BUMBLEBEE AS POLLINATORS FOR PROTECTED CULTIVATION OF HORTICULTURAL CROPS IN TAIWAN

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ABSTRACT

Protected cultivation of horticultural crops comprises a total area of 25,647.64 hectare in Taiwan. Two most common ways of pollinating horticultural crops in protected cultivation are artificial pollination and honeybee pollination. In order to increase product productivity and quality, production efficiency, and decrease the cost of labors, more species of quality insect pollinators can be applied to the protected cultivation production facilities. Bumblebees (Bombus spp., Hymenoptera: Apidae) are important insect pollinators second only to honeybees that have the potential to be utilized in Taiwan. In 2013, Taiwan's Council of Agriculture launched an eight year action plan called “Building Golden Agricultural Corridor”. It aims to create an energy- and water-conserving agricultural zone, which is also envisioned to promote increase protected cultivation area that can result in the increased needs of pollinators. In line with this, Taiwan researchers have surveyed indigenous bumblebee species, and explored their potential of using them in protected cultivation facilities. Results show that Taiwan has a total of nine indigenous bumblebee species and among them, the B. eximius Smith has the potential to be used in the subtropical area. On the other hand, foreign bumblebees can only be imported for research purposes under the supervision of the authority.

Keywords: Bumblebees, Indigenous, Pollinators, Protected Cultivation, Taiwan

INTRODUCTION

Pollinators come in all shapes and sizes. Over 100,000 invertebrate species — such as bees, moths, butterflies, beetles, and flies — serve as pollinators worldwide. At least 1,035 species of vertebrates, including birds, mammals, and reptiles, pollinate many plant species. Among these beneficial pollinators, one-third of all vegetables and fruits produced globally are pollinated by honeybees. Some experts estimate that the world's food supply being directly or indirectly affected by honeybee pollination is with the range of 50-80%. In Taiwan, more than 50 agricultural crops depend on artificial pollination and/or insect pollinators such as honeybees and other insects that disseminate pollen, accounting for about $2,536 billion in production (COA, 2014; COA, 2015). With the increasing awareness of global climate change affecting bee populations, scientists, farmers, and entrepreneurs all over the world are looking for alternative pollination methods and pollinators to solve negative the impacts on productions caused by the change of environment and restrictions of natural behavior of honeybees.

PROTECTED CULTIVATION IN TAIWAN

Taiwan has a total land area of about 36,000km². According to the 2010 agricultural, forestry, fishery and husbandry census (DGBAS, 2010), there is a total of 576,617.15 hectares of cultivated land which include 30,110.77 hectares protected agricultural cultivation area and 48,000 farming household. Protected cultivation facilities used for the production of horticultural crops (fruit and vegetables) occupied 25,647.64 hectares (Fig. 1). The ratio of horticultural crops’ cultivation area under tunnel shed, shelving, netting shelter, greenhouse, and others is 5.18%, 49.32%, 28.76%, 1.87%, and 0.01%, respectively (Fig. 2).
Fig. 1. Cultivated land area, by kinds of facilitated farming

- Cultivated land: 576,617.15 ha
- Protected cultivation facilities: 30,110.77 ha
- Horticultural crops: 25,647.64 ha

Fig. 2. Percentage of horticultural crops (fruit and vegetable) under protected cultivation

- Tunnel shed: 5.18%
- Shelving: 49.32%
- Netting shelter: 28.76%
- Greenhouse: 1.87%
In Taiwan, growing horticultural crops (fruit and vegetables) under protective structures to shield them from pests and weather is becoming more common. Nylon net tunnels, net houses or plastic houses are increasingly used by smallholder farmers for growing leafy vegetables in peri-urban areas, and plastic houses or rain shelters are also used for tomato production during the hot-wet season. New generation greenhouse production system equipped with low energy consumption, low carbon emission, water conservation, weather control, and many advanced technologies is getting popular and has its advantages of producing high economic valued crops.

