Int. J. Indust. Entomol. Vol. 9, No. 1, 2004, pp. 95~99

International Journal of
Industrial Entomology

Correlation between Body Weight and Colony Development of the Bumblebee Queen, *Bombus ignitus*

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(Received 9 July 2004; Accepted 24 August 2004)

This study was carried out to investigate the effect of body weight of queen on the developmental characteristics of foundation queens in the *Bombus ignitus* collected in Korean locality. Queens were classified into six groups based on their body weight (*i.e.,* 0.4 g, 0.5 g, 0.6 g, 0.7 g, 0.8 g and 0.9 g). The average weight of 200 foundation queens collected was 0.657 ± 0.095 g and 0.6 g-class was most abundant (38%) among six weight classes. The queen that had the heavy body weight showed the trends of higher rate of oviposition, colony foundation and progeny-queen production and shorter periods of preoviposition and colony foundation, suggesting the positive correlation between the body weight of queen and colony developmental characteristics. Also, the numbers of worker and progeny-queen emerged from the queen with heavy body weight were slightly higher than those with light body weight queen.

Key words: Bumblebee, *Bombus ignitus*, Body weight, Colony development

Introduction

The bumblebee is an important pollinator of various greenhouse crops, especially for tomatoes and there has been increasing interest in commercial use of the insects for pollination (Free, 1993). Recent advances in commercial rearing of the European bumblebee (*Bombus terrestris*) made it possible to package bumblebee for crop pollination (Masahiro, 2000). Bumblebees are distributed world widely including alpine, cool temperate and even arctic environments of the northern continents (Williams, 1989).

Bumblebee colonies are short-lived and new colonies start each year. Queens are the only caste to overwinter (enter diapause), and workers and males die during late summer and early autumn. In early spring queens that overwinterd leave their hibernation sites. The queen builds up a store of pollen and lays her first batch eggs into the pollen mass after searching a suitable site to found a colony. As soon as the workers of the first brood have emerged they take over the foraging actives of the queen, who from now on spends her time predominantly on the laying of eggs. In the late summer, many males and new queens are produced and only mated queens hibernate and emerge in spring (Heinrich, 1979; Duchateau and Velthusis, 1988).

Body size is one of the most important life history characters of the organism. Its effects on fitness are well documented and have been extensively studied both theoretically and empirically (Calder, 1984; Schmidt-Nielsen, 1984; Roff, 1992). Body size evolution is one of the dominant features of evolution in many lineages of animals and also body weight like body size is considered as a relevant index for evaluating insect reproduction and development (McShea, 1988). In bumblebee, variations in the size of morphological characteristics of pollinators can affect their ability to extract rewards from flowers of different sizes and may affect pollen collecting behaviors (Brian, 1952; Free and Butler, 1959; Dafni and Kevan, 1997; Stout, 2000). Bumblebee pollinators show body size variation at a range of scales: body size varies among species, within the same species and even among individuals within a single colony (Alford, 1978; Cnaani and Rush, 1994). The average size of workers is thought to increase as the season progresses (Plowright, 1968). In the case of *B. terrestris*, the chance of surviving from dia-

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pause is strongly determined by the wet weight of the queen at the beginning of hibernation. Queens with a low weight (less than 0.6 g) do not survive diapause (Beekman *et al.*, 2000).

We chose *Bombus ignitus* out of seven Korean native bumblebees, because the species showed the best results both in artificial multiplication and in pollinating ability (Yoon *et al.*, 1999). Now, we are studying an artificial year-round mass rearing of *B. ignitus* selected as the most reliable native species in crop pollination (Yoon *et al.*, 2002; Yoon and Kim, 2003). Therefore, this study was conducted to identify whether colony development of collected *B. ignitus* queens would be affected by the body weight as basic research data for breeding bumblebee.

