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INVERTEBRATE PREDATORS AND PARASITOIDS OF PLUM CURCULIO, *CONOTRACHELUS NENUPHAR* (COLEOPTERA: CURCULIONIDAE) IN GEORGIA AND FLORIDA

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Abstract

The extent of predation and parasitism on larvae of the plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), was measured independently with several different experimental designs at sites in northern Florida and central Georgia. Experimental manipulation in Monticello, FL, and in Byron, GA, demonstrated equivocal impacts by predation. However, direct observations in Byron, GA, revealed that ants are the dominant invertebrate predators of plum curculio larvae, causing up to 62% mortality. Primary ant predators included *Solenopsis invicta* (Buren) (Hymenoptera: Formicidae) and *Dorymyrmex bureni* (Trager) (Hymenoptera: Formicidae). Predation may be more important later in the season when infested fruit does not abscise and plum curculio larvae must drop to the ground from the trees and spend a considerable time burrowing into the soil. This contrasts with the early season when infested fruit abscise and larvae crawl from the fruit directly into the soil, reducing their exposure to predators. Recorded parasites included *Nealiolus curculionis* (Fitch) (Hymenoptera: Braconidae) and *Cholomyia inaequipes* Bigot (Diptera: Tachinidae). Parasitism, particularly by *N. curculionis*, was common in northern Florida but rare in middle Georgia.

Key Words: *Dorymyrmex bureni*, *Solenopsis invicta*, *Nealiolus curculionis*, *Cholomyia inaequipes*

Resumen

El nivel de depredación y parasitismo en contra de *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), fue medido independientemente usando diferentes diseños experimentales en lugares como el norte de Florida y la zona central de Georgia. Manipulación experimental en Monticello, FL, y en Byron, GA, demostró que el impacto de depredación no fue preciso. Sin embargo, observaciones directas en Byron, GA, revelaron que las hormigas son el invertebrado dominante en la depredación de la larva de C. nenuphar, causando hasta 62% de mortalidad en las larvas. Entre las principales hormigas depredadoras se encuentran, *Solenopsis invicta* (Buren) (Hymenoptera: Formicidae) y *Dorymyrmex bureni* (Trager) (Hymenoptera: Formicidae). La depredación es más importante en la temporada tardia, cuando las frutas infestadas no han caido al suelo, por lo tanto las larvas tuvieron que llegar al suelo desde los arboles y pasaron un tiempo considerable tratando de enterarse en el suelo. Contrario a esto, en la temporada temprana cuando las frutas infestadas cayeron al suelo y las larvas pasaron de la fruta al suelo directamente, reduciendo el tiempo que las larvas estuvieron expuestas a los depredadores. Los parásitos reportados incluyen *Nealiolus curculionis* (Fitch) (Hymenoptera: Braconidae) y *Cholomyia inaequipes* (Bigot) (Diptera: Tachinidae). Parasitismo, particularmente por *N. curculionis*, fue común en el norte de Florida pero raro en la zona central de Georgia.

Translation provided by the authors.

The plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), an insect native to North America (Quaintance & Jenne 1912), is the primary direct insect pest of peaches in the Southeastern United States (Horton & Ellis 1989). Adult plum curculios migrate in early spring from overwintering sites in adjacent woods to infest peach orchards (Snapp 1930; Yonce et al. 1995). The females oviposit on young fruit, often causing it to abscise (Quaintance & Jenne 1912;

Snapp 1930). Larvae develop in the fruit and move into the soil to pupate. In the bivoltine southern strain of plum curculio (Chapman 1938), adults emerge from these pupae the same summer to continue the infestation, but their offspring emigrate from the orchard to overwintering sites in adjacent woods or other locations with plenty of leaf litter (Quaintance & Jenne 1912; Snapp 1930; Yonce et al. 1995).

Plum curculio is currently controlled with highly efficacious organophosphate insecticides. The use of these pesticides is being restricted as a result of the implementation of the Food Quality Protection Act. Recent insecticide losses, e.g., methyl parathion, have caused the peach industry in the southeast to seek more sophisticated integrated pest management strategies that take into account the target pest's natural history and biology. These approaches include soil applications of entomopathogenic nematodes and fungi against the larval and pupal stages (Shapiro-Ilan et al. 2002; Shapiro-Ilan et al. 2004; Tedders et al. 1982).

