Crop Pollination by Japanese Bumblebees, *Bombus* spp. (Hymenoptera: Apidae): Tomato Foraging Behavior and Pollination Efficiency¹

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Buzz-pollination of tomato (*Lycopersicon esculentum* MILL) by four native species of Japanese bumblebees (*Bombus hypocrita hypocrita* PÉREZ, *B. ignitus* SMITH, *B. ardens ardens* SMITH, and *B. diversus diversus* SMITH) was examined. A high (84–100%) fruiting rate and almost no puffy fruit (0–7%) resulted from pollination by the Japanese bumblebees. There was no difference in the pollination efficiency between the imported non-native bumblebee (*B. terrestris*) and Japanese bumblebees. Pollination of tomato crops using native bumblebees is recommended because there are no ecological risks.

Key words: *Bombus*, bumblebee, buzz-pollination, pollinator, tomato

INTRODUCTION

Farmers depend greatly on natural pollinators. Several pollinators, such as the honey-bee (*Apis mellifera*), leaf-cutter bee (*Megachile rotundata*) and osmia mason bee (*Osmia cornifrons*) have been used as crop pollinators (FREE, 1993; MAETA and KITAMURA, 1981). Queens of the bumblebee (*Bombus* spp.) were taken from England to New Zealand in 1885 (DONOVAN, 1993) for crop pollination, and recently, the long-tongued bumblebee (*B. ruderatus*) has been exported from New Zealand to Chile for red-clover pollination (ARRETZ and MACFARLANE, 1986). Commercial year-round rearing of bumblebee (*B. terrestris*) colonies (RÖSELER, 1985) permits year-round pollination of greenhouse tomatoes (*Lycopersicon esculentum* MILL). Tomato pollination by *B. terrestris* imported from Europe has spread rapidly in Japan. Use of these pollinators saves labor and produces high quality fruit (IWASAKI, 1995). But imports of *B. terrestris* may result in competition with the 15 native Japanese bumblebee species and spread of non-endemic diseases and parasites (MACFARLANE et al., 1995). Trade transplantation of non-native species can harm native fauna and flora (ONO, 1994, 1995). Nine out of the 15 Japanese species of bumblebee can be reared in the laboratory (ONO et al., 1994). Consequently, this study compared the tomato pollination efficiency of four native Japanese species (*Bombus hypocrita hypocrita* PÉREZ, *B. ignitus* SMITH, *B. ardens ardens* SMITH, and *B. diversus diversus* SMITH) with one imported species (*B. terrestris*) as a step towards establishing a pollination system utilizing Japanese bumblebees.

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Table 1. Periods and tomato cultivars in bumblebee foraging experiments

Bumblebee species	Period	No. workers	Tomato cultivar
<i>B. ardens</i>	1–8 June	10–15	momotaro
<i>B. diversus</i>	26–28 Nov.	30–40	momotaro T93
<i>B. hypocrita</i>	12 Sep.–3 Oct.	30–45	momotaro T93
<i>B. ignitus</i>	13 Sep.–9 Oct.	45–80	momotaro T93
<i>B. terrestris</i>	26–31 Oct.	105	momotaro T93

MATERIALS AND METHODS

1. *Bumblebee colonies.* Colonies of *B. hypocrita hypocrita* and *B. ignitus* were reared in a laboratory from post-hibernating queens according to ONO et al. (1994) and ONO et al. (in preparation). Twenty *B. hypocrita* queens were collected from Oshino-mura, Yamanashi Prefecture on 13 and 20 May 1995, and 11 *B. ignitus* queens were collected from Shinanomachi, Nagano Prefecture on 23 May 1995.

Colonies of *B. ardens ardens* and *B. diversus diversus* were collected in Machida-shi, Tokyo on 25 May and in Tsukui-machi, Kanagawa Prefecture on 18 September 1995.

Commercial colonies of *B. terrestris* were purchased (Koppert Co., The Netherlands). All species were kept in the same type of nest box (250 mm × 175 mm × 120 mm) at 26 ± 1°C.

2. *Pollination experiment.* We used three net enclosures in a field and in a greenhouse for pollination experiments. The field cage (2 m × 2 m × 2 m) was constructed of 1.3-mm nylon mesh containing 2–5 potted tomato plants (momotaro, minicarroll cultivar). A bumblebee colony was placed in the cage and the occurrence of foraging was checked by the presence of bite marks on tomato anthers. The greenhouse net cages (2 m × 3 m × 2 m and 1.8 m × 3.6 m × 1.8 m) were constructed of 2-mm cloth mesh containing 10 tomato plants (momotaro T93 cultivar). The potted tomato plants were transferred to the cages before flowering. Bumblebee foraging behavior was observed for 3–8 h, and classified into four categories: 1. Buzzing on flower and hanging on anther; 2. Grooming pollen grains adhering to leg hairs while hanging on flower; 3. Flight from flower-to-flower; 4. Flight towards outside of cage and resting. After observation, bumblebees outside the colony were collected and returned with the colony to the laboratory. The experiment period and conditions are described in Table 1.

