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Physiological and Environmental Factors Related to the Dispersal Flight of the Convergent Lady Beetle, *Hippodamia convergens* (Guerin-Meneville)[1]

JAMES R. DAVIS AND REED L. KIRKLAND
Department of Entomology, University of Missouri, Columbia 65211

ABSTRACT: Ovarian development and dispersal flight were examined in convergent lady beetles collected at fall aggregation sites and stored overwinter at 32°C to simulate natural spring populations. Fed beetles attained ovarian maturity within 8 days. Beetles treated with juvenile hormone mimic (JHM), methoprene, showed intermediate ovarian development but maturity was not attained. Unfed convergent lady beetles showed 18% dispersal the day of removal from cold storage, 84% after 3 days and 66% after 6 days. Fed beetles showed 63% dispersal after 3 days. Fed and unfed convergent lady beetles flight tested from 8:00 a.m. to 12:30 p.m. did not significantly disperse until 11:00 a.m. when temperatures were 15 to 22°C, although feeding on aphids was observed at lower temperatures. It is suggested that naturally occuring spring dispersal flight of the lady beetles alternates with feeding behavior until the ovaries are mature.

Augmentation of lady beetle populations has long been a popular method of biological control used by organic farmers to control aphids (Yebsen, 1976). The most frequently utilized lady beetle in releases of this type is the convergent lady beetle, *Hippodamia convergens* (Guerin-Meneville). Unfortunately, convergent lady beetles which are collected from mountain aggregations either disperse from the field upon release, or feed at low and ineffective rates. Hagen (1962) has shown that beetles collected in the fall, from early-diapause aggregations, remain near the release site but do not feed on aphids; those collected in the spring, from late-diapause aggregations, exhibit a characteristic dispersal flight away from the release site. Davidson (1924) and Cooke (1963) also observed that even high densities of aphids failed to suppress this dispersal flight.

The migratory behavior of the convergent lady beetle from diapausing aggregations in California has been outlined by Hagen (1966). The beetles

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apparently overwinter in the Sierra Nevada Mountains of California until late February or March. After several warm days, the beetles fly upward until they reach a specific air temperature zone. Prevailing easterly winds then blow the beetles toward the central California valleys. Under normal weather conditions, the migratory flight of the convergent lady beetle is terminated at the valley floor.

A more detailed understanding of the naturally occurring migratory dispersal of the convergent lady beetle is necessary in order to understand and suppress the dispersal tendency of the beetles collected and released for biological control. It is also necessary to understand those factors which suppress dispersal behavior and initiate normal feeding and reproductive behavior.

Recent attempts to understand the migratory dispersal of the convergent lady beetle have concentrated on identifying physiological mechanisms. Hagen (1962, 1966) observed that convergent lady beetles collected from spring aggregation sites have undeveloped ovaries. Rankin and Rankin (1980), using a flight mill, showed that beetles collected in March immediately after migration from mountain aggregations exhibited maximum dispersal activity at ovarian weights of 1.0 mg. This dispersal activity continued until ovaries were completely developed (3.0 mg), at which time dispersal activity dropped to near zero.

This study was initiated to clarify and add to the information regarding the feeding, ovarian development and dispersal flight of spring collected convergent lady beetles. Unlike studies conducted by Rankin and Rankin (1980), field releases were made of the beetles, rather than flight mill tests in the laboratory.

Materials and Methods

INSECT SOURCE AND MAINTENANCE: The 5000 *H. convergens* used in this study were collected from fall aggregations at a latitude of 38° to 39°N in the Sierra Nevada Mountains of California. Following shipments to the laboratory in Columbia, Missouri, they were held in plexiglass cages placed in an environmental chamber (Percival E-30®) for 4–6 months under 3 ± 2°C and a 10L:14D photoperiod. Food was not available to the beetles in storage, but adequate water was provided. Female beetles were held in reproductive diapause under these conditions. This was confirmed by periodic dissections, as all examined beetles had immature ovaries throughout the storage period.

