. Phenology of full bloom and harvest dates are presented in Table 1. As a result of a warm winter, tree phenology was earlier in 2000 than in 2001. Apricot was the first to bloom in both years, but due to early spring frosts few fruit were available to evaluate. Bloom in Japanese plum, peach and Stanley plum followed apricot. Cherry, apple and pear trees were all similar in bloom times, with Granny Smith apple being last to bloom in each year. The order of harvest was similar in both years, beginning with sweet and sour cherry, Japanese plum followed by Stanley plum, peach, pear, Empire apple, and Granny Smith apple (Table 1).

Phenology of injury. In both years there was a highly significant effect of host species (2000: $F = 7.76$; df = 7, 28.6; $P < 0.0001$; 2001: $F = 21.21$; df = 11, 32.8; $P < 0.0001$), day (2000: $F = 7.02$; df = 8, 110; $P < 0.0001$; 2001: $F = 7.41$; df = 12, 80.8; $P = 0.0040$) and species by day interaction (2000: $F = 2.75$; df = 45, 112; $P < 0.0001$; 2001: $F = 3.27$; df = 81, 69.7; $P < 0.0001$) in the analysis of variance for the percentage of oviposition scars on fruit. In both years there was also a significant effect of species (2000: $F = 21.53$; df = 7; 38.5, $P < 0.0001$; 2001: $F = 41.16$; df = 11, 39.9; $P < 0.0001$), day (2000: $F = 2.42$; df = 7, 79.2; $P = 0.0257$; 2001: $F = 7.34$; df = 11, 133; $P < 0.0001$), and in 2001 a significant species by day interaction (2000: $F = 1.58$; df = 30, 69.2; $P = 0.0607$; 2001: $F = 3.37$; df = 52, 130; $P < 0.0001$) in the analysis of variance for the percentage of oviposition scars on dropped fruit.

Table 1. Phenology of flowering and harvest dates for experimental plum curculio host plants, 2000-2001

	Full bloom date		Harvest date	
Host species—cultivar	2000	2001	2000	2001
Apricot—Deatrick	18 Mar	8 Apr	NA	NA
Plum—Santa Rosa	24 Mar	12 Apr	18 Jul	23 Jul
Plum—Formosa	24 Mar	12 Apr	18 Jul	23 Jul
Peach—Loring	30 Mar	15 Apr	3 Aug	3 Aug
Plum—Stanley	5 Apr	19 Apr	31 Jul	3 Aug
Pear—Seckel	9 Apr	24 Apr	NA	30 Aug
Pear—Bosc	NA	24 Apr	NA	30 Aug
Apple—Empire	13 Apr	24 Apr	22 Aug	30 Aug
Cherry—Montmorency	18 Apr	22 Apr	12 Jun	15 Jun
Cherry—Ulster	NA	22 Apr	NA	15 Jun
Cherry—Emperor Francis	NA	22 Apr	NA	14 Jun
Apple—Granny Smith	20 Apr	25 Apr	3 Oct	12 Oct

NA indicates there was no bloom for that cultivar in that year or fruit were not available at harvest.

To illustrate the interactions between fruit injury and time, the pattern of oviposition injury to fruit and dropped fruit is shown in Fig. 1 for the year 2000 and Fig. 2 for the year 2001 for those species with moderate to high levels of injury. Average number of fruit per sample branch for each species at fruit set is given in Table 2. The plum species generally showed an increase in the percentage of fruit on the tree with oviposition scars (Fig. 1, 2). Plums also had a large proportion of dropped fruit with oviposition scars very early in the season followed by a decrease through the sum-

