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Conditions Governing Diapause Induction in the Lady Beetle, *Coccinella septempunctata bruckii* (Coleoptera: Coccinellidae)[1]

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In the lady beetle, *Coccinella septempunctata bruckii*, aestivation is true diapause controlled by corpus allatum, while hibernation is not. The condition for diapause induction was studied by rearing experiment. First-generation adults reared under an autumn condition did not diapause, but when these adults were transferred to a natural condition in summer, they diapaused. Also, in 2nd-generation adults a summer condition remarkably inhibited the respiratory activity. Rearing at 25°C demonstrated that the long photoperiod caused diapause, while the short photoperiod permitted oögenesis. Observation indicates that diapause is induced by the summer condition during adult stage.

INTRODUCTION

In Japan the lady beetle, *Coccinella septempunctata bruckii* MULSANT is basically bivoltine; the 1st-generation adults aestivate while the 2nd-generation hibernates (SAKURAI et al., 1983; SAKURAI and TAKEDA, 1986). In aestivating adults the respiration rate decreased to a low level and oögenesis was inhibited completely, reflecting the functional deficiency of corpus allatum (CA) (SAKURAI et al., 1981, 1986 a), whereas in hibernating adults, the respiration and CA function remained active. Topical application of juvenile hormone analogue to the aestivating adults caused termination of aestivation, while the hibernation was activated only by transferring them from the outdoors to 25°C (SAKURAI et al., 1986 a). This indicates that aestivation is a true diapause controlled by CA, while hibernation is not.

As to induction of aestivation in *C. septempunctata*, NIIJIMA and KAWASHITA (1982) and KAWAUCHI (1985) have reported that lack of aphids as prey in the field is the main factor. However, the role of temperature and photoperiod in diapause induction is obscure. The present paper deals with the conditions for diapause induction in *C. septempunctata* and demonstrates the summer conditions which play a primary role.

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MATERIALS AND METHODS

The hibernating adults of *C. septempunctata* were collected in the field in Kakamigahara-City, Gifu Prefecture in early spring and oviposited in the laboratory under natural photoperiod at 25°C. The eggs were placed under various experimental conditions and the hatched larvae were reared on aphids. About 20 species of aphids were used as prey, among which *Aphis craccivora*, *Aphis rumicis*, *Brevicoryne brassicae*, *Dactynotus formosanus* and *Myzus persicae* were utilized frequently. Drone honeybee powder (OKADA et al., 1972) and freeze-dried aphid powder were also utilized supplementally during summer when the aphid population became scarce. The lady beetles were reared in a plastic container of 10 cm diameter and 6.5 cm depth, in which 5 to 10 larvae were accommodated. These containers were kept in an insect growth cabinet, and temperature and photoperiod were automatically regulated. To rear the beetles under a natural condition, the container was kept in a screen box placed within a screen chamber outside the laboratory.

Diapausing state of beetles was estimated in female adults by examining the respiration rate, oviposition and oögenesis. Respiration rate was measured in each adult by Warburg respirometer for 1 hr at 25°C and expressed as μl O_2/mg wet weight/hr. The stage of oögenesis was determined according to the criterion by SAKURAI et al. (1986 a).

RESULTS

Conditions for diapause induction in 1st-generation beetles

Hibernating females oviposited in the laboratory on the 20th of April, 1981 and newly hatched larvae were reared under either natural condition (A) or 18°C, 11L–13D (B). The adults in B emerging around the 10th of June were transferred to natural condition after emergence (C). Developmental period from egg stage to adult emergence was 1.7 times longer in B than in A (Table 1).

The change of respiration rate was determined weekly from July to September (Fig. 1). The adults in A and C showed very low respiration rate by early August, while the adults in B had a higher respiration rate. The respiration rates in A and C increased moderately after mid August. Oviposition was observed after mid August in B and after late August in both A and C. The minimum respiration rates in

Table 1. Developmental period of 1st-generation beetles and minimum respiration rate of females reared under various conditions

Rearing condition	Developmental period (day)				Minimum respiration rate (μl O_2/mg/hr)
	Egg	Larva	Pupa	Total	
A: natural condition	5.9	18.9	5.3	30.1	0.46 ± 0.07^b
B: 18°C, 11L–13D	10.6	29.7	10.2	50.5	1.52 ± 0.08
C: $B \xrightarrow[\text{adult}]{} A^a$	10.6	29.7	10.2	50.5	0.40 ± 0.08

Hibernating females oviposited on the 20th of April, 1981.

[a] The adults in B emerged around 10th June and were transferred to A after emergence.

[b] Values are mean±SD ($n=10$).