BUMBLEBEES IN TAIWAN AGRICULTURE

Taiwan has a total of nine indigenous bumblebee species: *B. angulatus*, *B. wilemani*, *B. formosellus*, *Xylocopa bomboidae*, *B. bicoloratus*, *B. eximius*, *B. flavescens*, *B. sonani*, and *B. trifasciatus* (Starr, 1992). Among them, the population characteristics, seasonal occurrence of colonies, and distribution features four common species *B. bicoloratus*, *B. eximius*, *B. flavescens*, and *B. trifasciatus* were studied (Chiang, 2009; Sung et al., 2011). Two species *B. eximius* and *B. sonani* were successfully reared and evaluated under laboratory conditions. Comparing *B. eximius* and *B. sonani*, rates of successful colony production and virgin queen copulation were not different; the proportions of successful colony production and virgin queen copulation in both species were more than 60%. It is suggested that both species are suitable for rearing in the laboratory and have mass production potential for future commercial utilization, especially *B. eximius* (Chiang et al., 2009). Further evaluations have been done on *B. eximius* pollinated tomatoes and strawberry compared to the manual plant growth regulator treatment (4-CPA) and *Apis mellifera* L. respectively. Results showed *B. eximius* Smith pollinated tomatoes had higher rate of fruit set, significantly higher number of seed per fruit, and locular cavities are significantly larger; *B. eximius* Smith pollinated strawberries had less deformity and had 13.04% higher yield (Li, 2011). Comparison study of pollination effects of two pollinators, honeybee and *A. mellifera* and *B. eximius* on large-sized tomatoes shown both bees successfully pollinated the tomatoes and bumblebee pollinated tomatoes had lower malformation rate (Sung and Chiang, 2014).

Under the supervision of the authorities, the Bureau of Animal and Plant Health Inspection and Quarantine, Taiwan’s Council of Agriculture (BAPHIQ, COA); and for experimental study purposes, local tomato farmers (greenhouse cultivation in majority) imported commercial bumble bees, *B. terrestris*, from the Netherlands to Taiwan in January 2014. According to the farmer, the natural pollination process expedited by the bumblebees is just as effective as using artificial agents such as 4-chlorophenoxyacetic acid (4-CPA) to increase production. It is more environmentally friendly and requires less effort. Each commercial bumblebee hive cost USD120 that includes a nest of 50 worker bees and 50 pupae; it took three hives for a 0.02 ha greenhouse; these colonies can be used for 4-7 weeks (Liberty Times Net, 2015; News & Market, 2015). In Changhua County, Joydon International Agri-product Company introduced Dutch greenhouse system to grow cherry tomatoes. Their greenhouse facilities occupied a floor land of 0.66 hectare. They also imported *B. terrestris* to pollinate cherry tomatoes.

THE GOLDEN AGRICULTURAL CORRIDOR

The “Building Golden Agricultural Corridor” is an integrated agricultural action plan launched by COA, the Ministry of Economic Affairs, the Ministry of Transportation and Communications, and local governments. It creates incentives and provides guidance to farmers, marketing teams and agribusinesses aims to develop water conservation areas for agricultural production in Taiwan. This project targets the band area of 1.5 kilometers on both right and left sides of the high-speed railway between southern Changhua and Yunlin Counties. The project is anchored on its three goals (new technology, new farmer and new industry) to help build the Yunlin-Changhua corridor as a model of LOHAS (lifestyles of health and sustainability) agriculture. A total of US$100 million project fund has already been earmarked from 2013-2020.

There are four key guidelines in the creation of the “Golden Agricultural Corridor: (1) Create water-saving agricultural production zones; maximize use of agricultural resources; (2) Strengthen the application of water-conservation technologies and information; (3) Expand the scale of farm operations; attract new generations of farmers; and (4) Develop agri-tourism; bring sophistication to traditional products; diversify marketing strategies.

Protected cultivation could be one of many approaches to reach the goals of COA’s “Golden Agricultural Corridor”. For example, under the shelving or environmental controlled greenhouse facility, farmers are able to reduce the use of water, utilize solar power and generate from the structure itself, manipulate the environment for specified crops, and more. COA compensates fruit and vegetable farmers in the “Golden Agricultural Corridor” area...
those produce under protected cultivation and adopted the use of drip irrigation (Hsieh, 2014). With the increasing protected cultivation area, we can foresee the demand of pollinators for high economic value horticultural crop and the demand for tomatoes, cucumbers, peppers, egg plants, strawberries would also increase.

**IMPORTED BUMBLEBEES IN ASIAN AGRICULTURE**

Japan imported pollinator *B. terrestris* from the Netherlands, Belgium, etc. since 1992 (NIES webpage). Imported bumblebees in Japan showed great pollination efficiency, therefore in 2004, only this specified year, a number of more than 70,000 colonies of imported bumblebee were used (Goka et al., 2006). Various negative effects have been found few years after importation: (1) Competition (for nesting sites and plant use) with and reproductive interference to native *Bombus*; (2) Inter-specific copulation with some native species which resulted in non-viable offspring; (3) Prohibition of pollination of some native plants by nectar robbing; and (4) Having parasitic mites (*Locustacarus buchneri*). Nowadays, import, transport and keeping are prohibited in Japan by the Invasive Alien Species Act. Imported *Bumbus* pollinators are permitted only for agricultural purposes and in greenhouses with prevention of escaping by covering aperture part using net (NIES webpage).

