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PREDATION BY PODISUS MACULIVENTRIS ON DIFFERENT LIFE STAGES OF NEZARA VIRIDULA

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ABSTRACT
Predation capacity of fourth instars and male and female adults of Podisus maculiventris (Say) (Heteroptera: Pentatomidae) on the different life stages of the southern green stinkbug Nezara viridula (L.) (Heteroptera: Pentatomidae) was measured in the laboratory. Both nymphal and adult predators displayed high predation rates on eggs, nymphs and adults of the southern green stinkbug. However, developmental times of fourth instar P. maculiventris on eggs or nymphal instars of N. viridula were longer than on fifth instars of the cotton leafworm, Spodoptera littoralis (Boisdvual) (Lepidoptera: Noctuidae), suggesting that N. viridula is suboptimal prey for the spined soldier bug. Preference experiments in which fourth instar P. maculiventris were given a choice between fourth instars of N. viridula and fifth instars of S. littoralis indicated that the stinkbugs were less vulnerable to predatory than the caterpillars, mainly because of their greater agility. The potential role of P. maculiventris in augmentation or conservation biological control of the southern green stinkbug in greenhouse and field crops is discussed.

Key Words: Nezara viridula, Podisus maculiventris, Asopinae, predator, biological control

RESUMEN
La capacidad de depredación de cuartos instares y macho y hembra adultos de Podisus maculiventris (Say) (Heteroptera: Pentatomidae) sobre los diferentes estados del chinche verde hediondo sureño Nezara viridula (L.) (Heteroptera: Pentatomidae) fue medida en el laboratorio. Ambos depredadores de ninñas como de adultos demostraron alta capacidad de depredación sobre huevos, ninñas y adultos del chinche verde sureño. Sin embargo, los tiempos de desarrollo de los cuartos instares del P. maculiventris sobre los huevos o los instares ninfales de N. viridula fueron mayores que sobre los quintos instares de la rosquilla negra, Spodoptera littoralis (Boisduval) (Lepidoptera: Noctuidae), sugiriendo que N. viridula es una presa poco optim a para el chinche soldado. Experimentos de preferencia en donde a cuartos instares de P. maculiventris les fue dada la oportunidad de seleccionar entre cuartos instares de N. viridula y quintos instares de S. littoralis indicaron que los chinches fueron menos vulnerables a depredación que las larvas, básicamente debido a su gran agilidad. El papel potencial de P. maculiventris en el control biológico aumentativo o de conservación del chinche verde hediondo sureño en invernaderos y cultivos esta en discusión.
areas. The most important of these are the sce-lionid egg parasitoid Trissolcus basalis (Wollast-
on) and tachinid parasitoids belonging to the
genus Trichopoda, that attack large nymphs and
adults of N. viridula (Todd 1989, Corrêa-Ferreira
& Moscardi 1996, Panizzi et al. 2000). Although
predation is recognized to be an important mortal-
ity factor for N. viridula (see Todd 1989 for a re-
view), much less attention has been given to the
biocontrol potential of the pest’s predator complex.

The present study investigates the predation
capacity of the spined soldier bug, Podisus macu-
liventr is (Say), on N. viridula. This generalist
predator, belonging to the pentatomid subfamily
Asopinae, has been used since 1997 in European
greenhouses for the augmentative biological con-

trol of caterpillar outbreaks (De Clercq et al. 1998,
De Clercq 2000) and predation on N. viridula may
be an additional asset for this beneficial. In the
Southern United States, P. maculiventris is a com-
mon predator of lepidopterous and coleopter-
ous insects in various crops (Richman & Mead
1980) but it has also been observed to prey on
juveniles in various field collections in France, Spain and Italy.

Insects

A laboratory colony of N. viridula was estab-
lished in 1999, using insects originating from dif-

drent field collections in France, Spain and Italy.
Stinkbugs were fed on pods of green bean
(Phaseolus vulgaris L.) and on seed kernels of
sunflower (Helianthus annuus L.). A culture of
P. maculiventris was started in 1999, using speci-
mens originating from a field collection in 1996
near Beltsville, MD. The predators were fed
mainly larvae of the greater wax moth, Galleria
mellonella L., and of the cotton leafworm, S. lit-
ioralis, but were occasionally also provided with
larvae of the yellow mealworm, Tenebrio molitor
L. Cotton leafworms were reared on an artificial
diet modified from Poitout & Bues (1970). Colo-

dies of all insects were maintained in growth
chambers at 23 ± 1°C, 75 ± 5% relative humidity
and a 16:8 (L:D) photoperiod.