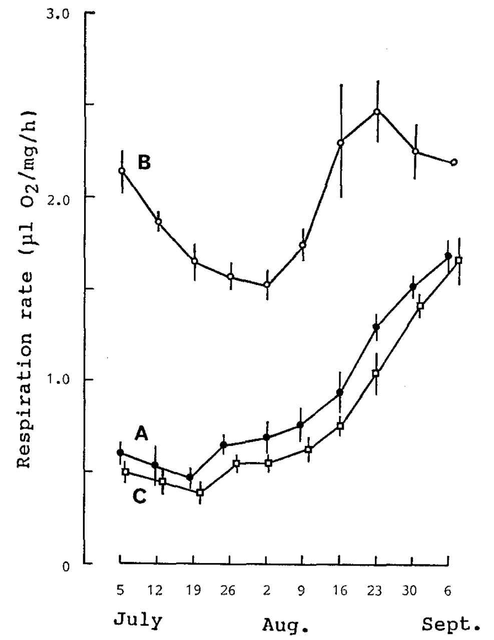

Fig. 1. Changes of respiration rate of 1st-generation female adults emerged under various conditions described in Table 1. Values are mean±SD.

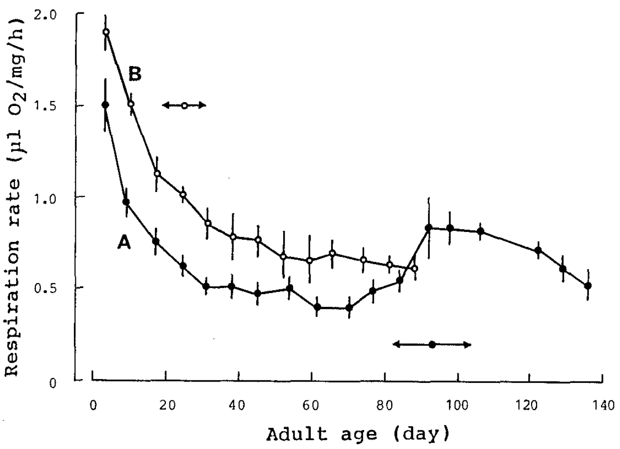

Fig. 2. Changes of respiration rate of female adults reared under different photoperiods at 25°C. A (●): 16L–8D, B (○): 10L–14D. Arrow (←→) shows oviposition period. Values are mean±SD.

Table 2. Changes of respiration rate of 2nd-generation females reared under 25°C, 16L–8D after each developmental stage

Experimental stage[a]	Respiration rate (*μl* O_2/mg/hr)			
	Nov. 25	Dec. 5	Dec. 15	Dec. 25
D: adult (control)	2.01±0.21[b]	1.87±0.19	1.83±0.12	1.96±0.20
E: adult	1.04±0.12	1.16±0.14	1.11±0.09	0.99±0.14
F: pupa	1.42±0.19	1.33±0.11	1.16±0.24	0.95±0.10

Insects were collected in the field on the 4th of November, 1981.

[a] D was reared under natural condition, while others were under 25°C, 16L–8D. F emerged on the 6–10th of November.

[b] Mean±SD ($n=10$).

A and C were less than 1/3 those in B (Table 1). Thus the adults reared under a summer condition entered diapause, while those under an autumn condition did not.

Diapause induction in 2nd-generation beetles

Adults and pupae were collected together in the field on the 4th of November, 1981. The adults collected were young ones having pale colored elytra corresponding to the color grades 1 and 2 (Sakurai et al., 1983). The adults as control (D) were reared under a natural autumn condition, while the adults (E) and pupae (F) were reared under 25°C, 16L–8D after collection. The change of respiration rate was determined every 10 days (Table 2). The respiration rate was kept at a high level in D, while that in

Table 3. Developmental period of 1st-generation beetles reared under different photoperiods at 25°C after hatching

Photoperiod	Developmental period (days)		
	Larva	Pupa	Total
A: 10L–14D	10.4±0.5[a]	4.9±1.0	15.3±1.2
B: 16L–8D	10.1±0.6	3.9±0.8	14.1±1.0

Hibernating females oviposited in early April, 1982.

[a] Mean±SD (n=10).

E decreased to half in D; the same change was seen in F. Thus the respiratory activity of 2nd-generation adults was inhibited by the summer condition.

Role of summer climate in diapause induction

To understand the role of summer climate in diapause induction, 1st-generation beetles were reared at 25°C after hatching under either short photoperiod (10L–14D) or long photoperiod (16L–8D). The developmental period of beetles was almost the same under both conditions (Table 3). These periods coincide with that reared under dark condition at 25°C (KITAMURA et al., 1980).

The change of respiration rate after emergence was determined weekly (Fig. 2). In the adults under long photoperiod (A), the respiration rate decreased sharply after emergence and dropped to a minimum level after 60 days. It moderately increased after 80 days and oviposition occurred during 84 to 108 days. In contrast, in the adults under short photoperiod (B), the respiration rate decreased gradually after emergence and dropped to a minimum level after 60 days. Oviposition occurred during 18 to 32 days and the adults died after 100 days without increase of respiration rate. Thus the long photoperiod at 25°C caused diapause, whereas the short photoperiod at 25°C permitted ovarian development.

