

August 2019

Bumblebees for Crop Pollination: Social Behavior

Case Study 15

Research goal	To understand the colony development, social behavior and reproduction of the buff-tailed bumblebee, <i>Bombus terrestris</i> , and to implement the findings of the basic research into successful rearing of the <i>B. terrestris</i> for industrial crop pollination.
Beneficiaries	Tomato growers, Growers of all crops that undergo pollination by bumblebees, Bee-rearing and pollination facilities, Environmental services, Habitat protection
Activities conducted in order to achieve the objectives	Study of the queen-worker dynamics in the two social phases of the <i>Bombus</i> colony development. Reproduction regulation and chemical signaling of the <i>B. terrestris</i> queen and workers
Funding	BARD awards: IS-2306-94, IS-3024-99, \$550,000.
Publications	11 journal publications.
Students involved	3 Ph.D. students. Current positions: 2 in academia, 1 in the US and 1 in Israel; 1 established a bumble bee rearing and research facility
Stakeholders' collaboration	Tomato growers, Seed industry, Biobee and Polyam bumblebee rearing facilities
Environmental impact	Nature preservation, Reduced use of pesticides, Enhanced biocontrol
Social impact	Enabled preservation of Israeli tomato industry when labor was lacking
Commercial engagement	Polyam - Yad Mordechai, Bizbee
Patents	none
Practical agricultural applications	Today, all US and Israeli greenhouse tomatoes are pollinated by <i>B. terrestris</i> and <i>B. impatiens</i> respectively. Worldwide pollination of tomatoes by bumblebees, primarily, <i>Bombus terrestris</i> . Bombus pollination leads to higher fruit quality and increased total yield, reduces costs in comparison to manual labor, provides an alternative to chemical pollination by hormones and reduces application of pesticides due to the necessity of biocontrol.
Economic impact	we could not estimate the direct contribution of the project, and therefore we did not attribute any benefit to BARD

1 Objective: To Study the Social Behavior and Reproduction Regulation of the Buff-Tailed Bumblebee.

The aim of the research was to understand the colony development, social behavior and reproduction of the *Bombus terrestris* (buff-tailed bumblebee) and to implement the findings of the basic research into successful rearing of the *B. terrestris* for industrial crop pollination.

2 Research Activities

BARD award IS-2306-94 was granted to A. Hefetz (Tel-Aviv University) and Gene E. Robinson (U. Illinois) in 1994 and BARD award IS-3024-99 was granted to A. Hefetz, Justin O. Schmidt (USDA, ARS) and Stephen L. Buchmann (U. Arizona) in 1999. See Appendix A for full details of the awards.

A. Hefetz's research focus is on evolution and mechanisms of social behavior amongst the social insects: honey bees, bumble bees and ants. The first BARD award followed upon a pilot study initiated by the Ministry of Agriculture, Israel, in which A. Hefetz together with Kibbutz Sde-Eliyahu reared a local sub-species of the *Bombus terrestris*, *B. t. dalmatinus*, to be used as pollinators for the local tomato growing industry (1991). Greenhouse tomatoes had previously been pollinated manually, and the bumble bee (BB) pollination was introduced to address an acute problem of labor stress. Local BB queens were collected from their wild environment and domestic colonies reared at the Sde Eliyahu facility (precursor to BioBee). Placement of the colonies in trial greenhouses in the Besor region led to successful tomato pollination. Tomato growers around the country were eager to adopt the technique and the demand for scale-up was immediate.

Following the introduction of this BB technique unto Israel, A. Hefetz collaborated with G.E. Robinson on BARD award IS-2306-94 to study key biological functions of the BB with respect to colony growth and social behavior; e.g. worker bee reproduction regulation, queen dominance and development from larvae to adult.

The natural cycle of a BB colony does not overlap with the tomato growing season (which is multi-seasonal in Israel) and understanding the social behavior of *B. terrestris* paved the way to facilitate colony manipulation and to adjust the colonies for specific pollination requirements. The basic research provided a knowledge base upon which BB rearing could be optimized.