Although predators and parasitoids are important components of integrated management programs for other curculionid pests (Stuart et al. 2003; Stuart et al. 2002; McCoy et al. 2000), little attention has been paid to potential predators or parasitoids of the plum curculio. Field efficacy trials against plum curculio often have variable mortality rates (Shapiro-Ilan et al. 2004; Quaintance & Jenne 1912; Snapp 1930), suggesting that natural sources of mortality may be involved and potentially sources of control. Even though researchers in the northeastern U.S. concluded that natural enemies of the plum curculio are inefficient (Van Driesche et al. 1987) we were interested in surveying predators and parasitoids of plum curculio in central Georgia.

Our objectives were to assess the effects of various natural enemies on the southern strain of plum curculio, *C. nenuphar*, by (1) quantifying the extent of plum curculio mortality attributable to predation and parasitism in northern Florida and middle Georgia, and (2) assaying biological control organisms, such as the fungus, *Beauvaria bassiana* (Bals.) Vuill. (Hyphomycetes) separately and in conjunction with the application of conventional pesticides (e.g., bifenthrin, thiamethoxam, and imidacloprid) to the soil targeting late larval and pupal stages of plum curculio are located. The impacts of these pesticides on potential natural enemies also were assessed.

Materials and Methods

Experiments Conducted at the Southeastern Fruit and Tree Nut Research Laboratory, Byron GA: Predation

At the USDA Southeastern Fruit and Tree Nut Research Laboratory in Byron, GA, (SEFTNRL) we compared the potential emergence under "optimal conditions" to emergence under field conditions in order to estimate overall mortality attributable to abiotic factors and to predators, parasitoids, and pathogens. In May 2004 we exposed 20 virgin female and 20 virgin male plum curculio to 360 green thinning apples (Red Delicious variety) for 2 weeks. Half of these apples were then randomly selected and distributed equally among 6 tilled locations (30 apples/location) at the base of peach trees and within the rows of an unsprayed peach orchard on the grounds of the SEFTNRL. Each tilled location was 0.6 m^2 in area. This orchard had not received pesticide applications in the previous 5 years. Six separate locations in the same unsprayed orchard were tilled and used as negative controls, each receiving 30 uninfested green thinning apples. Each location was covered with a cone emergence trap (Mulder et al. 2000) after 3 weeks. This allowed predators to access the infested apples without interference from the cages but was not enough time for adults to emerge from the soil. Cone emergence cages were monitored daily for the emergence of adults over 60 days. The remaining apples that had been exposed to ovipositing female plum curculio were divided equally among 6 plastic tubs (11.4 L Rubbermaid™ storage box). The infested fruit were placed upon a hardware cloth supported above the bottom of the tub by four 2-cm long corks. The tubs were stored in an environmental chamber at 25° ± 1°C and 50% RH (12:12, L:D) (Amis & Snow 1985). The tubs were monitored daily for the emergence of larvae which were then placed into pupation jars. Pupation jars were 950-ml glass jars 2/3 filled with a moistened mixture of potting soil and vermiculite (2:1) that had been sifted with a 10-mesh sieve to ensure that the soil did not contain insects and covered with a glass Petri dish. Pupation jars were monitored daily for the emergence of adult plum curculio. The number of emerging adult plum curculio was compared between fruits exposed to predators and fruits not exposed to predators using a t-test (SAS 2001).

We monitored plum curculio larvae as they burrowed into the soil, recording any predation we observed. Between Mar 15 and Aug 1, 2003, laboratory-reared plum curculio larvae (Amis & Snow 1985), within 12 h of emerging from green thinning apples, were harvested, taken to the field, and placed singly at random locations on an orchard floor in Byron, GA, between the hours of 8:00 and 20:00. Each larva was observed until the larva buried itself or was carried off by predators. The time interval between setting the larva on the ground and its complete burial or removal by predators was noted. Ant abundance (by species) was measured by counting the number of ants in an area of 0.21 m^2 at random locations in the orchard throughout the summer. An area of 0.21 m^2 was chosen because it was small enough for researchers to survey it intensively. Results were then converted to ants per m^2.

Parasitism

Abscised peaches were collected at Byron, GA, in 2004 and placed on trays with mesh bottoms over a large aluminum funnel (0.3 m high with a slope of 30%). The funnel was positioned over a collection pan so that larvae emerging from the infested fruit could be collected. Larvae were collected daily, enumerated and placed in pupation jars. Pupation jars were monitored daily for 60 d for the emergence of adult plum curculio or parasitoids.

