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Review Article

Apivectoring: Harnessing pollinators for sustainable crop protection and pollination

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ABSTRACT: Apivectoring, or Pollinator Biocontrol Vector Technology, employs bees to distribute biological control agents, offering a sustainable solution for managing plant diseases and insect pests while enhancing crop yield and quality. The most commonly used vectors in apivectoring are honey bees and bumble bees, though there's potential to explore other pollinator species. Commercial dispensers like BeeTreat Dispenser®, BVT Inoculum Dispenser® and Flying Doctors® have been developed in countries like Finland, Belgium, and Canada, respectively. Though initially pioneered in North America, Australia, and Europe, this method is now being evaluated in India. The technology is a promising alternative to chemical pest control, reducing pesticide usage and ensuring crop pollination, although challenges remain in regions deprived of local rearing and/or research facilities.

KEYWORDS: Apivectoring, biocontrol, diseases, insect pests, pollination

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INTRODUCTION

Pollination is a vital ecological process that plays a crucial role in maintaining biodiversity and ecosystem services. It acts as a link between agriculture and the cycle of life in terms of plant reproduction and crop production. Pollinators are the key factors contributing significantly to the crop yields in the agricultural economy since most of the cross-pollinated plants depend on vectors for the move of pollens from one plant to another (Gill *et al.*, 2016). Both managed bee species and wild pollinators contribute to enhancing the process of cross-pollination (MacInnis & Forrest, 2020). Animate agents such as bees, wasps, butterflies, moths, hoverflies etc. and inanimate agents viz., wind, and water carry out the process of pollination among plants. Cultivated plants are mostly pollinated by animate agents leading to 30 per cent of global food production. Bee pollination contributes to approximately one-third of the total human dietary supply, with *Apis mellifera* L. being the major bee-pollinating species worldwide. A variety of crops rely on bees for successful pollination, which includes fruits, vegetables and nuts. Pollinators not only increase the production of cross-pollinated crops but also enhance the quality of self-pollinated crops visited by them as compared to the unvisited ones, contributing significantly to worldwide economic and nutritional outcomes (Khalifa *et al.*, 2021).

Bees are renowned for their capacity to transport microscopic particles with the foremost of these being the pollen grains exhibiting a size range of 6 to 100 µm (Wodehouse, 1959). They have shown the ability to carry microscopic particles other than pollen such as fungal spores and bacterial cells from flower to flower. Some of these hurt the carrier itself, causing diseases, while others are harmful to the plants whose flowers are visited by the pollinators as demonstrated by *Erwinia amylovora* (Wael *et al.*, 1990; Morse & Nowogrodzki, 1990; Shaw, 1999).

The knowledge of bees acting as a vector of spores, bacteria and viruses has led to the idea of expanding the application of pollinators beyond pollination technology by covering crop protection in addition to crop production by using bees as carriers of bio-control agents in modern agriculture, which has led to the Pollinator Biocontrol Vector Technology (PBVT) approach *aka* apivectoring (Kevan *et al.*, 2005).

APIVECTORING

PBVT is a novel application strategy using bees as vectors of bio-control agents to suppress crop diseases and to some degree, insect pests (Hokkanen *et al.*, 2015). The objective of this technology is to reduce the reliance on synthetic pesticides and minimize the emergence of pest resistance while maintaining the quality and yield of crops (Macharia *et al.*, 2020).

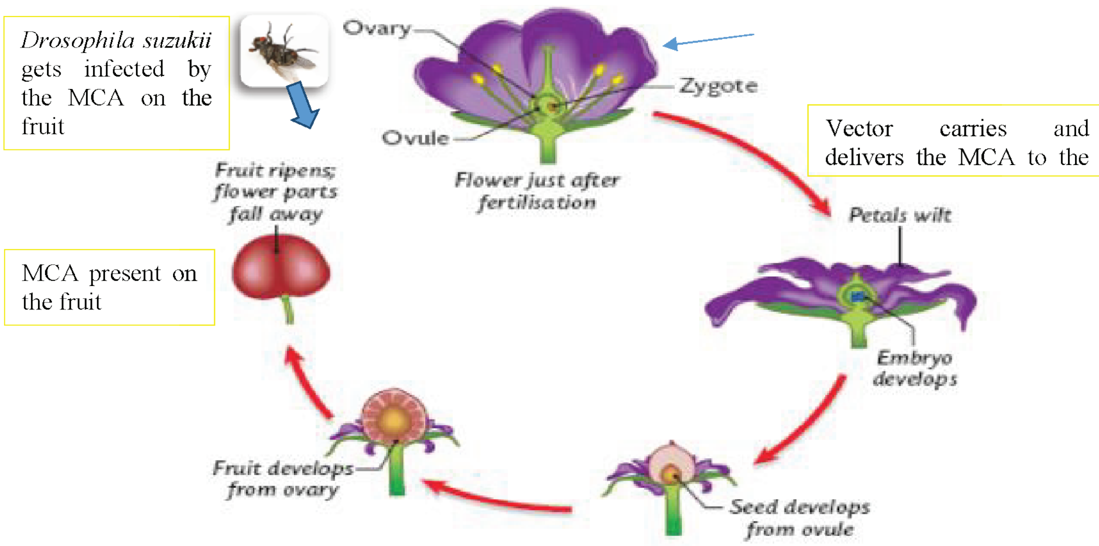

Figure 1. Management of *Drosophila suzukii* through apivectoring (Taning & Smagghe, 2020).

In bee vectoring technology, Bees transfer biological control agents onto flowers and protect the developing fruits (Kevan *et al.*, 2008). The potential of biocontrol agent *Metarhizium anisoplie* for the management of *Drosophila suzukii* with apivectoring technology has been well demonstrated in (Figure 1). In this scenario, the honey bee acting as a vector delivers the microbial agent to the flower during pollination. The microbial agent deposited on the flower sustains itself by preying on other insects residing on the flower until the fruit matures and ripens. *D. suzukii* attacking the fruits are exposed to the microbial agent present in the matured fruit, which leads to the cessation of *D. suzukii* (Taning & Smagghe, 2020).

HISTORY

The adoption of bio-vectoring technology poses a significant challenge to biodiversity conservation and represents a substantial threat to plant-pollinator interactions, the importance of which in contributing to crop productivity cannot be overstated (Ricketts, 2004). Emerging technologies that are reshaping agriculture, transitioning it from a labour-intensive industry to a capital-intensive one, include bio-vectoring technology, which came into existence with the idea of using pollinators as vectors of biocontrol agents (Al-mazra'awi *et al.*, 2006; Mommaerts & