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Effect of Photoperiodic Regimes on Oviposition and Colony Development of the Bumblebee, *Bombus ignitus*

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The effect of photoperiodic regimes on the oviposition and colony development of *Bombus ignitus* queens was examined with 0L, 8L, and 16L under 27°C and 65% R. H. Among these photoperiod regimes, the oviposition rate at 8L and 16L was 80.2% and 83.1%, respectively, which was 12 - 15% higher than that at the dark condition (0L). Duration up to first oviposition at 8L and 16L was 17.5 days and 16.5 days, respectively, which was 2 - 3 days shorter than that at 0L. The colony foundation rate at 8L and 16L was 9.2% and 10.4%, respectively, which corresponded to 1.7 - 2.0-fold higher than the value at 0L. In addition, the rate of progeny-queen production at 8L and 16L was also two fold higher than that at 0L. Taken these together, the light conditions (8L and 16L) rather than dark condition (0L) were more suitable for oviposition and colony development for *B. ignitus* in the indoor rearing conditon.

Key words: Bumblebee, *Bombus ignitus*, Photoperiod, Ovipositon rate, Colony development

Introduction

Bumblebees are one of the most widely distributed species group and approximately 300 species of bumblebees are known throughout the world (Prys-Jones and Corbet 1991). They undergo generally one generation per year. The young queens that have mated with males in late summer hibernate and emerge in spring (Heinrich, 1979). The queen builds up store of pollen and lays her first batch eggs into the pollen mass after searching a suitable site to found a colony. Sometimes this may take all day, a few days or possibly two weeks or longer. The eggs are hatched into milky white larvae and larvae pupate and emerge as adults. The queen usually lays another batch of eggs while the first batch is still in the larval stage. After workers from the first batch emerge, the queen can spend more time on oviposition because the workers start to forage two- or three-days after emerging. In the late summer, many males and new queens are produced and only mated queens hibernate and emerge in spring. It is essential for year-round rearing of the bumblebee, *Bombus ignitus* that undergoes one generation per year, to break diapause.

The diapause of insects is usually affected by photoperiod (Danilevskii, 1965). Because oviposition of bumblebee is also related to the adult diapause, the possibility must be trustworthy that the photoperiod affects the oviposition of queen and the further development of colony. Philogene and Mcneil (1984) demonstrate the importance of light on various aspects of insect reproduction, excluding diapause.

Bumblebee is generally reared in dark condition (Plowright and Jay, 1966; Heemert *et al.*, 1990; Asada and Ono, 2000). But in nature, bumblebee queens are subjected to day-light for several weeks in autumn before they bury themselves to hibernate, and in spring after overwintering when they seek a nesting place underground. Queens continue to be exposed daylight when they feed their first batch of larvae and even when the first workers have appeared (Heinrich, 1979; Tasei and Aupinel, 1994). Despite this well known behavior, there was no comparative experiment on the effect of artificial light on the oviposition and colony development of *B. ignitus* queens indoor-reared. It is therefore of interesting to evaluate whether light has a stimulating effect on the oviposition and colony development. In the present study, we examined the effect of three photoperiodic regimes on the ovi-

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position of *B. ignitus* queens.

Materials and Methods

Origin of experimental insects and indoor rearing

Experimental insects were CO_2 - treated 4th generation queens obtained from *Bombus ignitus* colonies year-round reared in a controlled climates room (27°C, 65% R. H. and continuous darkness). The queens were reared in three types of cardboard (1.5 mm thick) boxes each for nest initiation (10.5 × 14.5 × 6.5 cm), colony foundation (21.0 × 21.0 × 15.0 cm), and colony maturation (24.0 × 27.0 × 18.0 cm). Each box had a wire net window on its lid for ventilation. The sizes of these windows were 5.5 × 6.5 cm, 7.0 × 14.0 cm and 10.0 × 20.0 cm, respectively. Queens were first confined individually in small boxes for colony initiation and remained there until oviposition. To stimulate the egg laying, two narcotized old *B. ignitus* worker 10 – 20 days aged after emergence were added to each queen (Yoon and Kim, 2002). When the adults emerged from the first brood, the nest was transferred to a medium box for colony foundation, and left there until the number of workers reached 50. The nest was thereafter moved to the big box for further colony development (Yoon *et al.*, 2002).

Fifty percent honey solution and pollen dough were provided *ad libitum*. The pollen dough was made from 50% honey solution and fresh pollen collected from an apiary (v : v = 1 : 1).

For mating, newly emerged queens and males were collected from the colonies and maintained in a box until mating and one six-day-old virgin queens were placed in flight cages (55.0 × 65.0 × 40.0 cm) in mating room (uncontrolled photoperiod and 24 – 25°C) with one ten-day-old virgin males from other colonies during one week.