Materials and Methods

Collection of the post-hibernated queens

The post-hibernated queens of the Korean native bumblebee, *B. ignitus*, were collected in Jeongseon, Korea from April 15 to April 17 in 2003. These bumblebees did not start brood rearing (no pollen gathering) and visit to the blossom of *Corydalis speciosa* (Fumariaceae). The queens collected in the field were confined in round plastic containers (7.5 cm in diameter and 5.5 cm in depth; two or three queens per container), and supplied with 50% honey solution until they moved into the nest initiation boxes. The duration from collection up to the start of rearing was within one day.

Indoor rearing

The basic colony-rearing technique was followed as described in Yoon et al. (2002). The collected queens were reared in three types of cardboard (1.5 mm thick) boxes each for nest initiation (10.5 × 14.5 × 6.5 cm: small box), colony foundation (21.0 × 21.0 × 15.0 cm: medium box), and colony maturation (24.0 × 27.0 × 18.0 cm: large box). 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 collected in the field were first confined individually in small boxes for colony initiation and remained there until oviposition. 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.

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

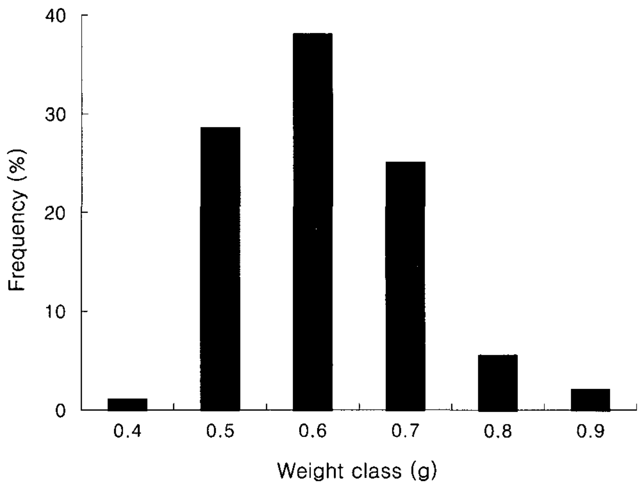

Fig. 1. Frequency distribution of the weight of foundation queens of *Bombus ignitus*. The total numbers of queen is 200 and the average weight with the standard deviation is 0.657 ± 0.095 g. The body weight of queens was classified with six weight classes: 0.4 g (0.40 – 0.49 g), 0.5 g (0.50 – 0.59 g), 0.6 g (0.60 – 0.69 g), 0.7 g (0.70 – 0.79 g), 0.8 g (0.80 – 0.89 g) and 0.9 g (0.90 – 0.99 g).

Frequency distribution of body weight and relationship between body weight and colony developmental characteristics of *B. ignitus* queen

To investigate developmental characteristics of *B. ignitus* depending on the body weight of the queen, we classified 200 foundation queens into six weight classes with the weight ranging from 0.4 g to 0.9 g (Fig. 1). In detail, the body weight of queens was classified 0.4 g (0.40 – 0.49 g), 0.5 g (0.50 – 0.59 g), 0.6 g (0.60 – 0.69 g), 0.7 g (0.70 – 0.79 g), 0.8 g (0.80 – 0.89 g) and 0.9 g (0.90 – 0.99 g). The numbers of queens allotted to each weight class were 2 in 0.4 g, 57 in 0.5 g, 76 in 0.6 g, 50 in 0.7 g, 11 in 0.8 g, and 4 in 0.9 g, respectively. The developmental ability of each colony was estimated by rate of oviposition, colony foundation and progeny-queen foundation, production of progeny, and period up to first adult emergence. Colony foundation here indicates that more than 50 workers emerged in a colony. Period up to first adult emergence designates the duration from the first oviposition to the first adult-emergence.

Statistical analysis was done with a one-way ANOVA test, Chi-square test and Tukeys pairwise comparison test (MINITAB Release 13 for Windows, 2000). The Chi-square test was used to compare the rates of colony development of *B. ignitus* by the body weight. Tukey's pairwise comparison test was used to examine the durations until colony foundation and first adult emergence, as well as the number of adults produced.

