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# Distance from migratory honey bee apiary effects on community of insects visiting flowers of pumpkin

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## Abstract

Honey bee, *Apis mellifera* L., plays a fundamental role in ecosystems through pollination, not only in feral plant communities but also in agricultural fields, where honey bees increase production and improve crop quality. Nevertheless, the relative importance of honey bees as a pollinator, an important task of honey bees in agricultural fields, remains unknown for most crops. Many Japanese beekeepers transfer their bees during summer to central Hokkaido in northernmost Japan because of its ample flowers. To reveal the relative abundance of honey bee as flower visiting insects in central Hokkaido agricultural fields, we examined the community of flower visiting insects at 14 fields growing pumpkins, *Cucurbita maxima* Duchesne, and the affecting factors of the community. Most flower visiting insects (93.7%) captured in pumpkin flowers were honey bees. Bumblebees (*Bombus diversus tersatus* Smith, *Bombus hypocrita sapporoensis* Cockerell), other bees (*Lasioglossum sibiriacum* Bluthgen), and hoverflies (*Syritta pipiens* L., *Sphaerophoria indiana* Bigot) were main non-*Apis* flower visiting insects. Rates of visits by honey bees and by all flower visiting insects to pumpkin flowers were negatively related with the distance separating the pumpkin fields from apiaries ($P < 0.01$, $P < 0.01$, respectively, GLMM). No significant negative relation between the number of honey bee visits and those of other flower visiting insects was detected ($P = 0.20$, GLMM), suggesting that honey bees do not compete with other flower visiting insects for pumpkin flowers. These results suggest that bees transferred to Hokkaido were the most common flower visiting insects in pumpkin fields of Hokkaido, and that the smaller the distance from the apiary to pumpkin field becomes, the more honey bees and more increased pumpkin production can be anticipated.

**Key words:** honey bee, *Apis mellifera*, pumpkin, pollinator, *Cucurbita maxima*, beekeeping.

## Introduction

Local and regional declines in the diversity and abundance of pollinators have been reported worldwide (Steffan-Dewenter *et al*., 2002; Kremen *et al*., 2002; Biesmeijer *et al*., 2006; Goulson *et al*., 2008; Ricketts *et al*., 2008; van Engelsdorp *et al*., 2008; Williams and Osborne, 2009; Winfree and Kremen 2009; Garibaldi *et al*., 2011). Although Ghazoul (2005) questioned the decline, asserting that it has occurred only within limited areas and taxonomic groups, literature presenting the opposite perspective has been accumulating (e.g., Biesmeijer *et al*., 2006). Consequently, recent declines in wild and domesticated pollinators attributed to habitat loss, habitat fragmentation, introduction of alien species, intensification of agriculture, and those causes' mutual interactions are widely recognized (Steffen-Dewenter *et al*., 2005; Potts *et al*., 2010), although uncertainty about declining pollinator-pollination activity remains. Because pollination is a key part of ecosystem services, with empirical assessments showing increased production with pollinators in 92 out of 108 leading global food crops (Klein *et al*., 2007), the decline in pollinators is fostering anxiety worldwide (Potts *et al*., 2010). To preserve and use ecosystem services by pollinators through pollination, the pollinator community in agricultural fields and the factors determining the community of pollinators must be elucidated. Unfortunately, knowledge related to pollinator communities and their determining factors remains insufficient for many crops (Kremen *et al*., 2002; Klein *et al*., 2007).

Pumpkin, *Cucurbita maxima* Duchesne, is a monoecious annual plant that requires insect visitors to transfer pollen among conspecifics for successful pollination (Walters and Taylor, 2006; Nicodemo *et al*., 2009). It is of great economic interest, being used as food among humans, as an energy source, as livestock food, and as a source of beta carotene (Nicodemo *et al*., 2009). Although squash bee, *Peponapis pruinosa* Say, and carpenter bees, *Xylocopa* spp., are the most efficient pollinators of pumpkin in terms of pollination efficiency per individual, honey bee, *Apis mellifera* L., is also a particularly important pollinator, especially in areas where other bees are absent (Hurd, 1964). For commercial production of pumpkins, honey bees are the only effective pollinator that can be provided in sufficient numbers for adequate pollination (Free, 1993). Walters and Taylor (2006) reported that addition of a honey bee hive to a field (of size 12 m long × 12 m wide, or 6 m wide) of pumpkin increased the quantity of set-fruit by 62% and total fruit weight by 100% under field conditions where sufficient natural pollinators bumblebees (*Bombus* spp.), carpenter bees (*Xylocopa* spp.), and squash bees (*P. pruinosa*) freely visited pumpkin flowers. Consequently, honey bee colonies are rented in large numbers by pumpkin growers for the promotion of pumpkin pollination.