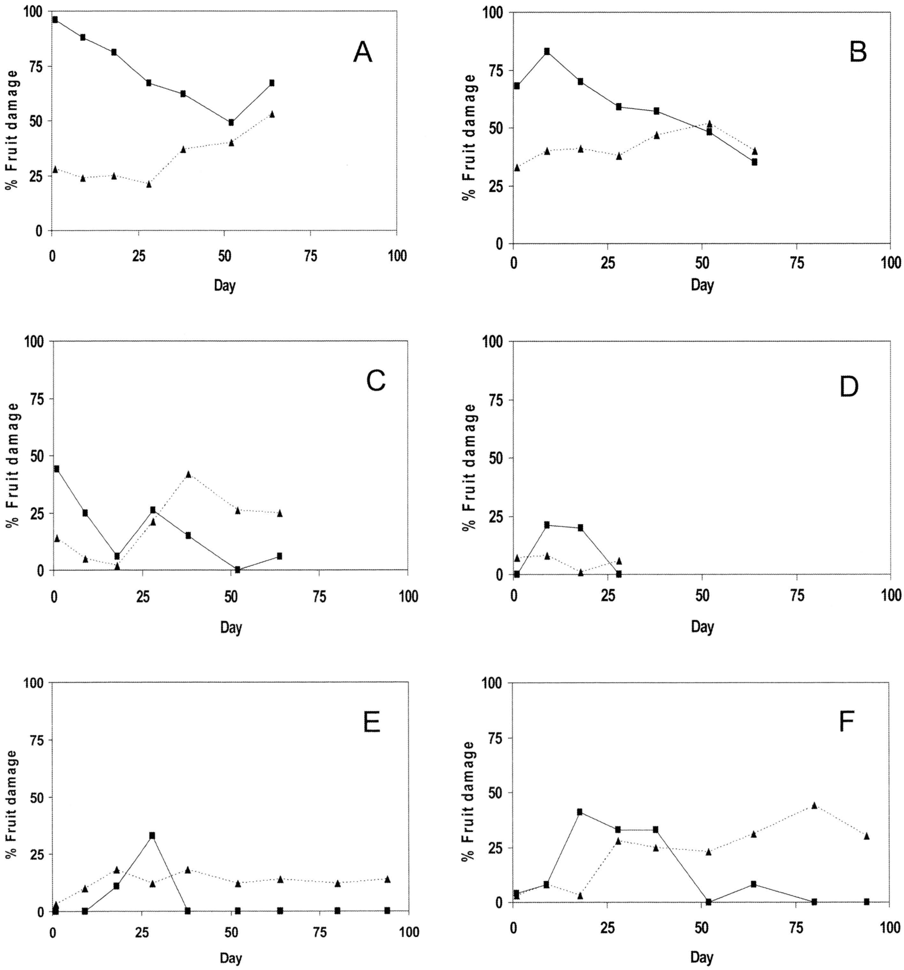

Fig. 1. Percentage of plum curculio oviposition injury to fruit on sample branches (triangles and dotted line) and dropped fruit (squares and solid line) over time in 2000 for: A, Stanley plum; B, Japanese plums (mean of Formosa and Santa Rosa); C, Loring peach; D, Montmorency cherry; E, Empire apple; and F, Granny Smith apple. Day 0 is 16 May, 2000.

mer, except for Japanese plums in 2001 which had over 90% of the dropped fruit with oviposition scars from 24 May to 21 June (Fig. 2). Ulster cherry and Seckel pear in 2001 also had high levels of dropped fruit with oviposition scars but, contrary to the trend in plums, had very low levels of injured fruit remaining on the tree (data not shown due to small sample size). Both apple cultivars also had a higher proportion of dropped fruit with oviposition scars than the proportion of injured fruit on the trees.

Peaches showed a gradual increase in the percentage of scarred fruit on the tree through the summer with a gradual decrease in the month before harvest (Fig. 1, 2). The proportion of dropped fruit with scars was variable throughout both years. Apricot

