Wild bees as crop pollinators in Taiwan

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Abstract

Over 110 flower-visiting bees from the Apidae, Colletidae, Halictidae and Megachilidae families are potential beneficial pollinators in subtropical area of Taiwan. The potential genera are consist of *Amegilla*, *Apis*, *Bombus*, *Braunsapis*, *Ceratina*, *Ctenoplectra*, *Lepidotrigona*, *Tetralonia* and *Xylocopa* in Apidae, *Hylaeus* in Colletidae, *Halictus*, *Lasioglossum*, *Lipotriches* and *Nomia* in Halictidae, and *Heriades*, *Lithurgus* and *Megachile* in Megachilidae. Honeybees *Apis mellifera* and *A. cerana* are common pollinators for most known crops such as cucumbers, longan, litchi, melon, pear and sunflower. The potential pollinators such as leaf-cut bees and sweat bees are abundant in the fields and have not evaluated well for their function. An oligolectic bee *Ctenoplectra chalybea* is the only pollinator for *Momordica cochinchinensis*. Bumblebee *Bombus eximius* is under development and has high fitness potential for pollination within agricultural facilities.

Key words: biodiversity, pollination, wild bees, Taiwan

Introduction

It is a well-known fact that more than 35% of global crop production depends on insect pollination. Most of these pollinators are wild bees (Klein et al. 2007). Since Langstroth designed a movable-frame hive for the western honeybee *Apis mellifera* in 1851, the beekeeping technique improved and the population increased rapidly worldwide (Crane 1999). In colony collapse disorder (CCD), infected colonies have experienced losses totaling 50 – 90% in beekping operations (Cox-Foster et al., 2007). Recent reports show that *A. mellifera* may result in increasing the ecological risks, e.g., competition with native bees, increasing weed abundances through pollination or migrating pathogen, virus or mite inter- / intra-species (Roubik 1989, Butz Huryn and Moller 1995, Oldroyd and Wongsiri 2006). C. D. Michener (2007) introduced worldwide bee species with a classification and phylogeny. The biodiversity of bee fauna and bee pollination is chiefly concerned with the importance to human life in the 21st century. As is generally known, bees are harmless or less harmful to plants in agro- and forest-ecosystems. Moreover, known species such as the honeybee *A. cerana*, bumblebee *Bombus terristris* or stingless bee *Melipona beecheii* are beneficial to pollination and economic value for human life (Crane 1999, Oldroyd and Wongsiri 2006, Velthuis and Doorn 2006). Specialist use *A. mellifera* as a pollinator for crops in the subtropical area of Taiwan (Lin and Wu 1996). However, poor knowledge may cause low pollination efficiency and ecological risks to some extent. The biodiversity, plant pollination and plant protection in related with wild bees are the main subjects in my researches (e.g., Sung et al. 2006b, Sung et al. 2006c,

Sung 2008, Sung et al. 2009). This paper is attempts to show the importance of biodiversity in bee fauna and the utilization of wild bees in the subtropical area of Taiwan.

Limitations for bee pollination in modern agricultural system in Taiwan

The Taiwan agricultural system consists of small-scale plantations (Chung 2008). Although growers own their small land area (generally 0.1 – 1 hectare), the revenue has been growing by improving the agriculture techniques and efficiencies. In open fields, bees or other pollinators are common and easier to use naturally or artificially for plant pollinations. The modern agricultural system introduced facility cultivation to prevent pests and improve the cost value. However, high temperatures and block materials within a confined space caused low effecicncy insect pollination problems. In addition, the attempts to change *A. mellifera* behaviors through decreasing the population in small-scale facilities produced the following factors. 1) Most foragers fail to adapt to the narrower space; 2) reduced colonies lack enough nectar to convert energy for the population; and 3) weak colonies lack the ability to recover soon and thus decrease the pollination efficiency (Sung, personal observation). The native honeybee *Apis cerana* distribution differs widely from the low to high altitude areas in Taiwan (Sung et al. 2006c). However, environmental changes, human disturbances, or unreasonable factors easily increase the environmental stress on this species producing absconding or migration (Oldroyd and Wongsiri 2006). Although honeybee pollination can reduce the cost, labor and chemical residue, but to achieve pollination for diverse plants is facing problem complexities. In fact, farmers utilize parthenocarpic plants, artificial pollination techniques or plant growth hormones to improve the fruit set. As a result, alternative wild bee pollinators are necessary to resolve the limitations of these measures.