OVARIAN DEVELOPMENT: Following storage, 5 groups of lady beetles were removed, anesthesized with CO_2 and sexed. These females received the following treatments: group 1—unfed; group 2—fed 0.2 g/♀ of grain moth, *Sitotroga cerealella* (Oliver), eggs daily; group 3—unfed, topical application of 2 μg/♀ of acetone; group 4—unfed, topical application of 1 μg/♀ of JHM (methoprene) dissolved in 2 μl acetone; and group 5—fed, topical application of 1 μg/♀ JHM dissolved in 2 μl acetone. During the experiment the temperature was maintained at 25 ± 2°C and 14L:10D. Hagen (1962) stated that mating occurs prior to fall aggregations, so it was not necessary to maintain males and females together.

The effects of the JHM, methoprene, on ovarian development was determined by comparing the control group 1 and the acetone group 3 with the JHM groups 4 and 5. As JHM was dissolved in the acetone before treating the beetles, it was necessary to examine the effect of acetone alone. The beetles in group 3 were anesthesized with CO_2 and received a topical application of 2 μl/adult of acetone on the ventral surface of the abdomen. The beetles in groups 4 and 5 were likewise anesthesized and received a topical application of 1 μl JHM dissolved in 2 ml acetone. Both the acetone and JHM treatments were applied with a 50 μl Hamilton® microsyringe.

To determine the status of ovarian development, dissections were performed 2, 4, 6, and 8 days after temperatures were raised to 25°C. The ovarian development of all beetles was categorized by using the following qualitative rankings:

1. Underdeveloped—ovarioles were long, thin, and showed no bulges.
2. Initiation of Development—the ovarioles were slightly bulbous.
3. Intermediate Development—the ovarioles were distinctly bulbous.
4. Maturity—the ovarioles were very large and often obscured by the presence of mature eggs.
5. Oviposition—eggs were observed in the specimen bottles.

DISPERSAL FLIGHT: Treatment methodology was the same as previously described for studies of ovarian development. *Hippodamia convergens* beetles were held individually in 100 mm dia. petri dishes with adequate water supplied by a cotton wick in a one dram vial. The beetles were flight tested 0, 3, and 6 days after removal from cold storage. Dispersal flight was examined under a photoperiod of 14L:10D.

Flight tests were conducted using four release pads placed in a clearing in a corn field. These experiments took place during August and September 1979 and 1980, so the corn was nearing maturity. Each pad was placed approximately 1.2 m from the nearest corn plant. Each release pad consisted of a wooden frame covered with a thin layer of cork. A water moat was constructed around each pad to prevent walking beetles from escaping.

Due to the logistics of monitoring dispersal flight, only one treatment group was flight tested at any one time. Therefore, different treatment groups were tested sequentially from 11 a.m. to 1 p.m. The petri dishes containing *H. convergens* were opened and placed gently on the flight pad. The beetles were then allowed 20 min. to take flight. During this test period an observer counted the number of beetles flying to the adjacent corn plants (non-dis-

Table 1. Effect of feeding *S. cerealella* eggs on the ovarian development of *H. convergens*, including Student's t-test.

Day	Treatment	Adult (no.)	Ovarian developmental stage (mean ± SE)	
2	Unfed	16	1.0 ± .1	**
	Fed	12	1.3 ± .1	
4	Unfed	15	1.5 ± .2	*
	Fed	12	2.0 ± .2	
6	Unfed	11	1.8 ± .3	**
	Fed	12	4.0 ± .3	
8	Unfed	9	1.7 ± .3	**
	Fed	15	4.4 ± .3	

* Significant at $P = 0.10$.
** Significant at $P = 0.05$.

persers) and those that dispersed from the area (dispersers). Due to the characteristic dispersal flight of the convergent lady beetle (Hagen, 1966), the so-called dispersers could be differentiated from those that merely flew to adjacent plants. Dispersing beetles characteristically flew upward for 2–4 m and then flew off at a 45° angle.

To determine the influence of air temperature, sunlight, and feeding on dispersal behavior, 400 females were removed from cold storage and maintained at 25 ± 2°C, 14L:10D photoperiod for 3 days.

The beetles were then placed in 80 waxed cups modified to allow air flow and direct sunlight. The 80 cups, of 5 beetles each, were divided into 4 groups. The beetles were placed in full sunlight at 7:00 a.m. Air temperature inside and outside the cups was monitored throughout the experiment. Air temperature inside the cups was maintained near outside temperatures by placing the cups on crushed ice when necessary.