DISCUSSION

First-generation adults of *C. septempuctata bruckii* reared under an autumn condition (18°C, 11L–13D) did not diapause (Fig. 1B). This coincides with their life cycle that the 2nd-generation adults emerging in autumn do not diapause (SAKURAI et al., 1986 a). When 1st-generation adults grown under an autumn condition were transferred to a natural summer condition, they entered diapause (Fig. 1C). This would indicate that diapause is induced by the summer condition. Such aspect can be ascertained in 2nd-generation adults in which respiratory activity was remarkably inhibited by the summer condition (25°C, 16L–8D) (Table 2). As to the effect of conditions during larval period on diapause induction, the climate in Gifu district in April and May during which the 1st-generation larvae usually grow is below 20°C on average and 13.5–15.5 hr in maximum day length (Fig. 3). However, the 1st-generation adults reared under the spring condition (18°C, 16L–8D) throughout their life did not diapause (HIRANO et al., 1982). Hence the spring condition during the larval period does not seem to be related to diapause induction.

The role of photoperiod in diapause induction can be understood by rearing at

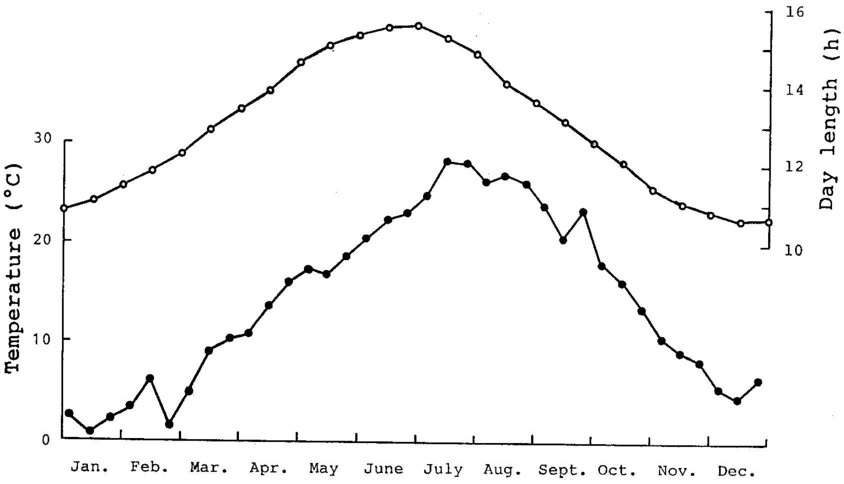

Fig. 3. Seasonal changes of mean atmospheric temperature in Gifu-City, 1981 (●), and maximum day length from pre-dawn to evening twilight at 35° N (○) (Beck, 1980).

25°C. The long photoperiod inhibited both respiration and oögenesis (Fig. 2A). Thus the photoperiod in summer causes the reproductive diapause. It is interesting that diapause was activated after 80–100 days under the fixed condition of summer. This indicates that climatic change in late summer, i.e., temperature decrease and photoperiodic shortening is not requisite for diapause activation. In fact, transferring the diapausing adults from natural condition in summer to an autumn condition (18°C, 11L–13D) caused diapause to terminate only slightly earlier (Sakurai et al., 1986 b), whereas in *C. septempunctata* L. in Europe, the winter diapause is activated by photoperiodic response (Hodek et al., 1977). Hence the summer diapause in the Japanese species seems not as deep as the winter diapause in the European one. It is also interesting that adults reared under a short photoperiod at 25°C oviposited for a short time after emergence and their respiration rate decreased gradually (Fig. 2B). Thus the short photoperiod and high temperature act antagonistically on the reproduction in newly emerged adults, being respectively stimulating and inhibitory, whereas both conditions stimulate oviposition in the hibernating adults (Sakurai et al., 1986 a). Such difference might be ascribed to physiological distinction between aestivation and hibernation of this beetle.

The diapause of *C. septempunctata bruckii* reflects declined activity of the corpus allatum (Sakurai et al., 1981; Sakurai and Takeda, 1986). Hence the summer condition might inhibit corpus allatum activity of 1st-generation adults. As to diapause induction in this beetle, Niijima and Kawashita (1982) and Kawauchi (1985) have indicated that lack of prey during summer is the main factor and both photoperiod and temperature affect only secondarily. The present study demonstrated that the temperature and photoperiod in summer affect primarily. Viewing their life cycle, the summer condition seems to affect predominantly the adult stage rather than the larval stage, whereas in the monovoltine population of *C. septempunctata* L. in Europe, winter diapause is induced by the conditions in autumn (Hodek, 1961; Hodek et al., 1977). Such difference in conditions in diapause induction between Japanese and European species might be attributable to difference in diapause type adapted to each respective environment.

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