Biodiversity of wild bees for pollination in Taiwan

Bees are a known pollinator for their nectar and pollen collecting behavior to provide food resources for their offspring. Michener (2007) indicated that the body of bees is usually more robust and hairy than that of wasps. The classification of bees is in the Order Hymenoptera, Section Aculeata, and the Superfamily Apoidea. It estimated that 150 – 160 species exist within five families in Taiwan (Dubitzky et al. 2008, Sung 2008). The five families are Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae (Michener 2007). Among them, Apidae, Halictidae, and Megachilidae are the major group, exceeding 90% of the species compared with the other two families. The average number of Apidae species per square kilometer shows the highest diversity among China, Japan, and Taiwan (Sung 2008). Due to the lack of studies, a number of uncertain taxonomic work remains (Dubitzky et al. 2008, Sung 2008). This might be a limiting factor for studying the functional bioversity of wild bees in Taiwan. According to field investigations and observations, important bee genera co-exist with crop production in agro-ecosystem areas (also regard as lowland of agricultural area) consisting of *Apis*, *Braunsapis*, *Ceratina* and *Xylocopa* in Apidae, *Halictus* and *Lasioglossum* in Halictidae, and *Megachile* in Megachilidae (Table 1). In addition, potential genera that are widely distributed in tropical or temperate regions might co-exist with seed plants in forest-ecosystem area (low- to high lands of forest area) in Taiwan. These genera plus *Amegilla*, *Bombus*, *Ctenoplectra*, *Lepidotrigona* and *Tetralonia* in Apidae, *Hylaeus* in Colletidae, *Nomia* and *Lipotriches* in Halictidae, and *Heriades* and *Lithurgus* in Megachilidae (Table 1) (Sung 2006a, Sung 2006b, Dubitzky et al. 2008, Sung 2008, Chiang et al. 2009, Sung et al. 2009, Sung, unpublished data).

Functional diversity of bees as pollinators

Viewpoint of ethology and morphology

Most of the pollinators are female bees because they collect pollen from anthers and nectar near the stigmata for their own and larvae foods. Male bees are less in number than females. They collect nectar but carry pollen only pollen that sticks onto their bodies. They have a less significant role in pollination (Michener 2007). One might consider that any bee visiting a flower can treat as a pollinator for that plant; however, the relationship between a bee and its floral food resources is a complex interaction (Inoue et al. 1993, Michener 2007). According to the visiting behavior, a few visitors may consider nectar thieves. For example, bumblebees and xylocopid bees damage the sides of tubular flowers and imbibe nectar without collecting pollen (Dedej and Delaplane 2004, Hargreaves et al. 2009). Social bees are usually active for a long season and they prefer distinct and long blossoming flowers. In contrast, many solitary bees are active for a short season and they favor flowers that bloom for only a few weeks each year (Michener 2007). For example, ctenoplectid bee and leaf-cut bee are foraged for specific plant (Kitamura et al. 2001, Schaefer and Renner 2008). The morphological characteristic of the body sizes, mouthparts, legs, and scopae (pollen-transporting brushes or areas) in bees show their adaptation for collecting and carrying pollen. These physical adaptations were reported to relate to the plant pollination mechanisms (Michener 2007). The following brief morphological characteristics of bee taxonomic groups as related to floral resource collection in Taiwan are as follows:

Apidae: This family belongs to the long-tongued bees, with scopa usually on the hind legs. The body size varies among the taxa. Many species have social or semisocial mechanisms. The subfamily includes Apinae, Xylocopinae, and Nomadinae (parasitic bees) in Taiwan. Important genera for pollination are *Amegilla*, *Apis*, *Bombus*, *Ctenoplectra* and *Lepidotrigon* in Apinae; and are *Braunsapis*, *Ceratina* and *Xylocopa* in Xylocopinae (Table 1). The foraging strategy is different among the taxa because of the diverse species and complicated social communication systems (Roubik 1989, Inoue et al. 1993). Honeybees (genus *Apis*) usually utilize a distinct flowering season, nectar plants and a large number of flowers because of the mass recruit systems (Michener 2007). In comparison with honeybees, the blue-banded bee (*Amegilla*) and bumblebee (*Bombus*) can utilize flowers with low quantity pollen. The behavior called buzz-pollination is due to their wing vibration in producing low frequency sonar to gather fallen pollen grains in the anther (Inoue et al. 1993). The least known ctenoplectid bees consist of the genus *Ctenoplectra* and *Tetralonia* oligolectics (collect pollen from specific plants) (Schaefer and Renner 2008, Sung et al. 2009, Sung unpublished data). Although stingless bees occur generally in Asian tropical areas and are potential pollinators for crops, the only species found is rare and problematic as a suitable pollinator in Taiwan (Sung et al. 2006c, Sung et al. 2008). Among the Xylocopinae the large *Xylocopa* are larger than 2 cm while the small *Braunsapis* and *Ceratina* are usually smaller than 1 cm in body sizes. They have potential for pollination efficiency beneficial for diverse plants.