In addition, wild plum fruit, *Prunus angustifolia* Marshall and *P. umbellata* Elliott, infested with plum curculio (as denoted by the distinct oviposition scar, Quaintance & Jenne 1912) were collected from Peach Co., GA, and placed in plastic tubs (11.4-L Rubbermaid™ storage box) and stored, as described earlier in the predation studies. The tubs were monitored daily for the emergence of larvae from fruit. Larvae were collected and placed into pupation jars and were monitored for the appearance of adult plum curculio and/or parasitoids.

One hundred abscised peaches collected from an unsprayed peach orchard at SEFTNRL were placed at each of 5 tilled areas (0.6 m^2) at the base of randomly selected peach trees in the orchard. The peaches were then covered with a cone emergence trap. The cone emergence trap was monitored for 60 d for the emergence of parasitoids historically associated with plum curculio (Krombein et al. 1979).

Experiments Conducted at the North Florida Research and Education Center, Monticello, FL

One thousand peach fruit that had abscised in response to infestation by plum curculio were gathered at the University of Florida, North Florida Research and Education Center (NFREC) in Monticello, FL, in 2003. These fruit were distributed among 10 locations (0.5 m^2) on an orchard floor, so that each location had 100 abscised fruit. Bifenthrin (Talstar® EZ, FMC Corporation, Philadelphia, PA) was applied (1 lb/acre) in a 3.14-m ring around, but not on, infested fruit at 5 locations. Five locations were left untreated as controls. The locations were covered with cone emergence traps and monitored daily for the emergence of adult plum curculio or parasitoids (Krombein et al. 1979).

Parasitoid emergence also was monitored in a separate field trial in 2003 by assaying 5 pesticides applied to the orchard floor and targeting plum curculio larvae. Twenty five sites (1 m^2) were selected and treated with imidacloprid (Admire® 2F, Bayer Crop Sciences, Kansas City, MO) at 1.75 L/ha, bifenthrin (Talstar® EZ, FMC Corporation, Philadelphia, PA) at 1.12kg/ha, thiamethoxam (Platinum®, Syngenta, Greensboro, NC) at 438.07 mL/ha, or *Beauvaria bassiana* (GHA strain, supplied by Emerald Bioagriculture, Butte, Montana) applied at a rate of 10^{14} conidia/ha, or with 2 L of water as a control treatment. All treatments were delivered in 2 L of water from a watering can. One hundred abscised fruit, gathered from the orchard floor, were deposited at each of the 25 sites (5 treatments with 5 replicates).

Results

Southeastern Fruit and Tree Nut Laboratory, Byron GA: Predation

Significantly more adults emerged from apples stored in the incubator (7.5 ± 1.3: mean ± SEM) than from apples stored in the orchard and exposed to predation, disease, and environmental factors (3.8 ± 1.0: mean ± SEM) (t = 2.75; df = 5; P = 0.022). No adult plum curculio emerged from the control plots that contained uninfested apples, indicating that it was likely that all of the curculio emerging in the cone emergence cages in the orchard were from the infested apples and not from plum curculio pupae that were in the soil prior to the experiment.

In total, 268 m^2 were surveyed for ant abundance and 4,038 ants were found. *Solenopsis invicta* Buren (Hymenoptera: Formicidae) comprised 77% of the ants found, *Dorymyrmex bureni* (Trager) (Hymenoptera: Formicidae) comprised 15%, and a *Paratrechina* sp. (Hymenoptera: Formicidae) comprised 8%. There was a mean of 15 (±0.88 SEM) ants of any species in a given m^2. Of these, 12 (±0.85 SEM) were S. invicta, 2 (±0.26 SEM) were *D. bureni*, and 1 (±0.10 SEM) was *Paratrechina* sp.

All 3 ant species were observed capturing and killing larval plum curculio that we had placed on the ground. In total, 229 last instar plum curculio larvae were observed on the orchard floor. Of these, 97 were discovered by *S. invicta*, 26 were discovered by *Paratrechina* sp., and 20 were discovered by *D. bureni*. Eighty six larvae were able to bury themselves before being discovered by ants. On average, all larvae discovered by fire ants were discovered in 13.94 min (SEM = 1.34). All larvae discovered by *Paratrachina* sp. were discovered on average in 9.35 min (SEM = 1.54). All larvae discovered by *D. bureni* were discovered on average in 20.10 min (SEM = 5.67). All larvae discovered by any species of ant were discovered on average in 13.97 min (SEM = 2.49). All larvae that successfully buried themselves did so on average in 15.41 min (SEM = 1.39).