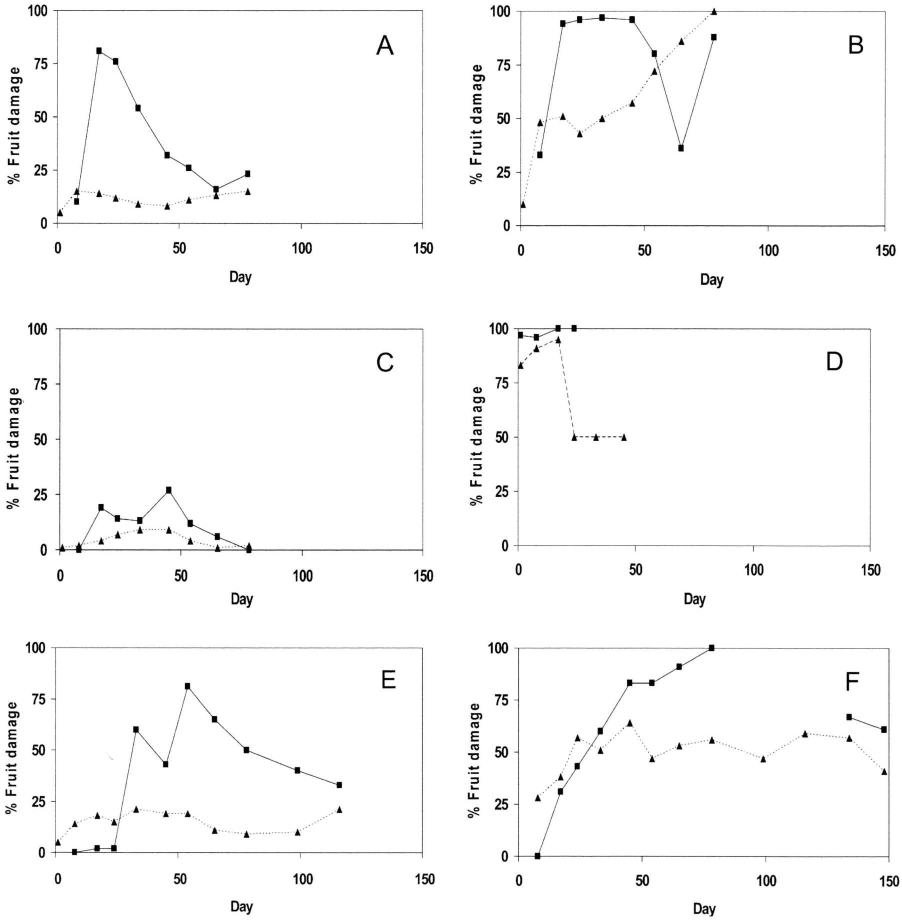

Fig. 2. Percentage of plum curculio oviposition injury to fruit on sample branches (triangles and dotted line) and dropped fruit (squares and solid line) over time in 2001 for: A, Stanley plum; B, Japanese plums (mean of Formosa and Santa Rosa); C, Loring peach; D, Deatrick apricot; E, Empire apple; and F, Granny Smith apple. Day 0 is 7 May, 2001.

Table 2. Relative fruit load on sample branches at fruit set for plum curculio host plants, 2000-2001

		2000		2001	
Host species—cultivar	No. sample branches	No. branches with fruit	No. fruit per branch	No. branches with fruit	No. fruit per branch
Apricot—Deatrick	12	0	–	8	4.1
Plum—Santa Rosa	6	6	51.5	5	30.4
Plum—Formosa	6	6	38.2	6	38.7
Plum—Stanley	12	12	24.8	12	69.5
Peach—Loring	12	8	15.9	8	58.5
Cherry—Montmorency	12	8	45.6	12	48.8
Cherry—Ulster	6	0	–	6	26.8
Cherry—Emperor Francis	6	0	–	6	40.7
Apple—Empire	6	6	8.5	6	40.8
Apple—Granny Smith	6	6	32.5	6	46.7
Pear—Bosc	6	0	–	4	25.8
Pear—Seckel	6	4	10.5	5	11.4

had a high level of oviposition scars at the first observation, 83%, which increased until early June, after which there remained a constant injury rate of 50% (Fig. 2) for the few fruit remaining on the trees (Table 2). The high level of dropped fruit with oviposition scars (97 to 100%) through the first month contributed to the decline in percentage of injured fruit remaining on the apricot trees. Sour cherry only had a significant amount of oviposition injury in 2000, when there was a constant percentage of scarred fruit through the season and higher percentages of injured dropped fruit in late May (Fig. 1).

Apples showed a gradual increase in the percentage of injured fruit during May, after which there was a relatively constant percentage of fruit on the tree with oviposition scars (Fig. 1, 2). The percentage of dropped fruit with oviposition scars began increasing about a month after observation (early June) and, in 2000, was near zero after mid-June for Empire and early July for Granny Smith. In 2001, however, Empire continued to drop a high percentage of injured fruit throughout the season, and Granny Smith had more than 75 % injured dropped fruit through most of the summer (note: there were no dropped Granny Smith fruit for days 98 to 120 in 2001, Fig. 2).

Relative host species utilization. Harvest evaluation data of plum curculio injury to the various hosts' fruit are given in Table 3. There were significant differences in the proportion of fruit with oviposition injury in both years (2000: $F = 31.43$; df = 6, 21; $P < 0.0001$; 2001 $F = 17.37$; df = 9, 26; $P < 0.0001$). Plums consistently had the highest amount of oviposition injury and also consistently high fruit loads (Table 2). Both cultivars of apple had at least twice as much oviposition injury in 2001 than in 2000, with injury to Granny Smith in 2001 being similar to the Japanese plums and greater than Stanley plum. Peach also had more oviposition injury in 2001 (29.2 %) than 2000 (0 %), however, the fruit load in 2000 was also low (Table 2). For cherry, only Montmorency had enough fruit to sample in 2000, but showed no oviposition injury. In 2001, Emperor Francis had 19.8% injury, but Montmorency had only 1% of the fruit with injury. Pear only had fruit at harvest in 2001, and oviposition injury was low.

