

vival of eggs, larvae, and pupae in the absence of parasites; (4) ample leaf surfaces for larval feeding and pupation; (5) lack of antibiotic resistance by the host plant because of optimum nutrition and growth conditions for the host plant (Singh 1970); (6) a life cycle requiring ca. 28 days, that is, 4 weeks, at 18.4°C. then, beginning with 1 mated female, there would be, at the end of the 4th generation, after a total elapsed time of about 112 days (16 weeks or 4 months), a total of 21,856,500 ♀. An initial infestation of 5 or 12 ♀ could therefore result in an infestation numbering 46,921 or 112,614 larvae, respectively, by the 2nd generation. Such numbers would appear to be sufficient to kill even large tansy ragwort plants, as reported by Kelsey (1937) in New Zealand.

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Voracity and Survival of *Propylea 14-punctata*¹ Preying upon Greenbugs^{2,3}

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ABSTRACT

The voracity and survival of *Propylea 14-punctata* L. larvae while preying upon the greenbug, *Schizaphis graminum* (Rondani), were determined. Life tables were constructed for *P. 14-punctata* reared in isolation and communally. Preliminary field observations were made of the survival of the adults under climatic conditions in Oklahoma.

During an average feeding period of 9 days, 50 isolated *P. 14-punctata* larvae consumed a mean of 198

greenbug nymphs. Sibling cannibalism reduced eclosion by ca. 32%. Predation upon younger larvae and pupae by 4th instars reduced survival to 14% among communally reared larvae, compared with 95% survival for larvae reared in isolation. Life expectancy also was much shortened for communally reared larvae. *P. 14-punctata* survived the 1970-71 winter in Oklahoma as hibernating adults.

Propylea 14-punctata L. is common throughout most of Europe where it is fairly polyphagous and feeds upon a large number of aphid species. In England, *P. 14-punctata* is an important predator of the bean aphid, *Aphis fabae* Scopoli, on beans and *Microlophium evansi* (Theobald) on nettles (Banks 1955, 1956a). The green peach aphid, *Myzus persicae* (Sulzer), is commonly among its prey in France (Iperti 1966). Patrascanu (1964) re-

ported that *P. 14-punctata* is a predator of aphids on apple trees in Rumania, particularly the apple aphid, *Aphis pomi* De Geer, and *Dentatus malicola* Mordvilko. Severe destruction to sorghum by the greenbug, *Schizaphis graminum* (Rondani), throughout the Plains States of America in 1968 prompted importation of *P. 14-punctata* to test its effectiveness against the greenbug. Our laboratory culture was established from a few beetles supplied by the USDA Insect Identification and Parasite Introduction Research Branch, New Jersey. The source of our imported stock has been reported (Rogers et al. 1971).

Predatory efficiency of coccinellids is dependent largely upon voracity of the species in question. The voracity of coccinellids, in turn, may be influenced by many factors, among which are host species and prey size (Azam and Ali 1970), plants upon which prey are found (Gurney and Hursey

¹ Coleoptera: Coccinellidae.

² Homoptera: Aphididae.

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1970), length of larval feeding period (Okuno 1961), searching efficiency and behavior of larvae (Banks 1956b, 1957), temperature (Gurney and Hursey 1970), and survival of the species while consuming different host species (Rogers et al. 1972a). Preparatory to large scale field testing of the effectiveness of *P. 14-punctata* against the greenbug, biological studies were conducted in the laboratory. Reported here are observations concerning the voracity and survival of *P. 14-punctata* while maintained on greenbugs in the laboratory, as well as observations from preliminary field tests.

METHODS AND MATERIALS.—*Voracity.*—Immediately following eclosion, 50 1st instars of *P. 14-punctata* were placed into individual 1-oz (29.6 ml) plastic cups for rearing. Each day a known number of 3rd or 4th greenbug instars were offered free choice to each isolated coccinellid larva. First and 2nd instars were given 25 greenbugs/day, whereas 3rd and 4th instars received 50 greenbugs/day. The number of greenbugs consumed was determined each day prior to aphid replacement.