The research conducted during BARD award IS-3024-99 aimed to enhance bee visitation (the North American *B. impatiens* and the Israeli *B. terrestris*) to male sterile tomato flowers used in the production of hybrid seeds. These flowers lack both pollen and nectar and are unattractive to bees. Exocrine products of the BB were tested as bee attractors, and some were shown to manipulate BB behavior and to lead to visitation to non-rewarding flowers. No practical applications emerged from this second BARD award.

3 Academic Impact

3.1 Publications

11 peer-reviewed journal publications have been published based on research from the 2 BARD awards.

3.2 Capacity Building

3 Ph.D. and a number of M.Sc. students were involved in the BARD supported research.

The BARD award leveraged funding for A. Hefetz from ISF and BSF for further research on evolution of chemical communication and social behavior of BB.

The two Israeli Ph. D graduates continued to BARD supported post-doctoral fellowships in the US. Guy Bloch conducted post-doctoral work with G. Robinson (PI on IS-2306-94) and continued in his laboratory for another 2 years after the BARD support terminated. G. Bloch is now Professor at the Hebrew University of Jerusalem. Jonathan Cnaani first continued to R&D at Polyam in the Israeli bee rearing industry and then conducted his post-doctoral research at the U. Arizona in collaboration with the bee research center at the USDA, ARS – Tucson. During this BARD post-doctoral fellowship at U. Arizona, J. Cnaani worked together with Prof. Daniel R. Papaj of the Ecology and Evolutionary Biology department, and continued to collaborate with him during subsequent post-doc research positions. This encounter was the instigation of D. Papaj's research interest in BB which is today a core interest of his research group. On his return to Israel, J. Cnaani established Bizbee, a commercial facility for rearing of *B. t. dalmatinus* colonies. J. Cnaani continued to research the social behavior of BB and to conduct genetic improvements to enhance the functionality of the colonies. Bizbee was acquired by Yad Mordechai 's bee rearing industry, Polyam, in 2014

The basic research with regard to BB evolution, social behavior, physiology and molecular and epigenetic studies to discover regulating factors of these have continued between the "successors" within the Robinson and Hefetz group. G. Bloch and G. Robinson received a BARD award together in 2011 researching the molecular basis of social evolution in BB, and their collaboration then continued through a later BSF award. H. Woodard, a Ph. D student in the Robinson group on this 2011 BARD award, now at Riverside CA, is collaborating with G. Bloch on a current BARD (2018) and BSF award. A student of G. Bloch joined the Robinson lab for post-doctoral research in 2013, and a BARD supported US post-doctoral researcher spent 2 years in the lab of G. Bloch (2012-14).

3.3 Stakeholder's Collaboration

The IS-2306-94 research was pioneering world-wide. Only a handful of laboratories at the time were involved in bumble bee social behavior research, and the BARD funded

research resulted in several breakthroughs in the understanding as to the functioning and regulation of the bee colony. These findings laid the grounds for most of the future work, not only of the researchers' laboratories, but also world-wide. The research findings also provided a platform for research on other social insects.

During the early IS-2306-94 research, connections were forged with many greenhouse tomato growers where domesticated colonies were set-up and the IS-3024-99 research forged connections with HaZera, a commercial seed company cultivating hybrid tomato seeds.

The Israeli researchers (Hefetz and Bloch) engage on an ongoing basis with the industry partners BioBee and Polyam. Services provision is reciprocal, i.e. acquisition of bees and colonies by the researchers from the industry but also provision of unique services to the industry by the researchers, such as controlled fertilization in order to diminish genetic diversity of the reared colonies. The academic groups are also in a position to provide early feedback on the quality of received colonies prior to them being placed for foraging, whilst the industry partners stay attuned to current and cutting-edge research.

3.4 Commercial Collaboration

BB rearing for pollination had previously been established and commercialized in Belgium in 1988 and a year later in Holland. Following the pilot study, Sde Eliyahu (BioBee) established the first commercial *B. terrestris* rearing facilities in Israel. This was conducted with the help of know-how from the Dutch company, Koppert who established *Bombus terrestris* pollinating colonies in 1988. Biobee provides colonies for local pollination needs and also export colonies to Chile and Japan.

A second BB rearing facility established in Yad Mordechai in 1995 benefited from the knowledge gained in award IS-2306-94 and follow-up research which was used as a foundation for the applied rearing methodologies. All bumblebee producers today have developed their own rearing systems, which are kept primarily secret¹.