Consumption Experiments

Predation by fourth instars and female and
male adults of P. maculiventris on the different
life stages of the southern green stinkbug was
measured in petri dishes. Predator nymphs were
newly (<12 h) molted, adults were 3-5 days old
and were starved for 24 h before testing. Preda-
tors were placed in individual disk-vent ed petri

plates (9 cm diameter, 2 cm high) lined with paper
towelling. For nymphs, each predator-prey combi-
nation was replicated 20 times; for adults, 10 rep-
licates were done for each sex and prey stage.

Predator individuals were offered either 1 batch
of eggs (with an average of 80 eggs per batch), 15
first instars, 8 second instars, 6 third instars, 6
fourth instars, 4 fifth instars or 2 adults (one male
and one female) of N. viridula per day. A slice
of green bean and 5 sunflower seed kernels were

supplied as food to nymphal or adult prey. Preda-
tors were supplied with moisture via a soaked pa-
ter plug fitted into an Eppendorf centrifugation
tube. Predation by P. maculiventris adults was re-
corded after 24 h. Predation by males and females
was compared using the non-parametric Mann-
Whitney test. For nymphs, predation was mea-

sured throughout the stadium. Dead prey were

replaced every day to keep prey density constant
throughout the experiment. Two-day-old
nymphal prey were replaced to minimize variabil-

ty in prey size and behavior. In addition to preda-
tion rates, developmental durations of predator
nymphs were recorded in each experiment.

A control group of 20 P. maculiventris fourth
instars was presented with late instars of the noc-

tuid S. littoralis, which can be considered optimal
prey for this pentatomid (De Clercq 2000). Indi-


dlvidual predators were offered 5 fifth instar cotton
leafworms per day. A slice of green bean and a

source of free water were also supplied. Dead prey

and prey over two days old were replaced as
above. Predation rates and developmental dura-
tions of predator nymphs were recorded. Develop-

mental times of P. maculiventris fourth instars

were compared among diets using a non-parametric

Kruskal-Wallis analysis of variance and multi-
ple comparison tests. The experiment-wise
probability of type I error was controlled by the
Bonferroni method.

Preference Experiment

To investigate the prey preference of P. macu-


liventris, fourth instars of the predator were given
a choice between caterpillars of S. littoralis and
nymphs of N. viridula. Twenty P. maculiventris
fourth instars were placed singly in 14 cm diame-
ter petri dishes, lined with absorbent paper. They

were presented with 2 fifth instars of S. littoralis

and 2 fourth instars of N. viridula. Predator

nymphs were newly (12-24 h) molted and had not
fed before the experiment; prey insects were

about one day old. Slices of green bean were added
to provide food for the prey and moisture for the

predators. Interactions between predator and

prey were monitored 5, 15, 30, 45 and 60 min af-

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ter the start of the experiment. In addition, survival of the prey was recorded after 24 h.

RESULTS

Consumption Experiments

All life stages of *N. viridula* were readily attacked by nymphal *P. maculiventris* (Table 1). Fourth instars of the predator consumed on average 9 eggs, 20 first instars, 9 second instars, 3 third instars, 2.5 fourth instars, 2 fifth instars or 1 adult of the southern green stink bug during the total stadium. Male and female adults of *N. viridula* were similarly attacked: 58% of the adults killed were males. Survival of the predator nymphs was 90-100% in all treatments. Developmental times indicate, however, that eggs and nymphs of *N. viridula* were suboptimal prey for *P. maculiventris* (Table 1). Fourth instars took 1.5-3 days longer (*H = 66.19, df = 7, P < 0.001; Kruskal-Wallis ANOVA) to reach the next stadium on these prey stages than on fifth-instar caterpillars of *S. littoralis*. Fourth-instar *P. maculiventris* killed on average 6 fifth-instar cotton leafworms during the total stadium.

Predation rates of adult *P. maculiventris* on different life stages of the southern green stinkbug are reported in Table 2. Whereas females of the predator did not accept eggs of *N. viridula* as food, males consumed about 4 eggs over a 24-h period. Predation rates on nymphal instars and adults did not differ (*P > 0.05; Mann-Whitney tests) between male and female *P. maculiventris*. Adult predators killed on average 3.5-7.5 first instars, 2.5 second instars, 3.5 third instars, 1.5 fourth instars, 0.7 fifth instars or 0.5 adults of the pest per day.