Results and Discussion

Frequency distribution of body weight of foundation queens of *B. ignitus*

To elucidate correlation between body weight and developmental characteristics of *B. ignitus*, we assorted 200 foundation queens by the body weight (Fig. 1). The average weight of queen was 0.657 ± 0.095 g. Among six weight classes, 0.6 g-class was highest (38.0%), 0.5 g-class was next (28.5%), and 0.7 g-class was third (25.0%). The number of queens included in 0.4 g- and 0.9 g-class among 200 post-hibernated queens were two (1.0%) and four (2.0%). The average weight of 364 queens of *B. terrestris* collected in other study was 0.829 ± 0.141 g and distributed into the range from 0.4 g to 1.2 g (Beekman *et al.*, 2002). The shape of its frequency distribution is very similar to the frequency distribution of the weights of 1,535 *B. terrestris* queens that were kept in a greenhouse by Holm (1972), whereas Holms study did not result in any queens with a weight above 1 g (1972). These previous studies suggest that the weight of post-hibernated queen of *B. ignitus* is lower than that of *B. terrestris*.

Developmental characteristics depending on body weight of post-hibernated queens of *B. ignitus*

We investigated correlation between the body weight and developmental characteristics, rates of oviposition, colony foundation and progeny-queen production, of *B. ignitus* queen (Fig. 2). In rate of oviposition, the foundation queens of 0.8 g-class showed the best performance as 100.0% among six weight classes and decreased in the order of 0.6 g, 0.5 g, 0.7 g, 0.9 g and 0.4 g-class. 0.9 g- and

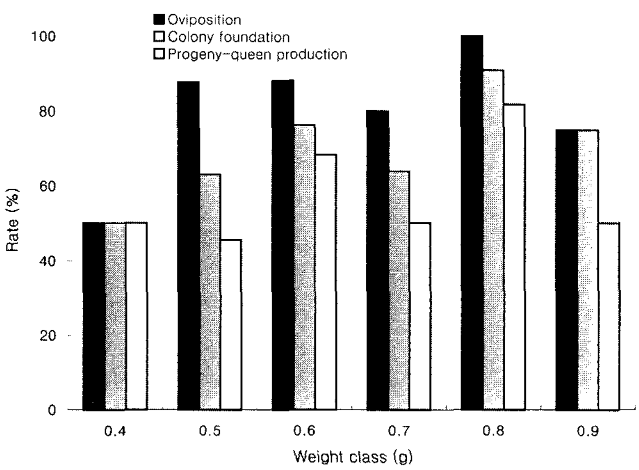

Fig. 2. Comparison of colony development of *B. ignitus* depending on body weight of queen. Rate of progeny-queen production are significantly different at $p < 0.05$ by Chi-squared test.

0.4 g-class were 2.0 fold lower than that of 0.8 g-class. But ovipositon rate of *B. ignitus* was not affected by the body weight of queen except for 0.4 g and 0.9 g, which has less five individual in the number of queens surveyed (Chi-squared test: $x^2 = 3.799$, df = 3, $p = 0.284$).

In case of rate of colony foundation, the foundation queens of 0.8 g-class showed the best performance as 90.9% among groups, and it was 1.8 fold higher than that of 0.4 g-class (Fig. 2). The rates of colony foundation of 0.6 g- and 0.9 g-class were 76.3% and 75.0%, respectively and decreased in the order of 0.7 g, 0.5 g and 0.4 g-class. The rates of colony foundation of *B. ignitus* were not statistically significant among groups depending on body weight of queen either (Chi-squared test: $x^2 = 5.872$, df = 3, $p = 0.118$).