A mean of 4.2 (SEM = 1.2) adult plum curculio emerged from 100 abscised fruit under the 5 cone emergence cages. Only 1 specimen of *Nealiolus curculionis* (Fitch) (Hymenoptera: Braconidae) was detected from the cone emergence cages.

In total, 930 abscised peaches were collected from the orchard floor in Byron, GA. We collected 528 larvae from these fruit and placed them into pupation jars. One specimen each of N. *curculionis* and *Cholomyia inaequipes* Bigot (Diptera: Tachinidae) was reared from these plum curculio.

In total, 1,146 scarred fruit of *P. angustifolia* and 269 of *P. umbellata* were collected. These fruit yielded a total of 546 plum curculio larvae (39% of infested fruit yielded larvae). Two *N. curculionis* were reared from these larvae.

North Florida Research and Education Center, Monticello, FL

A mean of 13.8 (±2.4 SEM) adult plum curculio emerged from 100 abscised fruit in the untreated controls and 12.8 (±2.8 SEM) adult plum curculio emerged from 100 abscised fruit in the locations that received bifenthrin as a ring treatment to prevent entry of fire ants. These results were not different (t = 0.355; df = 4; P = 0.899).

The only parasitoid recovered was *N. curculionis*. The percent of plum curculio infected with this parasite, based on the number of adult plum curculio recovered and the number of adult parasitoids, ranged from 30% to 47%, with an average of 37% (SEM = 2.77) (Table 1). The pesticides assayed did not demonstrate significant control of plum curculio compared to untreated controls, nor did they appear to significantly impact numbers of parasitoids in each treatment (Table 1).

Discussion

There was a significant reduction in plum curculio mortality when plum curculio were reared indoors, in the absence of natural enemies or adverse environmental conditions, as opposed to those on the orchard floor. However, there was no significant difference between the number of adult plum curculio emerging in areas that had been surrounded with a treatment of bifenthrin and areas that had not received a pesticide treatment to preclude foraging ants. These results suggest a number of scenarios, including the following: (1) predation plays a small role in plum curculio mortality, (2) the pesticide applications used did not preclude foraging ants, or (3) differences in mortality observed between plum curculio reared outdoors and those reared indoors may be attributed to regulated humidity and temperature, consistent environment, and fewer pathogens. Direct field observations reveal that predation by ants alone may be responsible for the mortality of more than 60% of plum curculio larvae attempting to burrow into the soil, with the caveat that placing lab reared plum curculio larvae on the orchard floor is not natural and may exaggerate mortality due to ant predators. Furthermore, there may be a seasonal component to the

TABLE 1. MEAN NUMBER (±SEM) OF ADULT *CONOTRACHELUS NENUPHAR* AND *NEALIOLUS CURCULIONIS* EMERGING FROM 100 ABSCISED PEACHES COLLECTED IN MONTICELLO, FL.

	Water control (2 L of water)	Imidacloprid at 1.75 L/ha	Bifenthrin at 1.12 kg/ha	Thiamethoxam at 438.07 mL/ha	Talstar® as a fire ant barrier	*Beauvaria bassiana* at 10^{14}conidia/ha	Untreated control
Conotrachelus nenuphar	18.8 (+6.1) a[1]	14.2 (±2.3) a	6 (±2.1) a	11.6 (±0.9) a	12.8 (±2.8) a	14.8 (±3.7) a	13.8 (±2.4) a
Nealiolus curculionis	9 (±3.1) a	11.2 (±3.7) a	4 (±1.1) a	10.4 (±0.9) a	6.2 (±1.2) a	7.8 (±1.8) a	5.8 (±1.6) a

[1]Means followed by the same letter are not significantly different according to a Student-Neuman-Keuls test. For *Conotrachelus* nenuphar, α = 0.05; F= 1.39; P=0.2531; df=28. For *Nealiolus curculionis*, α = 0.05; F = 1.87; P = 0.1210; df = 28.

effect of predation by ants. Peaches infested earlier in the season are small and usually abscise and drop to the ground when infested with plum curculio larvae (Quaintance & Jenne 1912; Detjen 1938). The larvae continue to develop in the fruit and can burrow directly from the fruit into the soil, probably reducing their chances of being encountered by foraging ants. Peaches infested later in the season do not abscise and larvae must drop from the fruit to the ground. Subsequently, the summer generation of plum curculio in late season peaches may be more susceptible to ant predation. The lack of significant difference between number of adults emerging from infested fruit that were chemically protected from predators and infested fruit that was accessible to predators lends credence to the possibility that larvae moving directly from infested fruit into the soil may suffer less predation than larvae that drop from the tree to the ground.