Preference Experiment

Three out of 20 predator nymphs did not attack prey within the first 5 min of the experiment and had not done so by the end of the 60-minute observation period (Fig. 1). Seven out of the remaining 17 individuals (41%) directed their first attack towards *N. viridula*. However, after 30 min none of these predators had succeeded in capturing a *N. viridula* nymph. After 1 h, four out of these seven individuals had successfully attacked a larva of *S. littoralis*, whereas the remaining three had not resumed attacking prey. All tested predators had killed at least one prey item after 24 h. Overall, 72.5% of the *S. littoralis* larvae offered had been killed after 24 h versus only 5% of the *N. viridula* nymphs.

DISCUSSION

Although the different life stages of *N. viridula* were attacked by fourth instars and adults of *P. maculiventris*, our results indicate that the southern green stinkbug is not optimal prey for the spined soldier bug. Developmental rate of fourth-instar *P. maculiventris* on adult *N. viridula* was similar to that on late-instar cotton leafworms, which can be considered optimal food for development of the predator (De Clercq 2000), but when eggs or nymphs of different instars were provided, developmental rates were lower than on caterpillar prey. Slower development on eggs and nymphs of *N. viridula* than on fifth-instar *S. littoralis* is believed to be related mainly to size and mobility of the prey. Predators had difficulty detecting and feeding on eggs and early instars of *N. viridula*. Feeding on lepidopteran prey of small size has also been found to prolong development in *P. maculiventris* (De Clercq & Degheele 1994, De Clercq et al. 1998). Further, the predators had to spend more time capturing the more agile late instars of *N. viridula* than they did to kill a larva of *S. littoralis*. When *P. maculiventris* was given a choice between *N. viridula* nymphs and *S. littoralis* larvae, nearly half of the first attacks were directed against *N. viridula*. However, nymphs of the southern green stinkbug reacted with agility when the predator positioned its rostrum onto the prey body and tried to insert its stylets, and they

| Prey              | Predation rate | Developmental time (days) |
|------------------|----------------|--------------------------|
| *S. littoralis* fifth instar | 5.8 ± 0.4 | 4.55 ± 0.13 a |
| *N. viridula* egg        | 8.9 ± 1.1 | 6.30 ± 0.27 c |
| *N. viridula* first instar  | 20.5 ± 1.5 | 5.95 ± 0.20 bc |
| *N. viridula* second instar | 9.3 ± 0.5 | 7.75 ± 0.27 d |
| *N. viridula* third instar  | 3.3 ± 0.3 | 6.00 ± 0.29 bc |
| *N. viridula* fourth instar | 2.4 ± 0.3 | 6.50 ± 0.30 cd |
| *N. viridula* fifth instar | 2.0 ± 0.2 | 7.37 ± 0.39 d |
| *N. viridula* adult     | 1.0 ± 0.1 | 5.22 ± 0.21 ab |

*Mean number of prey killed during the total stadium.

Means within a column followed by the same letter are not significantly different (*P > 0.05, Kruskal-Wallis test with Bonferroni correction).
often managed to escape. Predators were sometimes seen pursuing an escaping nymph of *N. viridula* with extended rostrum but usually they quickly gave up the chase. When encountering a larva of *S. littoralis* in the process, the attention was easily diverted to the caterpillar. Although fifth-instar cotton leafworms reacted by vigorous thrashing movements when the predator inserted its stylets into the prey body, most of them did not succeed to escape from the hold of the predator once the stylets were firmly fixed. These observations indicate that more caterpillars than stink-bug nymphs were killed in choice tests basically because of their greater vulnerability.

Prey preferences and predation rates observed in this study may have been biased by the fact that stock colonies of *P. maculiventris* were maintained mainly on lepidopteran larvae. Selective adaptation to the food received during culturing cannot be ruled out and may have influenced the outcome of the experiments. Nonetheless, although the majority of Asopinae are highly polyphagous, reviews of the literature suggest that they have a preference for slow-moving, soft-bodied insects, primarily larval forms of Lepidoptera, Coleoptera, and Hymenoptera (McPherson 1980, Schaefer 1996, De Clercq 2000). Most predatory pentatomids appear to have more difficulty capturing heavily sclerotized prey. The only known exception is the oriental asopine *Amyotea malabarica* (F.), that has demonstrated a strong preference for *N. viridula* over lepidopterous prey (Singh 1973, Singh et al. 1973).

