ISSN 0013-8738, Entomological Review, 2010, Vol. 90, No. 4, pp. 411–414. © Pleiades Publishing, Inc., 2010.
Original Russian Text © S.Ya. Reznik, 2010, published in Entomologicheskoe Obozrenie, 2010, Vol. 89, No. 2, pp. 273–278.

On the Effects of Diet and Photoperiod on *Harmonia axyridis* (Pallas) (Coleoptera, Coccinellidae) Larval Development

S. Ya. Reznik

Zoological Institute, Russian Academy of Sciences, St. Petersburg, Russia

Received July 30, 2009

Abstract—It is known that the light day length and diet could act as cue factors inducing adult (reproductive) diapause in aphidophagous coccinellids. However, the rate of coccinellid larval development could also depend on photoperiod and diet. The present study examines the effects of photoperiod (L : D = 12 : 12 or 16 : 8) and diet (the green peach aphid *Myzus persicae* or eggs of the Angoumois grain moth *Sitotroga cerealella*) on preimaginal development of the multicolored Asian lady beetle *Harmonia axyridis*. At 20°C, a short light day and feeding on aphids shortened larval development by 1.4 and 4.6 days, respectively. In combination, both factors caused a simple sum of separate impacts indicating the absence of their interaction. The duration of the pupal stage was independent of photoperiod, but decreased by 0.3 days in individuals fed on aphids. The proportion of the larvae that successfully completed preimaginal development was also independent of the light day length, but significantly depended on diet (84 and 60% in individuals fed on green peach aphids and on grain moth eggs, respectively). In sum, these results suggest that in the case studied, diet does not play the role of cue factor, but directly influences the larval growth and development of *H. axyridis*.

DOI: 10.1134/S0013873810040019

INTRODUCTION

Environmental factors could influence insect growth and development in two quite different ways. The so-called vital factors exert a direct influence on metabolism, while the influence of environmental cues is mediated by neurohormonal mechanisms (Danilevsky, 1961; Tyschenko, 1980; Zaslavskiy (Zaslavsky), 1984; Tauber et al., 1986; Chernyshev, 1996; Saulich and Volkovich, 2004; Danks, 2007). However, one and the same parameter (e.g. temperature) could be both a vital factor (development slows down with the temperature decrease) and a cue factor (low temperature could induce diapause). Similarly, the absence of prey (aphids) exerts a twofold influence on females of predatory coccinellids (Evans, 2000; Evans et al., 2005; Riddick, 2009). Moreover, special experiments (Zaslavskiy et al., 1998; Semyanov and Vaghina, 2001; Semyanov, 2002; Semyanov and Vaghina, 2003; Reznik and Vaghina, 2006) have demonstrated that diet is the only cue factor inducing reproductive diapause in the predatory lady beetle *Harmonia sedecimnotata* (Fabr.) (Coleoptera, Coccinellidae). Separation of "vital and cue components" of the same factor is often methodologically difficult work. In particular, the cue effect of a factor could be efficiently revealed by the analysis of its interaction with some other environmental cue whose influence is known to be mediated by the neuroendocrine system of the insect (e.g., the light day length). When some factor influences only the level of the photoperiodic response but does not change the pattern of the reaction (the impacts are summarized without interaction), the two effects are most probably based on different mechanisms. If the studied factor interacts with the light day length, changing the pattern of the photoperiodic response (as it was repeatedly demonstrated e.g. for temperature), this suggests that reactions to both factors are based on the same mechanism (Zaslavskiy, 1996). However, photoperiod could cause in insects not only "qualitative responses," such as diapause induction or termination, but also "quantitative responses" (e.g. changes in fecundity or in the rate of development). Moreover, there are reasons to believe that qualitative and quantitative manifestations of the photoperiodic response are based on the same mechanism (Zaslavskiy, 1984, 1996; Saunders, 2002). The present study was aimed at analyzing the joint influence of diet and photoperiod on the rate of development in the predaceous coccinellid, *Harmonia axyridis* (Pallas). This species was widely used for biological control of aphids in greenhouses (Koch, 2003; Roy and Wajnberg, 2007; Belyakova and Balueva, 2007) but recently it has also

attracted particular attention by its unexpected ability to invade natural ecosystems (Roy and Wajnberg, 2007; Soares et al., 2007).