Dispersal flight tests were conducted with the 4 groups at 8:00 a.m., 9:30 a.m., 11:00 a.m., and 12:30 p.m. Dispersal flight was observed as previously discussed. Forty minutes prior to release on the pads, 10 cups of each group were provided with 20 recently killed 3rd instar greenbugs per cup. After the 20 min. of observation the remaining aphids were counted and aphid consumption per beetle was estimated.

Results

OVARIAN DEVELOPMENT: The effect of feeding *S. cerealella* eggs on ovarian development was distinct (Table 1). The unfed group scarcely achieved the

Table 2. Effect of acetone and JHM on ovarian development of *H. convergens*, including Student's t-test.

Day	Treatment (group)	Adult (no.)	Ovarian developmental stage (mean ± SE)	
2	Control	16	1.0 ± .1	ns
	Acetone	22	1.2 ± .1	ns
	JHM	23	1.6 ± .1	**
4	Control	15	1.5 ± .2	ns
	Acetone	12	1.7 ± .2	ns
	JHM	24	2.4 ± .1	**
6	Control	11	1.8 ± .2	ns
	Acetone	7	2.1 ± .2	ns
	JHM	16	2.8 ± .1	**
8	Control	9	1.7 ± .2	ns
	Acetone	11	1.6 ± .2	ns
	JHM	6	2.5 ± .3	**

ns = not significant.
** Significant at $P = 0.05$.

stage of initial development ($\bar{x} = 1.7$) on day 8. The fed group, however, showed significant ovarian development by day 4 and nearly all beetles reached maturity by day 8. It was noticed that no beetles achieved ovarian maturity in the unfed group, whereas the fed group had a significantly higher rate of maturation on all days examined.

JHM AND ACETONE TRIALS: Topical application of JHM dissolved in acetone was found to increase ovarian development significantly in those *H. convergens* tested (Table 2). Topical application of acetone alone did not increase ovarian development significantly on any day, so apparently JHM was responsible for the observed effect. The JHM group reached an intermediate level of ovarian development (2.8) on day 6. However, oviposition did not occur in any of the beetles in the JHM group.

FEEDING PLUS JHM TRIALS: Studies on the effect of feeding combined with JHM applications indicated no significant difference between the combination treatment and feeding alone on days 2, 4, and 8 (Table 3). A small and inexplicable difference was obtained on day 6, but this may have been due to sampling error or a slight delay in reproductive maturity that was compensated for by day 8.

DISPERSAL FLIGHT: Unfed beetles were flight tested 0, 3, and 6 days after removal from cold storage (Table 4). The extremely low dispersal rates observed on day 0 coincide with Hagen's (1962) observation that convergent

Table 3. Effect of feeding *S. cerealella* eggs plus application of JHM on ovarian development of *H. convergens*, including Student's t-test.

Day	Treatment (group)	Adult (no.)	Ovarian developmental stage (mean ± SE)	
2	Fed	12	1.3 ± .1	ns
	Fed + JHM	16	1.5 ± .1	
4	Fed	12	2.0 ± .3	ns
	Fed + JHM	10	2.1 ± .3	
6	Fed	12	4.0 ± .3	**
	Fed + JHM	12	2.8 ± .3	
8	Fed	15	4.4 ± .3	ns
	Fed + JHM	26	4.2 ± .2	

ns = not significant.
** Significant at $P = 0.05$.

lady beetles exhibit only short flights before the initiation of the major migratory flight. The 66% dispersal rate observed on day 6 supported experiments by Rankin and Rankin (1980) in which dispersal flight activity continued for a greater length of time than that necessary for the initial migration to the feeding sites.

Fed beetles were flight tested 3 days after removal from cold storage (Table 4). Unlike earlier experiments (Rankin and Rankin 1980), beetles that were fed and that presumably had attained the initial stages of ovarian development showed lower dispersal rates than unfed beetles. It should also be noted that unfed beetles on day 6 showed approximately the same ovarian development as fed beetles on day 4 (Table 1) and that dispersal rates are also similar for these two groups, 66% and 63% respectively (Table 4).