Migratory beekeepers transfer their apiaries for ample flowers to collect honey, or to grow bee colonies. Honey bees frequently forage within agricultural fields because visitation to crop flowers, opening simultaneously and abundantly, is efficient. In addition, foraging in proximate fields is more efficient than in distant fields, *caeteris paribus*. Therefore, optimal foraging theory predicts that the community of flower-visiting insects in crop fields is affected strongly by the distance between an apiary and a crop field. Nevertheless, few studies have examined the positional relation between apiaries and the community of flower visiting insects in a pumpkin field, although previous studies revealed appropriate numbers of bee colonies within pumpkin fields for sufficiency of pollination (Eckert, 1962; Wolfenbarger, 1962) and the addition of a honey bee hive within the field increased pumpkin production (Fuch and Müller, 2004; Walter and Taylor, 2006; Nicodemo *et al*., 2009).

This study was undertaken to examine the community of flower visiting insects and affecting factors of the community for *C. maxima* flowers in central Hokkaido, the northernmost main island of Japan, where many migratory beekeepers set bee hives during summer when pumpkins are in full bloom there. We particularly addressed the distance from the apiary to a pumpkin field as a factor shaping the community of flower visiting insects.

## Materials and methods

This study was conducted in *C. maxima* fields in Wassamu, central Hokkaido, Japan (44.01°-04°N, 142.35°-43°E; figure 1). The area produces pumpkin, rice (*Oryza sativa* L.), cabbage (*Brassica oleracea* L.), soybean (*Glycine max* L.), and includes secondary forests (*Picea jezoensis* Carriere, *Abies sachalinensis* Masters). Pumpkin is an important primary crop in Wassamu, both in terms of planted area (768 ha) and annual production (8260 t). Many Japanese migratory beekeepers transfer their bee colonies to the area because of its ample flowers, and its cool, dry weather during summer. In the area, we mapped all apiaries (total 220 hives) and arbitrarily chosen 14 pumpkin fields with various distances from the apiaries. Then we measured the distances between the pumpkin fields and the closest neighbouring apiaries using GPS (NVG-M2 YAMANAVI2; MOVEON Co. Ltd., Tokyo). Wild *A. mellifera* do not exist in Japan. No insecticide was applied in the pumpkin field during the study period.

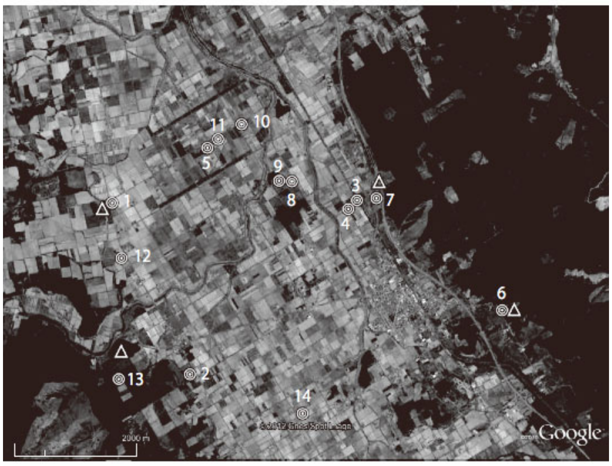


**Figure 1.** Area of study, locations and ID numbers of the 14 study fields of pumpkins (*C. maxima*) ◎ and locations of the apiary Δ.

Pumpkin is a monoecious plant with yellow showy pistillate and staminate flowers occurring singly in the axils of the leaves (Free, 1993). The seed set of pumpkin depends on insect pollination (Fuch and Müller, 2004; Nicodemo *et al*., 2009). Floral longevity is restricted to approximately 4 hr in the morning (Hoehn *et al*., 2008). The start of blooming in Hokkaido during the study period was approximately 5:00 AM (Tamura, 1959).