MATERIALS AND METHODS

The experiments were conducted with the laboratory strain of *H. axyridis*, originated from insects collected in 2004 in Kedrovaya Pad' Natural Reserve (Khasanskii Region, Primorskii Territory of Russia) and reared by the standard methods (Semyanov, 1996) under constant conditions: the temperature of 25°C, photoperiod of L : D = 18 : 6, feeding on larvae and adults of the green peach aphid, *Myzus persicae* (Sulz.) (Homoptera, Aphidae) reared on broad bean, *Vicia faba* L. plants.

For the experiment, a group of the 1st instar larvae hatched during 2 h was randomly distributed between two photoperiodic regimens (L : D = 16 : 8 or 12 : 12) and two feeding regimens: larvae and adults of *M. persicae* or eggs of the Angoumois grain moth *Sitotroga cerealella* Oliv. (Lepidoptera, Gelechiidae). The experiments were conducted in a thermostatic room at 20°C. The larvae were kept individually in plastic Petri dishes, food was provided daily in excess. The larvae were offered aphids on the bean seedlings, grain moth eggs were glued to a paper with the honey solution (in the latter case, a wet cotton ball was placed in the Petri dish as a water source). Pupation and adult emergence were recorded daily at the same time (4–6 h after the light-on). In total, development of 40–45 individuals was studied for each combination of diet and photoperiod.

The distribution of the duration of the larval development was close to normal and this variable was treated by multifactorial ANOVA. The proportions of individuals successfully developed to the adult stage were compared using the chi-square test with the Mantel-Haenszel adjustment for the analysis of numerous contingency tables. All the calculations were made with Systat 10.2.

RESULTS

Two replicates of the experiment gave similar results that were pooled. Preliminary treatment did not reveal any significant gender influence on the duration of development and thus data on males and females were also pooled for further treatment.

Two-factor ANOVA has shown that the duration of larval development was significantly ($p < 0.001$) dependent both on feeding regime and on photoperiod, although the influence of the day length ($F = 22.5$) was much smaller than that of the diet ($F = 233.7$). It is noticeable that the interaction of these factors was practically absent ($p = 0.957$). Independently of the feeding regime, at the short light day (12 h) the duration of the larval development was smaller than that with the long light day (16 h), the difference between the means being 1.4 days both in the larvae fed on aphids and in those fed on the grain moth eggs (Fig. 1). The influence of the diet was also practically independent of photoperiod: at the short and the long light day, larvae fed on aphids developed, correspondingly, 4.7 and 4.6 days faster.

As for the pupal stage duration, it was independent of photoperiod ($p = 0.90$) but significantly ($p < 0.001$) depended on the feeding regime: in individuals fed on aphids it was on the average 0.3 days shorter (Fig. 1). Similarly, the proportion of the larvae successfully developed to the adult stage was significantly ($p = 0.001$) dependent on diet, but not on photoperiod ($p = 0.49$). Judging by this parameter, aphids were also more favorable food than grain moth eggs: the average proportion of the larvae that successfully developed to adults was 84% and 60% in individuals fed on aphids and on the grain moth eggs, respectively (Fig. 2).

DISCUSSION

In many insect species, and particularly in predatory coccinellids, the rate of larval development and adult maturation could depend on the feeding regime (Dreyer et al., 1997; Evans, 2000; Koch, 2003; Evans and Guntner, 2005; Riddick, 2009). It is also known that the diapause-inducing short light day often accelerates the development of the stages preceding diapause, thus ensuring survival of the major part of the insect population during the unfavorable period (Danilevsy, 1961; Tyschenko, 1980; Zaslavskiy, 1984; Tauber et al., 1986; Saunders, 2002; Saulich and Volkovich, 2004; Danks, 2007).