Larval Survival.—Survival data for larvae reared in isolation were obtained simultaneously with the voracity study. Survival data for larvae reared communally were obtained by observing progeny resulting from 5372 ova over a 10 month period. The number of 1st instars was recorded at eclosion. Thereafter, the number of larvae surviving by instar was recorded. Larvae were reared on greenbugs in cages described by Raney et al. (1971). Communal larvae usually were reared at a density of 5–15/cage, with an ample supply of greenbugs available. Pupal survival and adult longevity also were recorded. These data were used to construct life tables for *P. 14-punctata*. The biology, life history, reproductive data, sex ratio, and survival of F_1 generation progeny are reported elsewhere (Rogers et al. 1972a, b).

The laboratory tests were conducted under 12-hr photoperiods, $27 \pm 2.5^\circ\text{C}$, and 45–65% RH.

Preliminary Field Tests.—Observations of the ability of *P. 14-punctata* to survive in the climate of Oklahoma were made with adults in $1 \times 1.3 \times 1.7$ -m nylon cloth-covered field cages containing sorghum infested with greenbugs. Fifty adult beetles were put into a field cage during July and August 1970 for summer observations. Overwintering studies were made of 37 adults placed into a cage during November 1970. The overwintering cage contained a shel-

ter for the beetles in the form of a hollow concrete block filled with excelsior and covered with polyethylene film, through which a small entrance was cut. During April 1971, 187 beetles were placed into a field cage containing wheat infested with corn leaf aphids, *Rhopalosiphum maidis* (Fitch). Another cage containing bermudagrass infested with yellow sugarcane aphids, *Sipha flava* (Forbes), also received 118 beetles during April 1971.

RESULTS AND DISCUSSION.—*Voracity.*—First instars consumed a mean of 24 3rd- and 4th-stage greenbugs. Although the normal range for greenbugs consumed by 1st instars was 11–50, one larva consumed 70 greenbugs over a 6-day period and died without molting. Second instars consumed 15–75 ($\bar{x} = 36$) greenbugs. Third instars consumed a mean of 41 greenbugs, with the consumption varying from 15–70. Greenbug consumption by 4th instars equalled that of the 1st 3 instars combined. An average of 97 greenbugs was consumed by 4th instars of *P. 14-punctata*. One 4th instar consumed 156 greenbugs. Total consumption by the larvae ranged from 155 to 267 greenbugs. The mean number of greenbugs consumed by *P. 14-punctata* larvae was 198.

Okuno (1961) reported that *P. japonica* Thurnberg larvae consumed a mean of 282 adults of the cabbage aphid, *Brevicoryne brassica* (L.), during an average of 14.7 days, whereas *Coccinella septempunctata* Mulsant consumed a mean of 1156 in an average feeding period of 21.2 days. Iperti (1966) reported that the mean daily consumption of *M. persicae* 1st, 2nd, 3rd, and 4th instars was 8, 15, 18, and 22, respectively. In our test, the mean daily consumption of greenbugs was 11, 19, 23, and 31 for 1st, 2nd, 3rd, and 4th instars, respectively. Patrascanu (1964) observed that *P. 14-punctata* larvae consumed ca. 25 apple aphids and *D. malicola* daily as 1st and 2nd instars, and 50 daily as 3rd and 4th instars. Also, Patrascanu (1964) reported that an adult *P. 14-punctata* consumes about 75 apple aphids daily. Extrapolation of these results to the greenbug indicates that a *P. 14-punctata* adult could consume between 4500–6750 greenbugs during an active life of 60–90 days (Rogers et al. 1972b).

Larval Survival.—Table 1 (No. surviving column) indicates the survival of immature *P. 14-punctata* reared in isolation and communally. A tremendous difference existed between the survival rate of larvae reared in isolation and communally; ca. 95% of the 1st instars reared in isolation survived to the adult

Table 1.—Life table for *P. 14-punctata* when larvae were reared in isolation and communally on greenbugs.

Stage	Mortality ^a within interval		No. ^b surviving		Mortality ^c		\bar{x} life ^d	
	Isol.	Com.	Isol.	Com.	Isol.	Com.	Isol.	Com.
Ovum	320	320	1,000	1,000	320	320	78	78
1st instar	18	394	680	680	26	578	92	63
2nd instar	12	100	662	286	18	351	86	72
3rd instar	4	55	650	186	6	295	85	75
4th instar	0	0	646	131	0	0	83	83
Pupa	2	39	646	131	3	221	77	68
Adult	644	92	644	92	1,000	1,000	73	73

^a Per 1000 entering population at age 0.