This is the first quantitative study of the impact of certain predators on plum curculio, although many anecdotal observations have been published (Quaintance & Jenne 1912; Snapp 1930). Plum curculio larvae were monitored in close quarters (within 1 m) for accurate identification of predators. Such proximity to the larvae precluded larger predators, such as birds and carabid beetles, although these may be additional and important sources of mortality. Although *Solenopsis invicta* was not present in central Georgia at the time, Snapp (1930) and Quaintance & Jenne (1912) report that *Dorymyrmex bureni* (reported as *Dorymyrmex pyramica*) was an important predator of larval plum curculio. Quaintance & Jenne (1912) list ground beetles (Coleoptera: Carabidae) and a soldier beetle, *Chauliognathus pennsylvanicus* (De Geer) (Coleoptera: Cantharidae), as important predators of larval plum curculio. Unfortunately, the soldier beetle appears to be in decline in Georgia, perhaps as a result of predation by *S. invicta* (Jenkins & Matthews 2003). Dissections of spadefooted toads, *Scaphiopus* sp., revealed that they are consumers of plum curculio (J. Payne, pers. comm.).

Parasitism was of minimal importance as a mortality factor in middle Georgia but appeared to contribute significantly to the mortality of plum curculio in northern Florida. Though we realize the estimates for parasitism in Florida are necessarily high, the sheer numbers obtained need no statistical differentiation from those obtained in the Byron, GA, studies, considering that of more than 1000 larvae collected from peach and wild plums in central Georgia only 2 yielded parasitoids. It is possible that the *N. curculionis* individuals collected in cone emergence traps in Monticello, FL, had used hosts other than *C. nenuphar*. Indeed, *N. curculionis* is known to use many other hosts (Krombein et al. 1979).

There are a number of parasitoids that have been recorded from plum curculio but that were not found in the current study. These include *Nealiolus collaris* (Brues), *N. rufus* (Riley), *Triaspis kurtogaster* Martin, *Bracon mellitor* Say, *B. politiventris* (Cushman), *B. variablilis* (Provancher) (Hymenoptera: Braconidae), *Tersilochus conotracheli* (Riley) (Hymenoptera: Ichneumonidae), *Patasson conotracheli* (Girault) (Hymenoptera: Mymaridae), *Myiophasia aenea* Wiedemann, *Cholomyia inaequipes* Bigot (Diptera: Tachinidae), and *Pegomyia fusciceps* Zett. (Diptera: Anthomyiidae) (Riley 1871; Quaintance & Jenne 1912; Snapp 1930; Armstrong 1958; Arnaud 1978; Krombein et al. 1979; Tedders & Payne 1986). All of these species, with the exceptions of *T. conotracheli* and *B. politiventris*, have been recorded in Georgia or Florida (Krombein et al. 1979). The vast majority of these parasitoids utilize a variety of other hosts, although many of their hosts are often found in fruit (Krombein et al. 1979).

Historically, percent mortality and percent mortality attributable to parasitism has varied greatly. Quaintance & Jenne (1912) report that the percent of adult plum curculio that emerged from larvae ranged from 9% to 60% with a mean of 32% and that parasitism ranged from 0.7% to 21% with a mean of 8.1%. Snapp (1930) reported that the percentage of adults that emerged from larvae ranged from 1.7% to 18.7% with a mean of 7.4%. Armstrong (1958) reported a range of parasitized plum curculio larvae of 7.5 to 26.6 with an average of 20% parasitized. Even in our study, parasitism varied greatly between the 2 sites and presumably does so from year to year. This broad host range suggests that the abundance of alternate hosts may play an important role in rates of parasitism of *C. nenuphar*.

In summary, variation in mortality of plum curculio is extremely high, as is variation in incidence of parasitism (Quaintance & Jenne 1912; Snapp 1930). The high levels of parasitism observed in Florida are possibly important sources of natural control of plum curculio populations. Further research is needed to elucidate mortality factors and the causes of this variation. Understanding these factors may lead to better pest management strategies.

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