We established a 50 m or 100 m transect parallel to field margin, depending on the abundance of pumpkin flowers in a field. When a straight transect could not be established because of insufficient field length, two transects were established parallel to ridges. We sampled all insects visiting pumpkin flowers along the transect using an insect net during July 24 - August 1, 2011. Sampling was conducted only on days with clear weather and between 6:00 and 9:00 because pumpkin flower fertility drops after blooming, and no fruit set took place after 9:00 AM (Nicodemo *et al*., 2009). Each field was sampled twice. The order of sampling was randomized. Sampled insects were brought to a laboratory for subsequent identification. Specimens were deposited in a Honeybee Research Unit, NARO, National Institute of Livestock and Grassland Science.

### Statistical analysis

To assess whether the distance separating the apiary from pumpkin fields affected the pollination community on pumpkin flowers, we applied a generalized linear mixed model (GLMM; Wolfinger and O'Connell, 1993), assuming a binomial error structure and using the logit function. The response variable was visitation by insects (honey bees only, or all flower-visiting insects) to each pumpkin flower. The distance from the apiary to the field, and the pumpkin field were designated respectively as fixed and random effects. Numbers of pumpkin flowers per meter along the transect were also designated as fixed effects as an index of quantity in resources. To examine whether honey bees compete against other insects for pumpkin flowers, we also conducted statistical analysis using a GLMM with a Poisson error structure and a log link function. The number of non-honey bee insects was assigned to the response, and the number of honey bees sampled within a field and the number of pumpkin flowers per meter along the transect as an index of the quantity of resources were assigned to fixed effects. Pumpkin fields were assigned to random effects. All analyses were conducted using software (R ver. 2.11.1; R Development Core Team, 2010).

## Results

In total, 348 individuals of 14 species were sampled on the pumpkin flowers (table 1). Among insects visiting pumpkin flowers, Hymenoptera (97.1%) was predominant, but Diptera and Coleoptera were represented by few individuals: 7 (2.0%) and 2 (0.6%), respectively. Of Hymenoptera, *A. mellifera* was dominant, accounting for 93.7% of all flower visiting insects. *Bombus diversus tersatus* Smith, *Bombus hypocrita sapporoensis* Cockerell, *Lasioglossum sibiriacum* Bluthgen, *Lasioglossum*

**Table 1.** Community of flower visiting insects on pumpkin flowers in the 14 study fields in central Hokkaido, Japan during July 22 - August 1, 2011. Insects captured from two samples in the same field were combined.

| | ID of pumpkin field | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| No. flowers (Mean ± S.D.) | 117 ± 23 | 170 ± 21 | 27 ± 1 | 62 ± 1 | 57 ± 9 | 30 ± 17 | 59 ± 10 | 37 ± 14 | 96 ± 37 | 146 ± 27 | 48 ± 22 | 86 ± 25 | 83 ± 26 | 103 ± 37 |
| Distance to nearest neighbouring apiary (km) | 0.05 | 0.53 | 0.36 | 0.87 | 1.97 | 0.03 | 0.74 | 1.46 | 1.68 | 2.67 | 2.46 | 0.67 | 0.39 | 2.13 |
| **Honey bees** | | | | | | | | | | | | | | |
| *Apis mellifera* | 62 | 85 | 14 | 13 | 3 | 28 | 42 | | 6 | 3 | 4 | 7 | 45 | 14 |
| **Bumblebees** | | | | | | | | | | | | | | |
| *Bombus diversus tersatus* Smith | | | | | | 1 | | | | | | | 1 | |
| *B. yezoensis* Matsumura | | | | | | 1 | | | | | | | | |
| *B. shrencki albidopleuralis* Skorikov | 1 | | | | | | | | | | | | | |
| *B. pseudobaicalensis* Vogt | 1 | | | | | | | | | | | | | |
| *B. hypocrita sapporoensis* Cockerell | 1 | | | | 1 | | | | | | | | | |
| **Hoverflies** | | | | | | | | | | | | | | |
| *Syritta pipiens* L. | | | | | | | | 1 | 1 | | | | 1 | |
| *Sphaerophoria indiana* Bigot | 1 | 1 | | | | | | | | 1 | | | 1 | |
| **Other bees** | | | | | | | | | | | | | | |
| *Lasioglossum* sp. | | | | | 1 | | | | | | | | | 1 |
| *Lasioglossum sibiriacum* Bluthgen | | | | 1 | | | | | | | | 1 | 1 | |
| **Beetles** | | | | | | | | | | | | | | |
| *Popillia japonica* Newman | | | | | | | | | 1 | | | | | |
| *Atrachya menetriesi* Faldermann | 1 | | | | | | | | | | | | | |
| **Sawfly** | | | | | | | | | | | | | | |
| *Allantus luctifer* Smith | | | | | | | | | 1 | | | | | |
| **Ant** | | | | | | | | | | | | | | |
| *Formica* sp. | | | | | | | | | | | | 1 | | |