Megachilidae: megachilid bees are long-tongued bees, with scopa on the metasomal sterna. Megachilid bees have leaf-cuting behaviors that might damage some plants. However, these are good pollinators in fruit pollination in many countries. *Megachile rotundata* is a good pollinator for alfalfa in the USA (Kemp and Bosch 2000). Excluding parasitic species, more than 20 megachilid bees have

been found in Taiwan (Yasumatsu and Hirashima 1965, Wu 2006). The important genera for pollination are *Heriades*, *Lithurgus* and *Megachile* (Table 1). Megachilid bees build nests in tubular holes in bamboo nodes or tree logs. Nest traps have applied for pollination use (Inoue et al. 1993). So far, megachilid bees have not been use because a number of *Heriades* and *Megachile* are ground-nesting species in Taiwan. The *Osmia* species in Megachilidae are useful pollinators in temperate regions, but they lack distribution in Taiwan.

Halictidae: Halictidae belongs to short-tongued bees, with scopa on hind femur. They have social or semisocial behaviors, with nests found in soil, forming tunnel like shapes (Wcislo and Engels 1996). The subfamily includes Halictinae and Nomiinae in Taiwan, consisting of over 50 species recorded in *Ceylalictus*, *Evylaeus*, *Halictus*, *Lasioglossum*, *Lipotriches*, *Nomia*, *Pachyhalictus* and *Steganomus* (Strand 1913, 1914, Michener 2007, Pesenko 2007, Dubitzky et al. 2008, Sung 2008). Halictid bees are small to moderate size (usually 0.5 – 1.5 cm) and abundant in fields. They are important for tree and crop pollinations in natural forest- and agro-ecosystems. One of the examples is that *Lasioglossum* is a potential pollinator for mango fruit (Sung et al. 2006b). So far, the utilization of halictid bees for pollination is difficult on the commercial scale because of the ground-nesting behaviors (Wcislo and Engels 1996).

In comparison with social bees, the foraging behavior and the body size in solitary bees such as megachilid and halictid bees varies so that they fulfill an important role for pollination. Recent studies showed that utilizing solitary bees could decrease the labor and costs and increase the fruit sets (e.g., Inoue et al. 1993, POST 2010). The management of solitary bees for pollination includes rearing and nesting inducement methods in specific areas depending on the behavior and physiological function of the bees. The following points are influence factors for a potential pollinator: 1) communal nesting behavior; 2) high preference to a respective plant; 3) potential for managing the nest or rearing artificially; 4) potential for controlling the natural enemies; 5) high reproductive ability; 6) foraging period matches the crop flowering season (Inoue et al. 1993).

Because of environmental and cultural differences, vegetables and fruits grow in different ways or types. The fauna for pollinators is different among countries. Utilizing an introduced species as a pollinator without suitable risk assessment may cause ecological problems (Matsumura et al. 2004, Goka et al. 2006). The government provided a law to limit the use of introduced pollinator *Bombus terristris* in Japan, 2006. Thus, *Bombus ignitus* was recommended as a substitute for farm use (Yoneda et al. 2008). Table 2 shows the flower preferences of potential bees in Taiwan. As shown in Table 2, the honeybee, blue-banded bee, bumblebee, carpenter bee, ctenoplectid bee, small carpenter bee, leaf-cutter bee and sweat bee relate with agricultural crops, although they have not confirmed as respected pollinators. Excluding the *Ctenoplectra*, *Lithurgus*, and part of the *Megachile* species are oligolectics; whiles most of them are polylectics.