Photoperiodic regimes

To examine the photoperiod favorable for colony development of *B. ignitus*, the following environmental conditions were provided. Photoperiodic regimes were defined as 0L (continuous dark), 8L (light for 8 hrs per day) and 16L (light for 16 hrs per day) under a constant 27°C and 65% R. H. The numbers of queens allotted to experimental regimes for photoperiod were 35 and that had two repetitions. The light was provided by fluorescent tubes (TL40D) and the intensity of 70 – 140 lux was measured at the level of the rearing boxes.

The developmental ability of each colony was estimated by the following criteria: 1) oviposition; 2) colony foundation; 3) production of progeny; and 4) period up to first adult emergence. Oviposition here means formation of the first egg cell, and colony foundation indicates that more than 50 workers emerged. Period up to first adult emergence designates the duration from the first oviposition to the first adult-emergence. The queens that did not oviposit in 60 days were excluded from the number of oviposited colonies. Statistical analysis was done with one-way ANOVA test and Tukeys pairwise comparison test (MINITAB Release 13 for Windows, 2000).

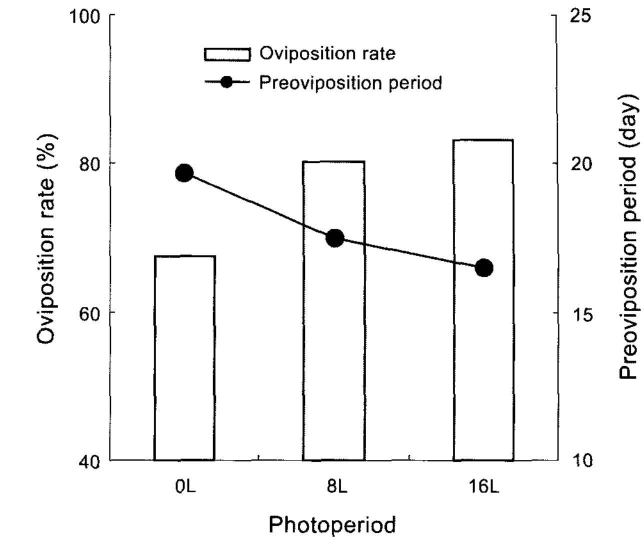

Fig. 1. Oviposition rate and preoviposition period of *B. ignitus* by different photoperiod. For the statistical analysis, oneway ANOVA and Tukey's pairwise comparison test were used. Alphabets (a and b) indicate statistical difference between different alphabets. Thus, there was statistically significant difference at $\alpha = 0.05$ for oviposition rate. However, no significant difference was found for preoviposition period at $\alpha = 0.05$.

Results and Discussion

Effect of photoperiod on oviposition of *B. ignitus*

In the photoperiodic regimes of 0L, 8L, and 16L under 27 and 65% R. H., the oviposition rate of 8L and 16L was 80.2% and 83.1%, respectively, and these were 12 – 15% higher than that at 0L ($F = 34.23$, $p = 0.009$) but there was no significant differences between 8L and 16L at $\alpha = 0.05$ ($F = 1.90$, $p = 0.302$) (Fig. 1). Duration up to first oviposition at 8L and 16L was 17.5 days and 16.5 days, respectively, and these were 2 – 3 days shorter than that at 0L but no significant difference was detected between photoperiod regimes ($F = 1.86$, $p = 0.159$). Duration up to first oviposition at each 8L and 16L did not show any significant difference at all at $\alpha = 0.05$ ($F = 0.38$, $p = 0.540$) (Fig. 1).

Bumblebees are generally reared in dark condition (Plowright and Jay, 1966; Heemert *et al.*, 1990; Asada and

Ono, 2000). But our results showed that oviposition rate and preoviposition period of light condition (8L and 16L) is better than dark condition (0L) in indoor rearing of *B. ignitus*. In case of *B. terrestris*, delays to oviposition were significantly shortened by the 8L and the period from the start of brooding attitude to oviposition was also significantly reduced by the 8L compared with constant dark and constant light (Tasei and Aupinel, 1994). Also, it has been reported that the 8L-rearing was more suitable for oviposition and colony development of *B. terrestris* in indoor rearing than 0L- and 16L-rearing (Yoon *et al.*, 2003).

Effect of photoperiod on colony development of *B. ignitus*

In the photoperiodic regimes of 0L, 8L, and 16L, the colony foundation rate at 8L and 16L was 9.2% and 10.4%, respectively and it was improved 1.8 – 2.3 fold than the value at 0L and colony foundation between 0L and 8L was statistically different at $\alpha = 0.05$ ($F = 23.55$, $p = 0.040$) (Table 1). The rate of progeny-queen production of 8L and 16L was 11.8% and 14.3%, respectively, and these values were also 1.5 – 1.8-fold higher than that at 0L ($F = 11.33$, $p = 0.040$) (Table 1).