4 Practical Agricultural Applications

Commercial BB rearing started in 1987. Israel was the fourth country (after Belgium, Holland and Canada) to commercially use BB for tomato pollination. BB pollination has been shown to be more effective than manual or “vibration/blower” pollination. It leads to higher fruit quality and increased total yield, reduces costs in comparison to manual labor, provides an alternative to chemical pollination by hormones and reduces application of pesticides due to the necessity of biocontrol. Today commercial

¹ Hayo H.W. Velthuis, Adriaan Van Doorn. A century of advances in bumblebee domestication and the economic and environmental aspects of its commercialization for pollination. *Apidologie*, Springer Verlag, 2006, 37 (4), pp.421-451. hal-00892201

greenhouse tomatoes are pollinated worldwide by BB, including most European Countries, North America, Chile and some Asian countries such as Japan, Turkey, South Korea and China.

Many subspecies of *B. terrestris* were used in the early years of commercial rearing. However, from the commercial point of view *B. t. dalmatinus* proved to have superior characteristics. It produces the largest colonies, the success rate in the rearing is the highest and it is resilient to many diseases.

Global estimates of colony production for 2010 are 1.2 million colonies of *B. terrestris* and 140,000 colonies of *B. impatiens* out of a total of 1.4 Million colonies.

Greenhouse tomato is the major crop for bumblebee pollination, together with other crops like sweet pepper, eggplant, strawberry, melon and courgette. Open orchards' fruit crops such as cherry, pears, apples, almonds, blueberry and avocado are also successfully pollinated by bumblebees. In Israel, open orchard fruit crops utilize a combination of honey bee and BB for enhanced pollination.

5 Environmental Impact

Bumblebee pollination cannot tolerate chemical applications to the crops around the time of flowering, and as such its application has promoted biocontrol of crops. Because of this strong interrelationship, most bumblebee producers have started to sell not only bumblebees for pollination, but also insects, mites and microorganisms for crop protection.

The research contributed to nature conservation in Israel and the Western US by developing colonization of the local sub-species of BB and thus preventing influx of non-native species. (e.g., today in Chile, the import of *B. terrestris* for pollination has been associated with rapid population declines of the native Chilean bee *B. dahlbomii Guérin-Méneville*).

6 Economic Impact

6.1 Investment Cost

The pilot study initiated by the Ministry of Agriculture contributed around \$10,000. BARD contributed \$550,000 in research funds between 1994-2002.

6.2 The Benefits

The total turnover of the bumblebee industry, including production of bio-control agents for crop protection, can be estimated at €100 million per year; of which approximately €5 million can be attributed to the bumblebee rearing industry. Up to 50 bumblebee colonies are used per hectare during the growing season. The price of bumblebee colonies differs

from one country to the next, depending upon the species that is reared, the volume of the market, transport costs.

One of the postgraduates who was involved in this project was later the CTO of one of the two commercial companies acting in Israel. Later he opened his own company. He estimates that the BARD project facilitated him in promoting and establishing these companies. However, we could not estimate its contribution and therefore we did not attribute any benefit to BARD.

7 Appendix A: BARD Awards

Table 1: Details of the BARD awards

Project No	Full Title				
	Investigators	Institutes	Budget	Duration	Start Year
IS-2306- 94	Hormonal and Pheromonal Regulation of Reproduction in the Bumble Bee <i>Bombus terrestris</i>				
	A. Hefetz Robinson, G.E.	Tel Aviv U U Illinois	\$300,000	3 years	1994
IS-3024- 99	The Use of Bee-Borne Attractants for Pollination of Nonrewarding Flowers: Model System of Male-Sterile Tomato Flowers				
	A. Hefetz Schmidt, J.O. Buchmann, S.L.	Tel Aviv U USDA, ARS U. Arizona	\$250,000	3 year	1999

8 Appendix B: Information providers: Personal communication

- A. Hefetz - Co-PI for BARD grants, Chemical ecologist and evolutionary biologist., Tel-Aviv University
- J. Cnaani - Bumblebee Array Manager at Polyam, Yad Mordechai.
- G. Bloch - Dept. of Ecology, Evolution & Behavior, Hebrew University