Adult plum curculio feeding injury on harvested fruit was also significantly different among cultivars (Table 3) (2000: $F = 5.06$; df = 6, 21; $P = 0.0024$; 2001 $F = 3.73$; df = 9, 26; $P = 0.0040$). More adult feeding damage occurred in 2001, with Stanley plum and peach having the most injury. Other than plum and peach, pear was the only fruit to have adult feeding injury, with 3.3 % injury to Seckel and 3.6 % injury to Bosc in 2001 (Table 3) in spite of low fruit loads (Table 2).

Internal plum curculio larvae were found only in the stone fruits. Significantly more injury was found on Stanley plum (6.5%) in 2000 ($F = 4.84$; df = 6, 21; $P = 0.0030$) and on peach (13.2%) and Emperor Francis (12.3%) in 2001 ($F = 5.68$; df = 9, 26; $P = 0.0002$).

Discussion

Plums, Stanley and both Japanese cultivars, appear to be the most utilized hosts for plum curculio in this study (Table 3) and these species also had consistently high fruit loads (Table 2). The phenology of oviposition injury to plum also seemed to differ from that on other fruit in that the percentage of fruit injured increased until harvest, whereas other fruit species had a relatively consistent percentage of oviposition injury after the initial month following fruit set. Apricot may have been the most utilized host (Fig. 2D), but due to a low fruit load (Table 2) this could not be fairly evaluated. Granny Smith apple seemed to be more utilized than Empire, especially in the 2001 evalu-

Table 3. Summary of fruit evaluations for plum curculio injury at harvest

Year host species—cultivar	n	% Oviposition scars	% Feeding injury	% Internal larvae
2000				
Plum—Stanley	279	56.3a	5.4a	6.5a
Plum—Formosa	150	46.7a	1.3b	0.0b
Plum—Santa Rosa	150	20.7b	1.3b	0.7b
Peach—Loring	25	0.0c	0.0b	4.0b
Apple—Granny Smith	56	17.9b	0.0b	0.0b
Apple—Empire	66	12.1b	0.0b	0.0b
Cherry—Montmorency	200	0.0c	0.0b	0.0b
2001				
Plum—Stanley	251	35.1c	18.3a	5.6bc
Plum—Formosa	37	70.3a	5.4abc	2.7cd
Plum—Santa Rosa	24	54.2b	4.2abc	0.0d
Peach—Loring	250	29.2c	14.8ab	13.2a
Apple—Granny Smith	116	59.5ab	0.0c	0.0d
Apple—Empire	150	28.0c	0.0c	0.0d
Cherry—Montmorency	302	1.0d	0.0c	0.3d
Cherry—Emperor Francis	81	19.8c	0.0c	12.3ab
Pear—Seckel	61	3.3d	3.3c	0.0d
Pear—Bosc	55	1.8d	3.6bc	0.0d

Means followed by the same letter within a column and year are not significantly different, least square means separation, $P = 0.05$.

ation when Granny Smith had more than twice as much oviposition injury than Empire (Table 3). Cherry, both sour and sweet cultivars, and pear were least utilized hosts for plum curculio (Table 3). Among the cherry cultivars, however, Emperor Francis was more utilized than Ulster and much more than the sour cherry, Montmorency (Table 3). The low preference for Montmorency was also seen in an evaluation of 3530 cherry fruit in 1991, with only 0.5 % of harvested fruit showing oviposition injury and no larvae in the fruit (MWB, unpubl. data). The observed order of host utilization are in general agreement with previous reports (Quaintance and Jenne 1912, Maier 1990, Yonce et al. 1995), except that cherry was found to be much less utilized in the current study. The results also differ from other reports (Quaintance and Jenne 1912, Chandler 1932, Armstrong 1958) in that peach fruit did not consistently have more injury than apple. Earlier developing apples have been reported to be more damaged by plum curculio than later developing fruit (Racette et al. 1992), but in this study the later developing Granny Smith had greater injury than the earlier Empire (Table 3).

The differences in host utilization revealed in this study were from a natural population under natural conditions. Therefore, these data do not indicate an inability of plum curculio to use the less injured hosts for reproduction, or a lack of potential to become pests of cherry or pear in the mid-Atlantic region. Other factors affecting the observed host utilization patterns were differences in fruiting phenology and relative fruit loads of the various hosts. It is likely that any population of plum curculio has adapted its own inherent host preferences based on the available wild and cultivated hosts, and these preferences are likely to vary among regions.

Acknowledgments

I thank Clarissa R. Mathews for assistance with field sampling and data analysis, and Tracy C. Leskey, W. Harvey Reissig and Henry Hogmire for helpful comments on an earlier draft of this manuscript.

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