sp. were sampled more than once. Mean ± S.D. of the number of species captured within a field were 2.57 ± 1.55 (range, 1-6). The distance from an apiary to a pumpkin field negatively affected the rate of visits by honey bee to flowers ($P < 0.01$; figure 2; table 2). The flower density in each field and interaction between the effects of flower density and the distance did not affect the visitation rate by honey bee significantly ($P = 0.38$ for flower density, $P = 0.77$ for interaction; table 2). Numbers of non-honey bee insects visiting pumpkin flowers within a field were not significantly related with the number of honey bees visiting (estimated coefficient ± standard error, 0.06 ± 0.048, $P = 0.20$, GLMM; figure 3). The distance from the apiary to the field significantly and negatively influenced the visitation rate by all insects combined (figure 4; table 3). Neither the flower density nor an interaction term between the flower density and the distance was significantly related with the visitation rate by all insects ($P = 0.42$ for flower density, $P = 0.85$ for interaction; table 3).

**Table 2.** Results of generalized linear mixed models (GLMMs) examining the effects of the distance from apiaries to pumpkin fields, number of flowers / m, and their interaction with the visitation rate of *A. mellifera* to pumpkin flowers.

| Fixed effects | Coefficient ± S.E. |
|---|---|
| Distance | −1.269 ± 0.408 * |
| No. Flowers / m | −0.171 ± 0.195 |
| Distance × No. Flowers / m | 0.054 ± 0.181 |

Estimated coefficients and standard errors (S.E.) are shown for the effects of the distance from apiaries to fields, No. Flowers / m, and their interaction on the visitation rate of honey bees to pumpkin flowers. * denotes $P < 0.01$.

**Table 3.** Results of generalized linear mixed models (GLMMs) examining the effects of the distance from apiaries to pumpkin fields, number of flowers / m, and their interaction with the visitation rate of all insects to pumpkin flowers.

| Fixed effects | Coefficient ± S.E. |
|---|---|
| Distance | −1.137 ± 0.357 * |
| No. Flowers / m | −0.141 ± 0.175 |
| Distance × No. Flowers / m | 0.031 ± 0.1604 |

Estimated coefficients and standard errors (S.E.) are shown for the effects of the distance from apiaries to fields, No. Flowers / m, and their interaction on the visitation rate of all insects to pumpkin flowers. * denotes $P < 0.01$.

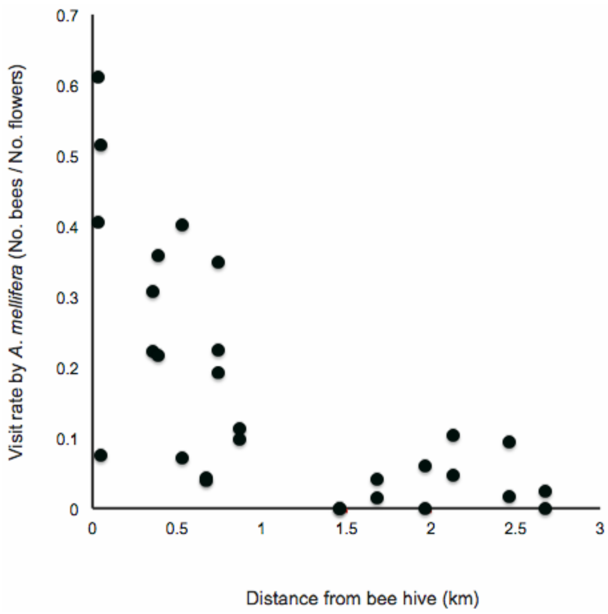


**Figure 2.** Relation of the visit rate by honey bees per pumpkin flower with the distance from the apiary to pumpkin fields (km). Visit rates by honey bees were measured by dividing the numbers of honey bees sampled by the number of pumpkin flowers blooming along the transect during a sampling date. Sampling was conducted twice at each pumpkin field during July 22 - August 1, 2011. Each plot represents the visit rate at a given field on a given date. These plots are not weighted by the number of flowers in each field, although the total number is considered in the GLMM analyses.