Since dispersal flight tests were conducted on 8 separate dates and may have been influenced by varying weather conditions, a chi-square analysis of the effect of flight test date was conducted. The effect of test date on dispersal flight was compared within treatments only. The analysis in the unfed, day 3 trials showed the only statistical inconsistency. The chi-square value of 11.28 was only slightly greater than the $P = 0.05$ value of 11.07. As this difference was small, it was decided to proceed with the analysis of the effect of treatment on dispersal flight using all data obtained.

FEEDING AND FLIGHT BEHAVIOR: Davidson (1924) and Cooke (1963) observed that nearly all released convergent lady beetles would disperse from an area even when aphid densities were high. Ignoffo et al. (1976), however, showed that when flight was prevented convergent lady beetles would feed on aphids. Rankin and Rankin (1980) further showed that dispersal activity

Table 4. Dispersal flight of unfed convergent lady beetles on days 0, 3, and 6, and fed beetles on day 3 after removal from cold storage.

Treatment	Test date	Number fliers	Non-dispersers No.	Non-dispersers %	Dispersers No.	Dispersers %
Day 0 Unfed	9/11/79	17	9	53	8	47
	9/11/79	18	12	67	6	33
	9/11/79	13	10	77	3	23
	9/11/79	13	10	77	3	23
	Total	65	47	72	18	28
Day 3 Fed	8/28/79	44	11	25	33	75
	9/04/79	26	10	38	16	62
	9/04/79	23	13	57	10	43
	9/09/79	25	9	36	16	64
	9/09/79	31	12	39	19	61
	Total	149	55	37	94	63
Day 3 Unfed	8/28/79	24	3	13	21	87
	9/02/79	18	0	0	18	100
	9/04/79	20	5	25	15	75
	9/04/79	26	8	31	18	69
	9/07/79	13	2	15	11	85
	9/09/79	15	3	20	12	80
	9/13/79	13	0	0	13	100
	Total	129	21	16	108	84
Day 6 Unfed	9/30/80	44	20	45	24	55
	9/30/80	42	15	36	27	64
	9/30/80	45	16	36	29	64
	9/30/80	44	9	20	35	80
	Total	175	60	34	115	66

Table 5. Dispersal flight of fed convergent lady beetles at varying times.

Time		Number Dispersers	Number Non-dispersers	Number Remaining on pad
8:00 a.m.	Fed	0	1	49
	Unfed	0	0	50
9:30 a.m.	Fed	1	13	36
	Unfed	0	10	40
11:00 a.m.	Fed	3	9	38
	Unfed	6	17	27
12:30 p.m.	Fed	5	14	31
	Unfed	6	23	21

Table 6. Temperatures inside and outside cups during study of feeding and dispersal flight of convergent lady beetles.

Time	Temperature (°C)	
	Outside	Inside
7:30	4	4
8:00	3	4
8:30	14	14
9:00	14	14
9:30	14	15
10:00	17	17
10:30	19	20
11:00	20	22
11:30	22	23
12:00	24	24
12:30	25	26
1:00	—	24

does not fully decrease until ovaries are completely developed. Our experiments, however, were designed to test whether feeding and dispersal can occur on the same days and thus potentially result in developed ovaries and termination of dispersal flight.

Table 5 shows that significant dispersal flight did not occur until 11:00 a.m. At this time, the temperature was 22°C. Apparently, the threshold for flight activity of any kind is between 4°C and 15°C and the threshold for dispersal flight is between 15°C and 22°C (Table 6). Hagen (1966) likewise observed that migratory dispersal flight of the convergent lady beetle occurs when the temperature exceeds 17°C. Cooke (1963) also found that sunlight influences dispersal flight since dispersal was suppressed on cloudy days.

In contrast to dispersal behavior, feeding behavior was initiated early in the day at much lower temperatures (Table 7). Aphid consumption increased throughout the morning to a total of 1.66 aphids per beetle in the 12:30 p.m. test group. Unfed beetles showed significantly greater total flight activity than fed beetles.

Discussion

Results from experiments with the convergent lady beetle suggest that naturally occurring spring dispersal flight alternates with feeding behavior

Table 7. Number of greenbugs consumed by convergent lady beetles at varying times in the morning.