In North America, predation by *P. maculiventris* on late instars of *N. viridula* has been observed in the field on a number of occasions. In most of these cases, the predator was seen preying on late instars of *N. viridula* (Jones 1918, Drake 1920, Stam et al. 1987) but Ragsdale et al. (1981), using serological assays, also noted significant predation on eggs of the pest. Based on his field records, however, Drake (1920) believed that another asopine, *Euthyrhynchus floridanus* (L.), was a more important natural enemy of the southern green stinkbug in Florida. Mead (1976) also listed *N. viridula* as a major prey of *E. floridanus* in Florida. In South America, *Podisus nigrispinus* (Dallas) is the most abundant predatory pentatomid in soybean and alfalfa fields, where it has been observed to attack a variety of pentatomid pests including *N. viridula* (Saini 1994). In Japan, Kiritani (1964) listed the holarctic asopine *Zicrona caerulea* (L.) as a predator of the southern green stinkbug in rice. A number of other heteropterans, mainly belonging to Reduviidae, have been noted to be predators of *N. viridula* with biocontrol potential (Drake 1920, Ambrose 1999, Grundy & Maelzer 2000).

Although the southern green stinkbug appears to be suboptimal prey for *P. maculiventris* compared to caterpillars, nymphs and adults of the predator were able to kill high numbers of eggs, nymphs and adults of the pest in the laboratory, suggesting that it may contribute to suppressing *N. viridula* outbreaks. In field crops, natural populations of *P. maculiventris* or *P. nigrispinus* could be augmented with laboratory-reared individuals. However, given the relatively high price

| *N. viridula* stage | Predation rate | Predation rate |
|---------------------|---------------|---------------|
| Egg                 | 4.2 ± 1.2 a   | 0.0 ± 0.0 b   |
| First instar        | 3.4 ± 0.7 a   | 7.6 ± 1.6 a   |
| Second instar       | 2.4 ± 0.6 a   | 2.4 ± 0.9 a   |
| Third instar        | 3.3 ± 0.4 a   | 3.6 ± 0.5 a   |
| Fourth instar       | 1.6 ± 0.4 a   | 1.6 ± 0.2 a   |
| Fifth instar        | 0.7 ± 0.2 a   | 0.6 ± 0.2 a   |
| Adult               | 0.6 ± 0.2 a   | 0.3 ± 0.1 a   |

*Mean number of prey killed per day; means within a row followed by the same letter are not significantly different *P* > 0.05, Mann-Whitney test*
for these soldier bugs (e.g., the market price for a fourth instar of *P. maculiventris* currently averages $0.25), augmentative releases may only be feasible for high-value crops, such as greenhouse crops. In European greenhouses, where damage by *N. viridula* has been increasingly reported in recent years, releases of *P. maculiventris* nymphs could help keep the pest in check especially when infestations are localized (i.e., in “hot spots”). On the other hand, measures may be warranted to conserve natural or augmented populations of predatory pentatomids, for instance when using chemical pesticides or biological control agents for the control of *N. viridula* and other pests in the crop. When targeting chemical treatments against *N. viridula*, it is worth considering that *Podisus* spp. are generally more tolerant to pyrethroids than to organophosphates or carbamates (Yu 1988, Picanço et al. 1996, Mohaghegh et al. 2000). Field-collected eggs of *Podisus* spp. and other asopines have been found to be heavily parasitized by the scelionid egg parasitoid *T. basalis* (Buschman & Whitcomb 1980, Orr et al. 1986, Corrêa-Ferreira & Moscardi 1995). As a consequence, augmentative releases of this parasitoid against phytophagous pentatomids like *N. viridula* could adversely affect populations of co-occurring predaceous pentatomids.

Because laboratory experiments using small arenas without refugia tend to overestimate the killing capacity of a predator (Wiedenmann & O’Neil 1992), further studies will assess predation by *P. maculiventris* on *N. viridula* under greenhouse conditions. Also, more field studies are needed to evaluate the impact of pentatomid predators on populations of the southern green stink bug in major field crops.

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