^b To start of interval per 1000 starting at age 0.

^c Per 1000 entering age interval.

^d (To the nearest day) remaining to those entering age interval.

stage, compared with 14% for those reared communally. This difference resulted from heavy predation upon 1st and 2nd instars and pupae by older larvae of a commune. Chances for larval survival increased proportionately with maturity. No mortality was observed among 4th instars and they appeared to be relatively immune to predation. About 68% of the ova in each group produced 1st instars. The apparent low hatchability of ova in both groups of larvae was due partly to sibling cannibalism. Ova usually are deposited in clusters and delayed hatching of some usually resulted in their destruction by older siblings. Sibling cannibalism appears to be a common practice among coccinellids, and has been confirmed with *Adalia bipunctata* (L.), *C. septempunctata* (Banks 1956b) and *Aphidecta obliterated* (L.) (Witter 1969).

The mean life expectancy for larvae reared in isolation followed the expected trend in that 1st instars were expected to live longer than older larvae (Table 1). The mean life expectancy for ova, however, was much shorter than that for larvae reared in isolation, due primarily to sibling cannibalism. After larvae were separated as 1st instars, predation was omitted and the larvae could undergo normal development. Larvae reared communally experienced a much shorter life expectancy than those reared in isolation; e.g., 1st instars reared communally had a mean life expectancy of only 63 days, compared with 92 days for those reared in isolation. The shorter life expectancy exhibited by communal larvae and pupae is an indication of, and a result of, the predation pressure that they experienced.

Although mean life expectancy for adults in both groups was observed to be ca. 73 days, older adults in a commune occasionally attacked and consumed newly emerged adults, even if aphids were available. Newly emerged adults were damp and soft and may have contained an olfactory stimulus that attracted older adults in the vicinity.

P. 14-punctata reared in isolation and communally clearly illustrate that in both cases the ova and early instars were most susceptible to mortality. Although larvae reared in isolation were removed from an egg mass as soon as possible following eclosion, some ova probably were destroyed by newly hatched larvae. Pupae of communal populations had a relatively high mortality. Once the adult stage was reached, the survival rate of both populations remained nearly constant until near the end of the normal life cycle. A population of *P. 14-punctata* may be regulated largely by the survival trends of the ova and early larval stages. Also, this is probably the most critical period for individual survival within a population. A wild population of *P. 14-punctata* probably would compare nearer to the "communal larvae" in Table 1 than to the one depicting "isolated larvae."

Preliminary Field Observations.—Fifty adult beetles when placed into a field cage during July 1970 produced viable ova. Larvae from the ova survived to the pupal stage. However, it is not known whether successful emergence occurred. A colony of ants invaded the cage and were seen carrying ova, young larvae, and greenbug nymphs from the cage. Six dead adults were recovered but the fate of the other 44 is unknown; they either escaped or were carried by ants from the cage after going into aestivation or dying.

At least 3 of 37 beetles placed into the field cage

during November 1970 survived the winter. Two females and 1 male were observed flying in the cage during the 3rd week of April 1971. Whether more than 3 beetles survived the winter is unknown.

Two days after putting 187 adult beetles into a field cage in May 1971, a hail storm destroyed the top and one side. Since some of the beetles probably had escaped, it was decided that observations of uncaged beetles might be worthwhile. Although an accurate count could not be made, ca. 24 beetles remained in the cage after a period of 2 weeks. By that time the presence of the convergent lady beetle, *Hippodamia convergens* Guérin-Ménéville, *Lysiphlebus testaceipes* (Cresson), and wheat maturity had caused a depletion of the aphids, and the *P. 14-punctata* had dispersed. Observations indicated that *P. 14-punctata* may not disperse as readily as other coccinellid species following release into a new area.

Observations of a mixed population of *P. 14-punctata* and *H. convergens* indicated that the native *H. convergens* may be able to replace *P. 14-punctata* in a confined area of close competition. A field cage containing a large population of yellow sugarcane aphids, ca. 24 *H. convergens*, and 118 *P. 14-punctata* adults contained only *H. convergens* after 30 days. The *H. convergens* population increased by 3-fold, whereas the *P. 14-punctata* population was eliminated, either through escape or by predation from the larger and more aggressive *H. convergens* adults and larvae.