However, in one of the earlier papers (Ongagna and Iperti, 1994), the authors concluded that the short light day slowed down *H. axyridis* larval development. The results of another study (Berkvens et al., 2008) were similar to ours: in individuals from the "laboratory" strain at the 12 h light day development from egg to adult stage was faster than that at the 16 h light day. On the other hand, the same authors have found that the development of the individuals from "natural" strain, cultured in laboratory conditions during only 4

generations, was faster at the long light day. In addition, larvae from the "laboratory" line feeding on the pea aphid, *Acyrthosiphon pisum* Harris developed slower than those fed on the eggs of the Mediterranean flour moth, *Ephestia kuehniella* Zeller, while in the progeny of individuals from the natural populations the rate of development in larvae feeding on aphids was the same or even higher than that in larvae feeding on the Mediterranean flour moth eggs.

Comparing these results with those of our study, it should be pointed out that relatively large eggs of the Mediterranean flour moth are most probably better food for the larvae than small eggs of the grain moth, although certain authors (Abdel-Salam and Abdel-Baky, 2001; Dong et al., 2001) considered *S. cerealella* eggs quite suitable food for *H. axyridis* larvae and adults. It is also possible that the laboratory strain reared on the Mediterranean flour moth eggs during many years, has adapted to this food. Generally speaking, comparing of the studies conducted with different lines of *H. axyridis* is hampered by its extremely high intraspecific variability that has been noted by all the authors.

Returning to the main purpose of the present study, it should be noted that special analysis of the interaction between photoperiod and diet in their influence on the rate of development in predatory coccinellids has not been conducted yet, although some data (Berkvens et al., 2008) suggested simple summation of the two effects. In our study, this conclusion could be made from Fig. 1 and supported by the ANOVA results. In addition, the diet significantly influenced the duration of the pupal stage and the preimaginal mortality, while our data showed that both parameters were practically independent of the light day length. Obviously, in our experiments the diet was a vital factor, directly influencing *H. axyridis* larval growth and development.

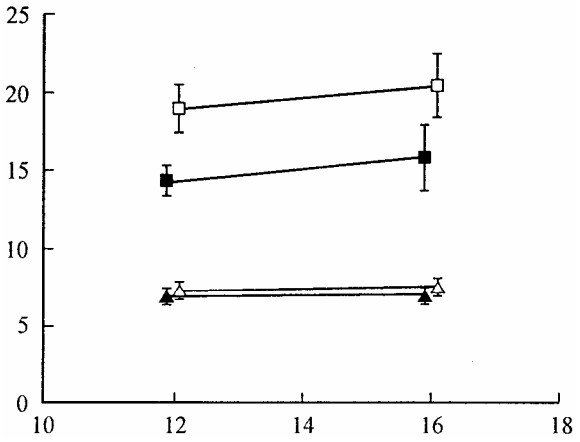

Fig. 1. Influence of diet and photoperiod on duration of different stages of *Harmonia axyridis* preimaginal development. Abscissa, the light day length (h); ordinate, duration of development (days). Quadrates, time from larval hatching to pupation (filled, in larvae fed on aphids; empty, in larvae fed on the grain moth eggs); triangles, the duration of the pupal stage (filled, when larvae fed on aphids; empty, when larvae fed on the grain moth eggs). Means and SD are shown.

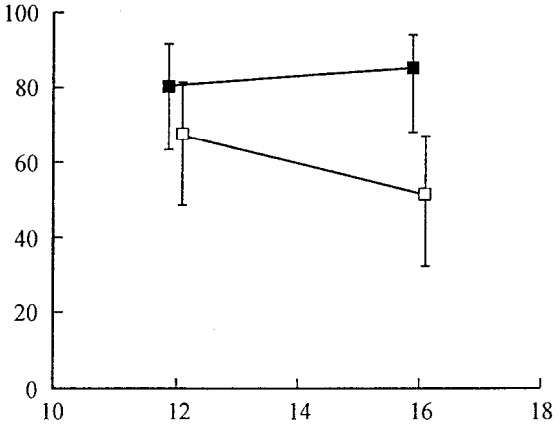

Fig. 2. Influence of diet and photoperiod on the percentage of *Harmonia axyridis* larvae successfully developed to the adult stage. Abscissa, the light day length (h); ordinate, the percentage of larvae successfully developed to the adult stage (filled quadrates, in larvae fed on aphids; empty quadrates, in larvae fed on the grain moth eggs). Percentage and 95% confidence intervals are shown.