3. *Evaluation of pollination efficiency.* We examined the fruiting and incidence of puffy fruits resulting from pollination by the five species of bumblebees. The fruiting rate was calculated 10 days after buzzing to preclude fruit abscission. Fruiting data was also recorded for unbuzzed tomato plants reared under the same conditions. Individual flowers were numbered using flowering order and position of flower truss. The incidence of puffy fruit was investigated by horizontal sectioning of tomatoes. For comparison, tomatoes that fruited by spraying with plant growth regulator (4-CPA) used widely in Japan for tomato production were examined.

Bombus ignitus

Bombus diversus diversus

Bombus hypocrita hypocrita

Bombus ardens ardens

Fig. 1. Japanese bumblebees buzz foraging on tomato flowers.

RESULTS

1. Foraging behavior of five bumblebee species

Figure 1 shows the four native species buzz-pollinating tomatoes. When bumblebees first left the colony, they tried to leave the cage, but on subsequent days, they flew well in the confined space. The time to first foraging on tomatoes took 2–4 days (Table 2). When this colony was examined again after a break of 2 days, the workers took 23 ± 3 (mean $\pm$ S.D.) min to begin foraging. Once workers had experienced foraging on tomatoes, the time to landing on tomato flowers was much reduced. At the first visit, workers of all five species licked the flower with the proboscis. After several repetitions of this behavior, they hung on the anther and vibrated their body rapidly. MATSUURA (1993) described this pollen collection by *B. terrestris* as “buzz-foraging,” which plays an important role in tomato pollination. The four native bumblebees showed the same buzz-foraging behavior as *B. terrestris*. When

Table 2. Days to the start of foraging by bumblebee colonies on tomato flowers

Bumblebee species	Days after start of foraging test							
	0	1	2	3	4	5	6	7
<i>B. ardens</i>	×	×	×	○				
<i>B. diversus</i> ^a	○	○						
<i>B. hypocrita</i> ^b	×	—	—	×	—	—	—	○
<i>B. hypocrita</i> ^b	×	—	×	○				
<i>B. hypocrita</i> ^b	×	×	○					
<i>B. ignitus</i>	×	×	○					
<i>B. terrestris</i>	×	—	×	×	○			

○ : Bees observed foraging. × : Bees not observed foraging. — : No observation.

^a *B. diversus* colony used in this observation had experienced buzz-foraging on tomato flowers.

^b Three different colonies of *B. hypocrita*.

Table 3. Duration of behavioral categories and number of flowers visited per minute by five bumblebee species

Bumblebee species	Duration of behavioral category (s) ^a			No. flowers visited per minute
	Buzzing	Grooming	Flight	
<i>B. ardens</i>	5.4 a (n = 77)	—	5.9 ab (n = 46)	4.6
<i>B. diversus</i>	7.5 ab (n = 46)	5.5 ab (n = 9)	4.5 a (n = 36)	4.2
<i>B. hypocrita</i>	12.0 bc (n = 39)	4.0 ab (n = 23)	9.4 c (n = 69)	3.6
<i>B. ignitus</i>	11.5 c (n = 40)	7.5 a (n = 15)	15.0 c (n = 34)	1.9
<i>B. terrestris</i>	8.5 bc (n = 52)	2.9 b (n = 24)	8.9 bc (n = 34)	3.5

^a Means followed by a different letter in the same column are significantly different at $p < 0.01$ by MANN-WHITNEY *U*-test.

Table 4. Fruiting rate and incidence of puffy fruit

Treatment	Fruiting (%)	No. fruits examined	Incidence of puffy fruit (%)					
			0	1	2	3	4	5 ^a
Pollinated by bumblebees								
<i>B. ardens</i>	100 (<i>n</i> = 28)	24	88	12	0	0	0	0
<i>B. diversus</i>	84 (<i>n</i> = 57)	24	83	17	0	0	0	0
<i>B. hypocrita</i>	94 (<i>n</i> = 62)	43	81	9	2	5	2	0
<i>B. ignitus</i>	86 (<i>n</i> = 91)	66	74	15	6	3	2	0
<i>B. terrestris</i>	88 (<i>n</i> = 75)	59	86	14	0	0	0	0
Spraying with 4-CPA	82 (<i>n</i> = 33)	42	38	19	17	17	2	7
No treatment	17 (<i>n</i> = 76)	13	92	8	0	0	0	0

^a Grade of puffiness

0 1 2 3 4 5
 mature ←————→ puffy

buzzing, the native bees also bite the anther in the same manner as *B. terrestris*. There were, however, some difference in the duration of the behavioral categories among the species. Buzz-foraging by *B. ardens* was shorter than that by *B. hypocrita*, *B. ignitus* and *B. terrestris* ($p < 0.01$ MANN-WHITNEY *U*-test). The duration of “grooming” by *B. ignitus* was significantly longer than that by *B. terrestris* ($p < 0.01$ MANN-WHITNEY *U*-test). The duration of “flight” differed significantly ($p < 0.01$ MANN-WHITNEY *U*-test) between *B. ardens*, *B. diversus* and *B. hypocrita*, *B. ignitus*. This duration by *B. ignitus* tended to be longer than that by *B. hypocrita*, *B. terrestris* ($p < 0.05$ MANN-WHITNEY *U*-test). The number of flowers visited each minute by *B. ignitus* was 1.9, which was less than that visited by other species (Table 3).