Practical and potential pollinators for crops in Taiwan

In Taiwan, a wide range of insect (bees, dipteran flies, and fig wasp) has recognized as crop pollinators (Table 3). The pollinators consist of two honeybees, dipteran flies, and a fig wasp. The honeybees *A. cerana* and *A. mellifera* are common pollinators for seed crops (Lin and Wu 1996), dipteran flies consist of calliphorid flies for mango trees and hoverflies for some facility reared

cultural plants (Sung et al. 2006b, Wu and Wang 2008), whereas the fig wasp *Wiebesia pumilae* is a pollinator for the jelly fig (awkeotsang) (Chen et al. 2006). The western honeybee *A. mellifera* introduced from Japan in the early 20th century. It soon became the dominant species around lowland agricultural areas (Sung et al. 2006a). It is superior in its abundance and ease of mass reproduction. Therefore, it has extended for use as a pollinator for numerous crops since the 1990's (Lin and Wu 1996). It has been use to pollinate various crops such as asparagus, citrus fruits, guava, litchi, longan, oilseed rape, and sunflower in open fields. In net houses, bitter gourd, cucumbers, Indian jujube, strawberry and cultured plants pollinated by *A. mellifera*. Commercial F_1 seeds such as broccoli, cabbage, or cauliflower vegetable are pollinated by *A. mellifera*.

A. cerana is difficult to maintain due to its biological characteristics. The habitat and distribution of *A. cerana* are more diverse and wider than *A. mellifera* (Sung et al. 2006c). Thus, the wild *A. cerana* population and possible wild bees may enough for fruit tree pollination in mountainous areas. These fruit trees include apple, carambola, litchi, longan, mango, oriental plum, peach, pear, persimmon, plum, strawberry, and wax apple. *A. cerana* is possible the major pollinator for rosaceous crops such as pear and plum because of the lack of *Osima* bees in Taiwan (Sung, unpublished data). The awkeotsang is a dioecism plant distributed in mountainous areas. It has high economic value for making the aiyu jelly drink. Female fruit fertilization is necessary by transferring pollen using the fig wasp *Wiebesia pumilae* from the male fruit (Chen et al. 2006). The Dipteran insects *Chrysomya*, *Lucilia* and *Musca* species are abundant due to their frequent occurrence on mango flowers. Recent study showed that potential pollinators might included honeybees (*A. cerana* and *A. mellifera*) and sweat bees (*Halictus* spp. and *Lassioglossum* spp.), and the Oriental latrine flies (*Chrysomya megacephala*, *C. pinguis* and *Lucilia caesar*) (Sung et al. 2006b).

Modern agricultural systems improve agricultural methods and create facility culture for higher production. Small colonies, a broad UV range of fitness and special collection behavior are the main factors for bumblebee use as pollinators in facilities. A native bumblebee species, *Bombus eximius* has been reared and to be applied in small-scale facilities for tomatoes and strawberry pollination (Chiang et al. 2009, Li et al. 2010). *Ctenoplectra* species collect pollen on *Thladiantha* and important fruit *Momordica* plants (Schaefer and Renner 2008). A potential species *C. chalybea is a known* pollinator for *M. cochinchinensis*. However, only aborigines in Taiwan utilize this fruit. For many fruit trees, wild bees can visit and pollinate in the open fields without problems. The utilization of pesticides and unified agricultural methods induced the habitat destruction for bees. Therefore, wild bee conservation methods should be tested and extended in the near future. It is possible to use artificial facilities to induce wild bee propagarion such as the blue-banded bee and leaf-cut bee for nest building around the fields (Inoue et al. 1993, Dollin 2006).

Conclusion

Increasing crop yield and quality through insect pollination has direct economic value (POST 2010). It is estimated that 85% labor cost savings per hectare can be obtained in pears, 80% in watermelon, and about 90% in cucumbers and bitter gourd production in Taiwan (Wu, personal communication). Wild bees are effective pollinators for many crops. For particular crops, wild bees can be more effective than domestic honeybees (POST 2010). Facility agriculture is a trend for modern growers because of the improvements in cost and efficiency per unit area. Bee species that are easy to rear,

manage, having a broad / specific range of fitness are urgently needed to solve pollination inefficiency in a diverse agricultural system. With environmental and ecological conservation enhancement, the government legal system is becoming stricter regarding animal and plant quarantines. Effective social, semisocial, and solitary bees, pollinator such Apidae, Megachilidae, and Halictidae are roughly estimated to approximate 110 species in Taiwan. There is a chance to utilize native bee species for diverse crop pollination, and thus reduce the environmental and ecological impacts.