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Combined Effects of Light and Carbon Dioxide on Egg Production of Indian Meal Moths^{1,2}

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ABSTRACT

Egg production and hatchability were reduced greatly when females of *Plodia interpunctella* (Hübner), reared under alternating 12-hour-light and 12-hour-dark cycles, were mated to males reared under continuous light and then were treated with CO₂. Carbon dioxide gas or continuous-light treatment singly were not so effective in re-

ducing egg production and viability as when they were used in combination. Oviposition was delayed by exposure of females to CO₂. Control females oviposited and died sooner than treated females. The results demonstrated the additive effect of 2 adverse factors, CO₂ and light, on egg production of *P. interpunctella*.

The reproductive potential of the female Indian meal moth, *Plodia interpunctella* (Hübner), as of most insects, is dependent essentially upon transfer of sufficient sperm by males during mating and production of the full complement of eggs before death. Lum and Flaherty (1969) showed that females mated to males reared under continuous light (LL) laid fewer eggs than females mated to males reared under a dark-light cycle. Also, the anesthetization of inseminated females with carbon dioxide (CO₂) gas reduced oviposition and egg hatchability (Lum and Flaherty, unpublished data). Therefore, reduced egg production can be expected from Indian meal moths after they are subjected to these stress conditions. A behavior common to the Indian meal moth and some other insects is the release of eggs under such stress as decapitation or exposure to CO₂ gas, dichlorvos vapor, or other insecticides or solvents (DeCoursey and Webster 1952, Rawnsley 1959). Morrison and Crawford (1970) showed that although fewer eggs were obtained from decapitated females than from normal females, many of the eggs hatched without apparent ill effects. The reduced egg production resulting from stress decreases the potential of a female, but a release of even small numbers of viable eggs can pose a threat of increased infestation and result in a buildup of the pest population. As 1 ♀ can deposit 200 or more viable eggs, large populations of the moths can be established in a few generations. Ideally, a control method for stored-product insects should entail not only the death of the insects but also prevention of release of viable eggs during the "death stress." Also, treatment of foods should involve minimal use of pesticides, especially those with high residual properties.

This study considered the possibility of using sublethal doses of CO₂ gas with continuous light to

reduce production and hatchability of eggs of the Indian meal moth.

MATERIALS AND METHODS.—Indian meal moths were reared at 30±2°C and 60±5% RH under continuous light or alternating 12-hr-light and 12-hr-dark cycles (LD) (Lum and Flaherty 1969). As they emerged, moths were sexed and placed in 2 groups: LD females paired with LD males and LD females paired with LL males. Each group consisted of 10 lots of 10 pairs of moths each. For mating, each lot of insects was placed in a 473-ml glass jar. About 24 hr later, males were removed from each jar. Five lots of females from the 2 groups were kept in the 473-ml jars and treated for 1 hr with commercially prepared 96% CO₂ gas. The flow of gas was regulated to 200 ml/min, and all insects were knocked down within 10 min after the introduction of the gas. After 1 hr, each lot of females was placed in another 473-ml jar and allowed to oviposit for 5 days. Eggs were collected daily beginning 24 hr after CO₂ treatment (with 1st collection denoted as Day 1 in Table 2) and incubated at 30±2°C and 60±5% RH. Hatchability was determined by recording the number of unhatched eggs remaining after 96 hr. Daily mortality was recorded, and after it died, each female was dissected to determine if it had mated (spermatophore present). Production and hatchability of eggs from anesthetized females were compared with production and hatchability of eggs from females in the remaining 10 lots, 5 of which (LD ♂ × LD ♀) served as controls. All tests therefore consisted of 5 lots of 10 ♀/lot.

RESULTS AND DISCUSSION.—Table 1 shows effects of LD or LL males, CO₂ gas, and combinations of both on the egg production of *P. interpunctella* females. Compared with that of the controls (LD ♂ × LD ♀), egg production was reduced to 35% when females were mated to LL males or to 37% when females mated to LD males were treated with CO₂. However, when females were mated to LL males and treated with CO₂, egg production was reduced to 16%.

¹ Lepidoptera: Phycitidae.

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