Time:	8:00	9:30	11:00	12:30
# greenbugs/beetle	.38	1.16	1.50	1.66

until ovaries are completely developed. Apparently, convergent lady beetles are capable of feeding within several days after spring weather conditions become suitable (Rankin and Rankin, 1980). Thereafter, feeding behavior is likely temperature-dependent and is suppressed only when food shortages or environmental conditions initiate dispersal. Without suitable food for ovarian development, dispersal flights will continue for at least 6 days. The results from these experiments have shown that when suitable food is present there is a potential for ovarian development, even though beetles frequently exhibit dispersal flight. Rankin and Rankin (1980) similarly confirmed that the dispersal flight of convergent lady beetles is suppressed only when the ovaries are completely developed.

It was noted that when beetles were maintained outside for the entire morning, the percent dispersal flight in a 20-min. period was only 11% at 12:30 p.m. and with temperatures of 25°C. In addition to the feeding that occurs in the morning, before environmental conditions are suitable for dispersal flight, it is also likely that significant feeding occurs between dispersal flights and in the later afternoon when conditions again become unsuitable for flight. Hagen and Sluss (1966) have shown that when an excess of spotted alfalfa aphids *Therioaphis trifolis* (Monel) are available approximately 1.10 aphids will be consumed per day and ovaries will fully develop in 3 days. The greenbugs utilized in this experiment have weights similar to that found for the spotted alfalfa aphid. Under natural conditions it is possible that fewer aphids are necessary for ovarian development and that a longer preovipositional period is satisfactory. Further experiments are necessary to determine whether convergent lady beetles are capable of consuming the necessary amount of aphids for ovarian development when feeding is occasionally disrupted by dispersal flight.

Acknowledgments

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Literature Cited

Cooke, W. C. 1963. Ecology of the pea aphid in the Blue Mountain area of eastern Oregon and Washington. USDA Tech. Bull. 1287. 48 pp.

Davidson, W. M. 1924. Observations and experiments on the dispersion of the convergent lady beetle (*Hippodamia convergens*) in California. Amer. Ent. Soc. Trans. 50:163–175.

Hagen, K. S. 1962. The biology and ecology of predaceous coccinellids. Ann. Rev. Entomol. 6:289–326.

———. 1966. Suspected migratory flight behavior of *Hippodamia convergens*. The Ecology of Aphidophagus Insects, I. Hodek (ed.). Academia, The Hague. 360 pp.

Hagen, K. S., and R. R. Sluss. 1966. Quantity of aphids required for reproduction by *Hippodamia* spp. in the laboratory. The Ecology of Aphidophagus Insects, I. Hodek (ed.). Academia, The Hague. 360 pp.

Ignoffo, C. M., C. Garcia, W. A. Dickerson, G. T. Schmidt, and K. D. Brevier. 1976. Imprisonment of entomophages to increase effectiveness: evaluation of concept. J. Econ. Entomol. 70(3):292–294.

Rankin, M. A. 1977. Hormonal control of insect migratory behavior. Evolution of Insect Migration and Diapause, H. Dingle (ed.). Springer-Verlag, New York. 284 pp.

Rankin, M. A., and S. M. Rankin. 1980. Some factors affecting the presumed migratory flight activity of the convergent lady beetle, *Hippodamia convergens* (Coccinellidae:Coleoptera). Biol. Bull. 158:356–369.

Yebsen, B. 1976. Organic Plant Protection. Rodale Press, Emmaus, Pennsylvania. 688 pp.

NOTICE

FIFTY-EIGHTH ANNUAL MEETING OF THE CENTRAL STATES (KANSAS) ENTOMOLOGICAL SOCIETY

DATES: April 23 and 24, 1982.
PLACE: Department of Entomology, Waters Hall and Little Theater, KSU Student Union, Kansas State University, Manhattan, KS.

Further information may be obtained from Alberto B. Broce, Department of Entomology, Waters Hall, Kansas State University, Manhattan, KS 66506. Phone (913) 532-6154.

Persons interested in presenting papers should submit titles and abstracts by March, 1982. (Less than one, double space, typed page please).

The Kansas Academy of Sciences will hold its annual meeting on April 23 at the KSU Student Union. The Academy has extended a formal invitation to our Society and members to participate in their meetings.

Additional information and an announcement of the program will be mailed at a later date to members and to others on request.

Alberto B. Broce
President

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