2. Tomato pollination efficiency of Japanese bumblebees

The fruiting rate of the native bumblebees and *B. terrestris* was 84–100% and there was no difference (Table 4) between species. All the tomato fruits formed seeds and there was no difference in the incidence of puffy fruits (0–7%) which ripened after the peak harvest. On the other hand, the rate of puffy fruits (grade 3–5) formed after treatment by spraying with 4-CPA was 26% and these fruits were mixed with mature fruit (grade 0–2) during the harvest season.

DISCUSSION

It is generally believed that bumblebee foragers do not communicate information about food sources to nestmates when returning from foraging (ALFORD, 1975). HEINRICH (1976) demonstrated that bumblebees select flowers with the highest benefit when foraging on several plant species, suggesting that an individual worker bumblebee has high flexibility in choosing forage flora. Consequently, each bumblebee may have the ability to adapt to foraging on tomato flowers. We confirmed that the duration of buzzing on tomato flowers decreased with experience of visiting the target flower. It may be possible to control flower selection by “training” bumblebees to pollinate other specific crops.

B. ignitus visited fewer flowers than the other four species, which may be related to its

flight habits. KATAYAMA and OCHIAI (1980) described that *B. ignitus* flew higher in the air than other bumblebees. *B. ignitus* may be more influenced by the small flight space than the other four species.

B. terrestris is a useful pollinator of tomato flowers but the four native bumblebees have the same pollination efficiency as *B. terrestris*. There was no difference between the native Japanese bumblebees and *B. terrestris* in fruiting rate and incidence of puffy fruit. Successful laboratory rearing of Japanese bumblebees (ONO et al., 1994; ONO et al., in preparation) promotes the development of a new pollination system utilizing native bumblebees instead of introduced non-native *B. terrestris*, and will thereby reduce the risk of ecological problems.

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REFERENCES

- ALFORD, D.V. (1975) *Bumblebees*. Davis-Poyner, London, 352 pp.
- ARRETZ, P.V. and R.P. MACFARLANE (1986) The introduction of *Bombus ruderatus* to Chile for red clover pollination. *Bee World* **67**: 15–22.
- DONOVAN, B.J. (1993) History and utilization of imported bumblebees in New Zealand. *Honeybee Sci.* **14**: 145–152 (in Japanese).
- FREE, J.B. (1993) *Insect Pollination of Crops*, 2nd ed. Academic Press, London, 684 pp.
- HEINRICH, B. (1976) The foraging specializations of individual bumblebees. *Ecol. Monogr.* **46**: 105–128.
- KATAYAMA, E. and H. OCHIAI (1980) On the locating and collecting techniques of bumblebee nests (Hymenoptera, Apidae). *Seibutu Kyouzai* **15**: 45–63 (in Japanese).
- IWASAKI, M. (1995) Introduction of commercial bumblebees into Japan. *Honeybee Sci.* **16**: 17–23 (in Japanese).
- MACFARLANE, R.P., J.J. LIPA and H.J. LIU (1995) Bumble bee pathogens and internal enemies. *Bee World* **76**: 130–148.
- MAETA, Y. and T. KITAMURA (1981) Pollinating efficiency by *Osmia cornifrons* (RADOSZKOWSKI) in relation to required number of nesting bees for economic fruit production. *Honeybee Sci.* **2**: 65–72 (in Japanese).
- MATSUURA, M. (1993) Pollination of tomato plants with the introduced bumble bee, *Bombus terrestris*. *Shokubutu bōeki* **47**: 173–176 (in Japanese).
- ONO, M. (1994) Crop pollination with the bumblebees in Japan—its present and future—. *Honeybee Sci.* **15**: 107–114 (in Japanese).
- ONO, M. (1995) Bumblebees and biological control agents. *Insectarium* **32**: 4–9 (in Japanese).
- ONO, M., M. MITSUHASHI and M. SASAKI (1994) Use of introduced *Bombus terrestris* worker helpers for rapid development of Japanese native *B. hypocrita* colonies (Hymenoptera, Apidae). *Appl. Entomol. Zool.* **29**: 413–419.
- RÖSELER, P.F. (1985) A technique for year-round rearing of *Bombus terrestris* (Apidae, Bombini) colonies in captivity. *Apidologie* **16**: 165–170.