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Table 1. List of bee taxa as potential pollinators in Taiwan, with the evaluation of the natural distribution in agro- and forest-ecosystem areas and estimation of the species number (from Michener's system).

Family and subfamily name	Tribal name	Genus	Agro-ecosystem areas	Forest-ecosystem areas	Species number
Apidae					
Apinae					
	Anthophorini	*Amegilla*	○	□	ca. 5
	Apini	*Apis*	□	□	2
	Bombini	*Bombus* (subgenus *Psithyrus* excluded)	-	□	8
	Ctenoplectrini	*Ctenoplectra*	○	□	3
	Eucerini	*Tetralonia*	○	□	2
	Meliponini	*Lepidotrigona*	-	□	1
Xylocopinae					
	Allodapini	*Braunsapis*	□	□	1 – 2
	Ceratinini	*Ceratina*	□	□	> 12
	Xylocopini	*Xylocopa*	□	□	4
Colletidae					
Hylaeinae		*Hylaeus*	○	□	ca. 7
Halictidae					
Halictinae	Halictini	*Halictus*	○	□	> 20
		Lasioglossum	□	□	> 11
Nomiinae		*Nomia*	○	□	ca. 12
		Lipotriches	○	□	1
Megachilidae					
Megachilinae					
	Lithurgini	*Lithurgus*	○	□	1
	Osmiini	*Heriades*	○	□	1
	Megachilini	*Megachile*	○	□	ca. 19

□: common, ○: not common or rare, -: lack.

Table 2. List of potential bees and their common preferrd families and crops.

Genus (common name)	Plant family (included common name of plant)
Apis (honeybee)	Anacardiaceae (mango), Compositae (sunflower), Cruciferae (oilseed rape), Cucurbitaceae (cucumbers, melon, sponge cucumber, watermelon), Myrtaceae (guava), Orchidaceae, Rosaceae (berries, pear, plum), Sapindaceae (litchi, longan), Rutaceae (citrus fruits)
Amegilla (blue banded bee)	Scrophlariaceae, Solanaceae, Verbenaceae, Zingiberaceae (small shellflower)
Bombus (bumblebee)	Orchidaceae, Rosaceae (apple, berries, pear, plum), Solanaceae (tomato), Zingiberaceae (small shellflower)
Ctenoplectra (ctenoplectid bee)	Cucurbitaceae (wild cucumber)
Lepidotrigona (stingless bee)	Cruciferae, Euphorbiaceae, Fagaceae, Rosaceae, Sapindaceae
Braunsapis (allodapine bee)	Euphorbiaceae, Palmae (betel nut), Verbenaceae
Ceratina (small carpenter bee)	Amaranthaceae, Compositae, Convolvulaceae, Cucurbitaceae (sponge cucumber, watermelon), Fabaceae (Indian sesbania), Verbenaceae, Zingiberaceae (small shellflower)
Xylocopa (carpenter bee)	Convolvulaceae, Cucurbitaceae (sponge cucumber), Melastomataceae (common melastoma)
Heriades (osmiine bee)	Compositae
Lithurgus (lithurgine bee)	Malvaceae
Megachile (leaf-cutter bee)	Compositae, Convolvulaceae, Fabaceae, Malvaceae
Halictus, *Lasioglossum*, *Lipotriches*, *Nomia* (sweat bees)	Compositae, Cruciferae (oilseed rape), Cucurbitaceae (sponge cucumber, melon), Solanaceae

Table 3. Known pollinators and target plants in Taiwan

Common name	Species	Target plants
Western honeybee	*Apis mellifera*	Asparagus, bitter gourd, citrus fruits, cucumbers, guava, Indian jujube, litchi, longan, melon, peach, pear, oilseed rape, strawberry, sunflower, facility cultural plants, vegetable and flower seed collecting
Eastern honeybee	*Apis cerana*	Apple, carambola, longan, litchi, mango, oriental plum, peach, pear, persimmon, strawberry, plum, wax apple
Fig wasp	*Wiebesia pumilae*	Jerry fig
Calliphorid flies	*Chrysomya megacephala* *Chrysomya pinguis* *Lucilia caesar* *Musca domestica*	Mango
Hoverflies	*Eristalinus* sp., *Eristalis* sp.	Cruciferous plants, facility cultural plants, melon