Rate of progeny-queen production was also compared depending on the body weight. As shown Fig. 2, the rates of progeny-queen production of the foundation queens of 0.8 g-class showed the best performance as 81.5% among six weight classes and that of 0.6 g was 68.4%. But those of the other four classes groups were under 50.0%. There was statistically correlation between rate of progeny-queen and the body weight (Chi-squared test: $x^2 = 10.829$, df = 3, $p = 0.013$). With above results, we supposed that colony development of *B. ignitus* was affected by the body weight. Beekman *et al.* (2000) mentioned that the bumblebee, *B. terrestris*, the chance of surviving from diapause is strongly determined by wet weight of the queen at the beginning of hibernation. Queens with a low weight (less than 0.6 g) do not survive diapause.

Table 1 shows the durations up to preoviposition, colony foundation and first adult emergence of *B. ignitus* by the body weight. The preoviposition periods of 0.8 g-class was the shortest (4.36 ± 1.29 days) among groups. It was 3.8 – 4.4 days shorter than those of 0.5 g and 0.6 g-class and prolonged in the order of 0.9 g, 0.7 g, 0.6 g and 0.5 g-class. However the preovipositon period was not affected by the body weight of queen (Tukey's pairwise comparison test, F = 0.89, df = 5, 166, $p = 0.491$). *B. ignitus* queen that oviposited first batch of eggs early could make colony stronger and could make colony foundation period shorter (Yoon *et al.*, 2004).

In periods of colony foundation, durations up to colony foundation of queens of 0.8 g- and 0.9 g-class were 46.50 ± 3.37 and 46.33 ± 3.06 days, respectively. It was 2 – 3 days shorter than those of other classes, which ranged from 49 to 50 days. However, statistical analysis did not support the difference of the duration of colony foundation among groups. Thus, the duration up to colony foundation was not affected by the body weight (Tukey's pairwise comparison test, F = 1.22, df = 5, 130, $p = 0.302$) (Table 1).

Table 1. Duration up to preoviposition, colony foundation, and adult emergence from foundation queens of *B. ignitus* by the weight of queens

Weight class[a] (g)	n[b]	Preovipositon (days)[c]	n[b]	Colony Foundation (days)[c]	First adult emergence (days)[c]					
					n[b]	Worker	n[b]	Male	n[b]	Queen
0.4	2	8.0	1	48	1	23	40	73	1	73
0.5	50	8.80 ± 5.97	35	49.71 ± 5.88	41	23.0 ± 3.58	44	71.6 ± 11.61	32	79.8 ± 8.99
0.6	67	8.19 ± 8.12	56	49.32 ± 6.25	62	22.5 ± 2.96	18	71.0 ± 13.79	52	79.1 ± 8.99
0.7	40	7.53 ± 6.30	31	48.81 ± 4.43	33	22.0 ± 2.48	12	70.9 ± 11.07	28	82.8 ± 11.76
0.8	11	4.36 ± 1.29	10	46.50 ± 3.37	10	21.9 ± 4.09	3	73.3 ± 5.98	9	79.6 ± 6.54
0.9	3	5.67 ± 2.31	3	46.33 ± 3.06	3	21.3 ± 2.08	5	58.3 ± 31.66	2	75.5 ± 2.12

[a]For weight class, see legend to Fig. 1.
[b]n means the number of colony surveyed.
[c]The figures stand for means SD. There were no significant differences in duration up to preoviposition, colony foundation, and adult emergence from foundation queens at $p < 0.05$ by Tukey's pairwise comparison test.

The durations up to first worker emergence at 0.4 g to 0.9 g-class were 21 – 23 days. The period of first worker emergence was not different at $p < 0.05$ by Tukey's pairwise comparison test. In case of first male emergence, 0.9 g-class was 58.3 days, and this estimate was about 12 – 15 days shorter than those of other groups although there was no statistical difference (Tukey's pairwise comparison test, $F = 0.72$, $df = 5, 140$, $p = 0.607$). For queens of 0.4 g-class, the periods up to first queen emergence was 12 – 15 days short than those at other classes. But the duration up to first queen emergence also did not differ by the body weight (Tukey's pairwise comparison test, $F = 0.77$, $df = 5, 116$, $p = 0.572$). The durations up to first emergence of worker, male and queen of *B. ignites* collected from the field was 18.90 ± 1.16, 68.96 ± 3.94 and 71.14 ± 6.88 days (Yoon *et al.*, 1999).