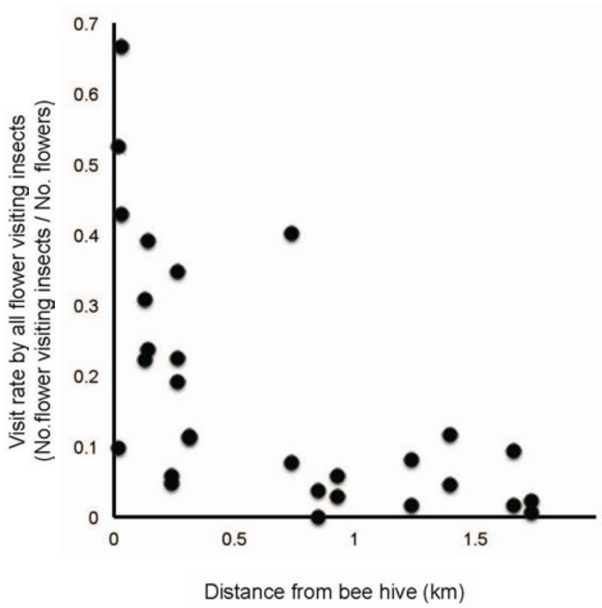


**Figure 4.** Relation among visit rates by all insects per pumpkin flower and the distance from the apiary to pumpkin fields (km) in central Hokkaido, Japan. Visit rates by all insects were measured by dividing the quantities of all insects sampled by the number of pumpkin flower blooming along the transect during the census. Sampling was conducted twice at each of 14 pumpkin fields during July 22 - August 1, 2011. Each plot represents the visit rate at a given field on a given date. These plots are not weighted by the number of flowers in each field, although the total number is considered in the GLMM analyses.

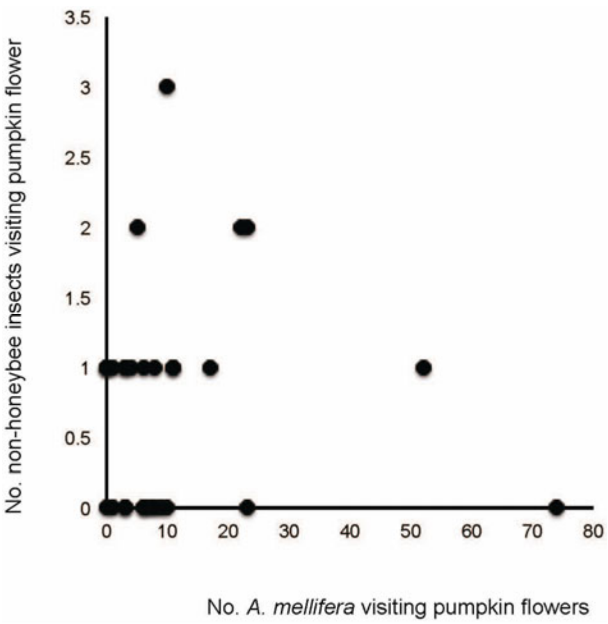


**Figure 3.** Relation between the number of flower visiting insects other than honey bee and the number of honey bees visiting pumpkin flowers. Sampling was conducted twice at each of 14 pumpkin fields during July 22 - August 1, 2011. Each plot represents the quantities of flower visiting insects at a given field on a given date.

## Discussion

This study revealed that 96.8% of all insects visiting *C. maxima* flowers are bees. Of those, *A. mellifera* is the most common pumpkin-flower-visiting insect (96.7% of all bees), which agrees with results of previous studies (McGregor, 1976; Fuchs and Müller, 2004; Nicodemo *et al*., 2009). The study area is famous nationwide for its pumpkin production. In addition to pumpkin abundance, crops are usually planted almost simultaneously. Consequently, during the pumpkin flowering season, pumpkin fields, where mass-flowering of only one species occurs in extremely high density, are very attractive to honey bees. Honey bees have a high search ability for flower resources, foraging optimally in terms of energy and time efficiency (Seeley, 1995), and visit only one species of flower in a bout. For that reason, honey bees actively visit pumpkin flowers, thereby becoming the most common insect visiting pumpkin flowers in the area, where many apiaries operate during summer.