CONCLUSIONS

(1) The short light day (L : D = 12 : 12) and feeding on aphids *Myzus persicae* accelerated *Harmonia axyridis* larval development, while the long light day (L : D = 18 : 6) and feeding on eggs of the Angoumois grain moth *Sitotroga cerealella* slowed it down. In case of the joint action, the impacts of the two factors were summarized, the occurrence of an interaction was not revealed.

(2) The duration of the pupal stage and preimaginal mortality were independent of photoperiod, but were significantly lower in individuals fed on aphids.

(3) Obviously, in our experiments the diet was not a cue factor, but directly influenced *H. axyridis* larval growth and development.

ACKNOWLEDGMENTS

I am deeply grateful to Dr. V.P. Semyanov for valuable suggestions and for providing the possibility to use the laboratory line of *H. axyridis* and to L.S. Ramenskaya for her assistance in conducting experiments. This study was partly supported by the Program of the Department of Biological Sciences of RAS "Biological Resources of Russia: Fundamental

Bases of Rational Use" and by the State contract "Unique collection funds of Zoological Institute RAS" (UFK ZIN, n. 2-2.20).

REFERENCES

1. Abdel-Salam, A.H. and Abdel-Baky, N.F., "Life Table and Biological Studies of *Harmonia axyridis* Pallas (Col., Coccinellidae) Reared on the Grain Moth Eggs of *Sitotroga cerealella* Olivier (Lep., Gelechiidae)," J. Appl. Entomol. **125** (8), 455–462 (2001).
2. Belyakova, N.A. and Balueva, E.N., "Prospects for Use of Polymorphic Cultures and Male-less Lines of *Harmonia axyridis* for Biological Control," IOBC EPRS Bull. **38**, 35–39 (2007).
3. Berkvens, N., Bonte, J., Berkvens, D., Tirry, L. and De Clercq, P., "Influence of Diet and Photoperiod on Development and Reproduction of European Populations of *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae)," BioControl **53** (1), 211–221 (2008).
4. Chernyshev, V.B., *Insect Ecology* (Moscow, 1996) [in Russian].
5. Danilevsky, A.S., *Photoperiodism and Seasonal Development of Insects* (Leningrad, 1961) [in Russian].
6. Danks, H.V., "The Elements of Seasonal Adaptations in Insects," Canad. Entomol. **139** (1), 1–44 (2007).
7. Dong, H., Ellington, J.J., and Remmenga, M.D., "An Artificial Diet for the Lady Beetle *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae)," Southwest. Entomol. **26** (3), 205–213 (2001).
8. Dreyer, B.S., Neuenschwander, P., Baumgärtner, J. and Dorn S., "Trophic Influences on Survival, Development and Reproduction of *Hyperaspis notata* (Coleoptera, Cocinellidae)," J. Appl. Entomol. **121** (5), 249–256 (1997).
9. Evans, E.W., "Egg Production in Response to Combined Alternative Foods by the Predator *Coccinella transversalis*," Entomol. Exp. Appl. **94** (2), 141–147 (2000).
10. Evans, E. and Gunther, D.I., "The Link Between Food and Reproduction in Aphidophagous Predators: a Case Study with *Harmonia axyridis* (Coleoptera: Coccinellidae)," Europ. J. Entomol. **102** (3), 423–430 (2005).
11. Koch, R.L., "The Multicolored Asian Lady Beetle, *Harmonia axyridis*: A Review of its Biology, Uses in Biological Control, and Non-target Impacts," J. Insect Sci. **3** (32), 1–16 (2003) (insectscience.org/3.32).