The number of adults produced from foundation queens depending on the body weight is shown in Table 2. In case of the number of worker produced from foundation queen, the number of worker produced at 0.8 g-class was 171.00 ± 20.17 and these values were 5 – 51 numbers more than those of other classes but the number of worker produced from foundation queen was not affected by body weight (Tukey's pairwise comparison test, $F = 0.59$, $df = 5, 135$, $p = 0.705$). The number of male produced from foundation queen of five classes except for 0.4 g-class was 220 – 240, and the numbers were not significantly different at $p < 0.05$. In case of the number of queens produced from foundation queen, the queen of 0.9 g-class produced their progeny queen well comparing with those at other classes. Particularly, 0.9 g-class produced 142.00 ± 107.48 queens, which corresponded to 3.7 – 4.3 fold of those at 0.5 g, 0.6 g and 0.7 g-class. The number of queen produced from foundation queen was significantly different depending on body weight at $p < 0.001$ (Tukey's pairwise comparison test, $F = 9.23$, $df = 5, 111$, $p = 0.001$). Longevity of foun-

Table 2. Number of adults produced from foundation queens of *B. ignitus* and by the weight of queens

Weight class[a] (g)	Number of adults produced						n[b]	Longevity of foundation queen (days)[c]
	n[b]	Worker[c]	n[b]	Male[b]	n[b]	Queen[c]		
0.4	1	120	1	194	1	69 ab	2	57.50 ± 63.50
0.5	36	158.2 ± 34.83	36	240.4 ± 103.16	26	34.27 ± 38.46 ab	54	78.74 ± 35.59
0.6	59	155.3 ± 40.05	59	223.6 ± 95.4	32	38.42 ± 45.21 ab	67	89.25 ± 28.78
0.7	32	153.4 ± 36.12	32	220.2 ± 97.31	25	32.84 ± 35.19 ab	47	74.96 ± 40.84
0.8	10	171.0 ± 20.17	10	221.0 ± 83.76	9	72.00 ± 4.73 ab	11	80.18 ± 29.70
0.9	3	165.7 ± 72.60	3	228.0 ± 46.51	2	142.00 ± 107.48 a	2	89.50 ± 7.78

[a]For weight class, see legend to Fig. 1.
[b]n means the number of colony surveyed.
[c]The figures stand for means SD. Means followed by different letters in the same column are significantly different at $p < 0.001$ by Tukey's pairwise comparison test.

dation queens of 0.4 g-class was 57.50 ± 63.50 days, which is 17 − 32 days shorter than those of the other classes though there was no significant difference by body weight (Tukey's pairwise comparison test, F = 1.19, df = 5, 177, $p = 0.315$).

In view of the results so far archived, the queen that had the heavy body weight showed higher at rate of oviposition, colony foundation and progeny-queen production and shorter at periods of preoviposition and colony foundation. And also, the numbers of worker and progeny-queen emerged from the queens with heavy body weight were slightly higher than those with light body weight queen though there was no statistical difference in case of the number of worker. *B. terrestris* queen with a wet weight below 0.6 g can successfully start a colony, whereas diapsusing queens with the same wet weight did not survive (Beekman *et al.*, 1998). *B. terrestris* queen with a wet weight of 1 g or more were no longer produced after several generations at rearing under controlled conditions in the laboratory. This suggests that the disappearance of heavy queens is caused by a deficiency of scare nutrients (Beekman *et al.*, 2000).

In conclusion, the present results indicate that colony developmental characteristics of queen that had the heavy body weight were better than those of the light weight body queen. Therefore, the body weight of foundation queen was suggested to be a criterion for the selection of superior colonies when *B. ignitus* if indoor-reared.

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