Since 1994, Korea started to import *B. terrestris* from Europe to pollinate various crops in greenhouses. By 2004, many Korean producers are capable of producing commercial used bumblebees. In 2009, there were over 35,000 colonies (70%) that were produced by Korean bumblebee companies and 15,000 colonies imported from foreign sources (Yoon and Park, 2010).

*B. terrestris* was introduced in China in 1998 to pollinate crop plants (Xie and Tang, 2009). Because the cost of imported bumblebees was too high for farmers and they were not able to be reproduced, China started to develop indigenous bumblebee as pollinator.

In Taiwan, few researches have been done to evaluate the use of imported *B. terrestris* as pollinators. It was found that only during the cool season (December to February) that *B. terrestris* can completely replace manual treatments (hormone and electric vibrator treatments) showing better fruit set percentage, smaller fruiting size, same maturing fruit weight and sugar content etc. (Chen and Hsieh, 1996). Although the cost and efficiency of producing quality greenhouse tomatoes match the experiences of other countries, researches and applications of using commercial imported bumblebees as alternative pollinators in Taiwan are still deterred due to the restrictions of year-round high temperatures, quarantine concerns, and growing awareness of indigenes species conservation.

In Asia, some commercial companies rear and/or trade bumblebees for pollination. The *B. terrestris* was reared in Israel, Japan, Korea, Turkey, whereas in China *B. terrestris, B. ignites* and *B. lucorum* these three species were produced (Table 1) (Velthuis and Doorn, 2006).

Table 1. List of Asian countries with production facilities for bumblebee rearing and the names of the companies involved.

<table>
<thead>
<tr>
<th>COUNTRIES</th>
<th>COMPANIES</th>
<th>(sub-)SPECIES REARED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>Bio-Bee, Yad Mordechai</td>
<td>B. terrestris dalmatinus</td>
</tr>
<tr>
<td>Japan</td>
<td>Api Company, Cats Agrisystems</td>
<td>B. terrestris</td>
</tr>
<tr>
<td>Korea</td>
<td>Sesi Corporation, Yae-choon Industry, Mr. Lee</td>
<td>B. terrestris</td>
</tr>
<tr>
<td>Turkey</td>
<td>BBB, Biobest, Koppert</td>
<td>B. terrestris dalmatinus</td>
</tr>
<tr>
<td>China</td>
<td>Beijing Yong-An-Xin Biological Pollination Company</td>
<td>B. lucorum, B. ignites, B. terrestris</td>
</tr>
</tbody>
</table>

Source: Partially modified from Table 1 of Velthuis and Doorn, 2006 paper.
**POTENTIALS OF BUMBLEBEE IN TAIWAN**

**Temperature is critical for bumblebees to perform regular behavior**

Every bumblebee species have their suitable growth temperature range. Most bumblebee species are found in temperate climates, and are often found at higher latitudes and altitudes than other bees. In subtropical Taiwan, most of the nine ingenious species were habituated in higher altitude, only some can be found in places with lower altitude. In Taiwan, *B. eximius* workers exhibited normal activities within their nest under ambient temperature between 25-29°C and showed a drastic decrease number of foragers in the netting shelter when temperature exceeded 30°C (Sung and Chiang, 2014).

Fig. 3 demonstrated habitat temperatures and seasonal occurrences of Castes of three *bombus* species (*B. terrestris*, *B. eximius* and *B. sonani*) studied in Japan and Taiwan. Other than the fact that Hokkaido, Japan is located in higher latitudes, two Taiwan species also habituated in cooler temperature seasons and/or altitudes.