12. Ongagna, P. and Iperti, G., "Influence of Temperature and Photoperiod on *Harmonia axyridis* Pall. (Col., Coccinellidae): Rapidly Obtaining Fecund Adults or in Dormancy," J. Appl. Entomol. **117** (3), 314–317 (1994).
13. Reznik, S.Ya. and Vaghina, N.P. "Dynamics of Fat Content During Induction and Termination of "Trophic Diapause" in *Harmonia sedecimnotata* Fabr. Females (Coleoptera, Coccinellidae)," Entomol. Obozr. **85** (1), 3–12 (2006) [Entomol. Rev. **86** (2), 125–132 (2006)].
14. Riddick, E.W., "Benefits and Limitations of Factitious Prey and Artificial Diets on Life Parameters of Predatory Beetles, Bugs, and Lacewings: a Mini-review," BioControl. **54** (3), 325–339 (2009).
15. Roy, H.E. and Wajnberg, E., "From Biological Control to Invasion: the Ladybird *Harmonia axyridis* as a Model Species," in *From Biological Control to Invasion: Ladybird Harmonia axyridis* (IOBC, 2007), pp. 1–4.
16. Saulich, A.Kh. and Volkovich, T.A., *Ecology of Photoperiodism in Insects* (St. Petersburg, 2004) [in Russian].
17. Saunders, D.S., *Insect Clocks* (Amsterdam, 2002)
18. Semyanov, V.P., "Methods of Rearing and Long-term Storage of a Tropical Coccinellid, *Leis dimidiata* (Fabr.) (Coleoptera, Coccinellidae)," Entomol. Obozr. **75** (3), 714–720 (1996).
19. Semyanov, V.P., "Obligatory and Facultative Diapause in Aphidophagous Coccinellids (Coleoptera, Coccinellidae): Similarity and Difference," in *Abstracts of XII Congress of Russian Entomol. Soc.* (St. Petersburg, 2002), pp. 313–314 [in Russian].
20. Semyanov, V.P. and Vaghina, N.P., "The Odor of Aphids as a Signal for Termination of the Trophic Diapause in the Lady Beetle *Harmonia sedecimnotata* (Fabr.) (Coleoptera, Coccinellidae)," Proc. Zool. Inst. RAS **289**, 161–166 (2001).
21. Semyanov, V.P. and Vaghina N.P., "Trophic Diapause Influence on Fecundity and Longevity in Tropical Coccinellid *Harmonia sedecimnotata* (Fabr.) (Coleoptera, Coccinellidae)," Entomol. Obozr. **82** (1), 3–5 (2003) [Entomol. Rev. **83** (8), 915–916 (2003)].
22. Soares, A.O., Borges, I., Borges, P.A.V., Labrie, G. and Lucas, É., "*Harmonia axyridis*: What will Stop the Invader?" in *From Biological Control to Invasion: Ladybird Harmonia axyridis*. (IOBC, 2007), pp. 127–145.
23. Tauber, M. J., Tauber, C. A. and Masaki, S., *Seasonal Adaptations of Insects* (New York, 1986).
24. Tyschenko, V.P., "The Signal Action of Ecological Factors," Zh. Obsch. Biol. **41** (5), 655–677 (1980).
25. Zaslavsky, V.A., *Photoperiodic and Temperature-Based Control of Insect Development* (Leningrad, 1984) [in Russian].
26. Zaslavskiy, V.A., "Diversity of Environmental Factors Controlling Seasonal Development of Insects, and Probable Unity of Underlying Physiological Mechanism," Entomol. Obozr. **75** (2), 233–243 (1996).
27. Zaslavskiy, V.A., Semyanov V.P., and Vaghina N.P., "Food as a Cue Factor Controlling Adult Diapause in the Lady Beetle, *Harmonia sedecimnotata* (Coleoptera, Coccinellidae)," Zool. Zh. **77** (12), 1383–1388 (1998) [Entomol. Rev. **78** (6), 774–779 (1998)].