Table 2 shows the duration up to first adult emergence of indoor-reared *B. ignitus* by different photoperiod. The period up to first worker emergence at 16L prolonged about 2.0 days than those at 0L and 8L, but there was no statistical difference ($F = 1.15$, $p = 0.326$). The period up to first male emergence at 16L was also 2.8 – 4.3 days longer than those at 0L and 8L, but there was no statistical difference between them ($F = 0.57$, $p = 0.569$). Besides, the period of first emergence queens was nor affected by photoperiod although the period of queens emergence at 8L was about 13.0 days shorter than that at 0L and 8L ($F = 0.64$, $p = 0.539$).

The number of workers and males produced at 0L, 8L, and 16L was surveyed with more than 50 workers emerged colonies (Table 3). The numbers of worker at 16L was 85.1 ± 22.7, which was 9 – 23 numbers less than those at 0L and 8L but there was no statistical difference ($F = 0.57$, $p = 0.569$). In case of the number of males produced at different photoperiods, the 0L-rearing bumblebees were 193.0 ± 27.8 numbers and these values were

Table 1. Rate of colony foundation and progeny-queen production of indoor-reared *B. ignitus* by different photoperiod

Photoperiodic regimes	Rate of colony foundation (%)[1)]	Rate of progeny-queen production (%)[1)]
0 L	5.3±1.1	7.8±0.5 a
8 L	9.2±0.2	11.8±2.4 ab
16 L	10.4±2.1	14.3±2.7 b

[1)]The figures stand for means SD. Means followed by different letters in the same column indicate statistically significant difference at $\alpha = 0.05$ by Tukey's pairwise comparison test.

Table 2. Duration up to first adult emergence of indoor-reared *B. ignitus* by different photoperiod

Photoperiodic regimes	Duration up to adult emergence					
	Worker[1)]	n[2)]	Male[1)]	n[2)]	Queen[1)]	n[2)]
0 L	25.4±3.5	10	44.4±14.4	27	92.8±18.8	6
8 L	24.9±4.0	16	42.9±15.3	34	79.9±26.1	7
16 L	26.8±4.0	18	47.2±14.8	34	92.6±26.9	8

[1)]The figures stand for means±SD. There were no significant differences in durations up to the first adult emergence.
[2)]n means the number of colony surveyed.

Table 3. Number of adults produced from queen of indoor-reared *B. ignitus* by different photoperiod

Photoperiodic regimes	Number of adults produced[3)]					
	Worker[1)]	n[2)]	Male[1)]	n[2)]	Queen[1)]	n[2)]
0 L	94.0±25.7	4	193.0±27.8	4	16.0±19.5	9
8 L	107.9±18.6	7	344.0±129.8	7	11.9±13.6	10
16 L	85.1±22.7	8	325.0±159.1	8	16.0±27.8	9

[1)]The figures stand for means SD. There were no significant difference in number of adult emergence.
[2)]n means the number of colony surveyed.
[3)]The number of workers and males produced was surveyed with more than 50 workers emerged colony.

132 − 151 numbers less than those at 8L and 16L, but there was no statistical difference between them at $\alpha = 0.05$ ($F = 1.40$, $p = 0.280$). The number of queens produced at 8L-rearing was 11.9 ± 13.6 numbers, and the value was four numbers less than those at 0L and 16L but statistical difference was not detected between them ($F = 0.14$, $p = 0.872$). The number of progenies produced in this experiment was much less than that of the post-hibernated queens in the field (Yoon *et al.*, 1999) and artificially overwintered queens in the laboratory (Yoon *et al.*, 2003). The difference between two experiments may have stemmed because we used CO_2-treated queens as experimental insect for this experiment. The results of CO_2 narcosis procedures on *B. terrestris* queens are variable and the treatment does not always reach at an optimum efficiency, sometimes causing detrimental side effects (Tasei, 1994). It has also been reported that CO_2 causes the emergence of males in advance in the first brood and decreases colony development (Röseler, 1985).

In view of the results so far achieved, light condition, specifically 16L, exerted a greater stimulation on colony development than dark condition (0L) in addition to ovipostion rate, preoviposition period, rate of colony foundation and rate of progeny-queen production. In case of *B. terrestris*, delays to oviposition were shortened and the period from the start of brooding attitude to oviposition was also significantly reduced by the 8L-rearing condition compared with constant dark (Tasei and Aupinel, 1994; Yoon *et al.*, 2003).

It is not clear whether the upper discrepancy that the effect of photoperiodic regimes of on oviposition and colony development of *B. ignitus* and *B. terrestris* is caused by a species-specific characteristic or insufficient investigation on the optimum photoperiod. further experiment can clearly this issue. The present results indicate that the light conditions (8L and 16L) are more suitable for oviposition and colony development for *B. ignites* in indoor rearing than at dark condition.

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