The “Golden Agricultural Corridor” developing region is flatland where average monthly temperature from May to September for 30 years is between 25.8-28.6°C; October to April is between 16.5-26°C (Taiwan Central Weather Bureau website, [http://www.cwb.gov.tw](http://www.cwb.gov.tw)). And with it higher adaptation to wide temperature range (16-28°C), *B. eximius* was found to be the most potential subtropical bumblebee pollinator in Taiwan (Chiang, 2009). It is suggested that the *B. eximius* could be used as major pollinators in the “Golden Agricultural Corridor” region from October to June. *B. sonani* and imported *B. terrestris* can also be used as pollinator from May to September under temperature controlled greenhouses.
Increasing need of greenhouse facilities and alternative pollinators

Greenhouse facilities are built to overcome climate conditions and are separated from the contamination of pests and through technologies. They are built for producing high economically yield crops like flowers, fruits, and vegetables. In Taiwan, protected cultivation facilities used for horticultural crops (fruits and vegetables) production occupied 25,647.64 hectares (Fig. 1). There are various types of protected cultivation structures (tunnel shed, shelving, netting shelter, greenhouse, and others); among them, shelving and netting shelter comprise more than 78% and greenhouse facilities only occupied 1.87% of protected cultivation land. Insect pollinators like honeybees have already been applied and released into shelving, netting shelter, and greenhouses; bumblebees have also been studied under shelving and greenhouse conditions (Sung and Chiang, 2014; Liberty Times Net, 2015; News & Market, 2015).

Greenhouses in Taiwan only occupied 1.87% of protected cultivation land; COA is compensating farmers involved in the “Golden Agricultural Corridor” project, especially those whose produce are under protected cultivation and those who have adopted the use of water saving drip irrigation (Hsieh, 2014). Indeed there are many advantages of growing horticulture crops in greenhouses. These include the following: (1) longer growing season / off season production; (2) plants, pests, and diseases isolation; (3) better conditioned environment, and etc. With the availability of flatland, more shelving / netting shelter are upgraded, and there is support (technologies, policies compensation and etc.) from universities, government, and industry. The demand of alternative pollinators like honeybees and bumblebees would also increase.

Bumblebees have the potential to be alternative pollinators in Taiwan

There are many positive aspects of facts and thinking those showing the increasing demand of using bumblebees as alternative pollinators to chemicals or other insect pollinators should be addressed: (1) consumers’ awareness of environmentally friendly production methods- Not using artificial chemical fertilizers/ pesticides; (2) consumption of organic produce increasing- organic farming ; (3) off-season production- environmental controlled greenhouses; and (4) higher fruit quality and increased total yield (Li, 2011; Sung and Chiang, 2014); and many more.

Taiwan can import foreign bumblebees with conditions

In Asia, many countries have started importing B. terrestris then go commercializing it locally. In China’s case, they also have commercialized B. lucorum and B. ignitus species (Table 1). Taking note from the negative effects of escaped imported B. terrestris that have already established colonies in Hokkaido, many Japanese feel threatened about their local species. Japan’s Invasive Alien Species Act now prohibits imperturbation and transportation of B. terrestris in the country; only agricultural use is permitted, and only in greenhouses with prevention of escaping by covering apertural part using nets. In Taiwan, importation of foreign bumblebees stayed in the stage of being used for research purposes only under the supervision of the BAPHIQ, COA. However, one should not ignore the positive benefits these pollinators can bring to the development of products with high economic value to the horticulture crops’ industry. It is also true that there are over 30 bumblebee producers in 19 countries in the world today (Velthuis and Doorn, 2006). Perhaps Japan’s Invasive Alien Species Act can be a good reference for the authority to considered and also open the imported bumblebees for agricultural use. Taiwan can import bumblebees under the conditions of “only in enclosed greenhouses”; and perhaps “use as pollinators should only be restricted in the flatland of the central to southern region (e.g. the golden agricultural corridor region)”, where average monthly temperature outside greenhouse during worker B. terrestris active season (May to September: 25.8-29.2°C) is unfavorable to their survival (Fig. 3).

CONCLUSION

The price of imported bumblebees are costly, and most temperate species have limitations in adjusting to local environment, posing threats to the balance of local species. In this regard, inputting more resources and fostering experts on studying indigenous bumblebees is critical in Taiwan.
Taiwan has the potential to produce indigenous bumblebees for commercial use. Among the nine indigenous bumblebee species in Taiwan, *B. eximius* and *B. sonani* were found to have potential for commercialization for local horticulture’s crop pollination (Chiang, 2009; Li, 2011; Sung and Chiang, 2014). However, techniques on how to expand the bumblebee colony to large scale; how to provide facilities that can accommodate their capacity to rear on a year-round basis; and how to find entrepreneurs who are willing to invest would be the challenges for now.

An ideal picture of developed commercialized Taiwan indigenous bumblebees industry would not only provide local farmers alternative pollinators, reduce their use of chemicals, get better quality produce, lower the labor cost for pollination. Moreover, the production of bumblebees can also be used for education. Because *B. eximius* is a subtropical species that has shown wider temperature adaptation range, perhaps in the future, it can also be exported to other subtropical countries for their agricultural use.

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