Floral visitation rates alone are not a good indicator of pollination effectiveness (Javorek *et al.,* 2002). Honey bees are not shown to be as efficient as bumblebees (Fuchs and Müller, 2004; Artz and Nault, 2011), squash bees, *Peponapis pruinosa* Say (Hurd, 1964), or native bees *Osmia cornuta* Latreille (Bosch and Blas, 1994) in terms of pollination efficiency per visit by an individual. Hoehn *et al*. (2008) reported that pollinator diversity, not abundance, is positively related to the seed set of other pumpkin species, *Cucurbita moschata* Duchesne ex Poiret. Consequently, honey bees might contribute less to the pollination of pumpkins than expected from the frequency of the flower visiting insect fauna. Honey bees, however, are the most abundant flower visitors in the fields. They probably provide the service of pollinators for pumpkin here.

Walter and Taylor (2006) reported that even under field conditions with sufficient natural pollinators, the addition of honey bees increased the production of *C. maxima*. In addition, significant negative relation between quantities of honey bees and other flower visiting insects was not detected in this study, suggesting that visits by honey bees to pumpkin flowers do not interfere with pumpkin pollination by other native pollinators even if pollination efficiency by honey bees is less than that of other native bees. Failure to detect a significantly positive relation between visitation rates by honey bees, or all flower visiting insects combined and the number of flowers also suggests that flower resources are sufficient for honey bees, or all insects. In the study area, a greater number of pumpkin flowers bloom during the flowering season. Each pumpkin flower has ample nectar. Therefore, resources for flower visiting insects during the blooming period of pumpkin might probably exceed the demand of insects, or declining native flower visiting insects because of habitat loss, agricultural intensification, and pesticide use (Steffan-Dewenter *et al.*, 2002; Kremen *et al.*, 2004; Potts *et al.*, 2010) prevents detection of competition among insects. Considering that farms aside from organic farms near natural habitats have experienced greatly reduced diversity and abundance of natural bees (Kremen *et al.*, 2002), and pumpkin production has suffered severe losses, partly because of decreased availability of pollinators (Fuchs and Müller, 2004). As Garibaldi *et al.* (2011) pointed out, addition of a honey bee hive to pumpkin fields cannot completely resolve the deficiency of pollination services. However, at least under the present environment, it should not be disputed that honey bees are primary pollinators in these pumpkin fields.

The closer the proximity of the apiary and pumpkin field becomes, the higher the visitation rate by honey bees per pumpkin flower in the field. Nicodemo *et al.* (2009) demonstrated that the higher the number of visits of honey bees, up to 16 per flower, by honey bees, the greater was the set fruit, fruit size, and weight fruit, and the set seed. We did not count the total visit numbers per flower, although we measured the visit rate by honey bees per flower. Considering, however, that the reception period of pumpkin flowers to pollination is extremely restricted (Tepedino, 1981; Hoehn *et al.*, 2008), and that the visit rate by non-honey bee per pumpkin flower was low, the high visitation rate by honey bees, attributable to the foundation of an apiary near the field, probably contributes to the increase in pumpkin production at our study site.

Recently, negative effects of insecticides applied to agricultural fields have been particularly investigated as a potential cause of decline in honey bees (Allen-Wardell *et al.*, 1998; Chauzat *et al.* 2006; Oldroyd, 2007; Johnson *et al.*, 2010; Maini *et al.*, 2010; Potts *et al.*, 2010; Lu *et al.*, 2012). In the study area, most pumpkin growers cultivate rice as well as pumpkins. Both crops are frequently situated as mutually adjacent. Taniguchi *et al.* (2012) reported that control for stink-bugs within rice fields during summer, when pumpkin flowers are in full bloom, causes severe damage to honey bees. As shown by this study, pumpkin growers can benefit from the establishment of apiaries near pumpkin fields, meaning that growers might suffer if beekeepers transfer their apiaries far from pumpkin fields to avoid side-effects of insecticides applied to rice fields. To protect the benefits of honey bees gained through pollination, growers should reconsider their pest control programs incorporating insecticides.

## Conclusion

In central Hokkaido, the northernmost main island of Japan, where many beekeepers transfer their domestic bees (*A. mellifera*) during summer, Honey bee is the common flower-visiting insect for pumpkin. Significant negative relations were found between the visit rates of pumpkin flowers by honey bees only, or by all insects combined, and the distance from the apiary to the pumpkin field. Combined with previous studies demonstrating that a numerical increase in visits by insects to pumpkin flowers led to an increase in pumpkin yields, establishment of apiaries near pumpkin fields can be advantageous for growers through increased pumpkin production.

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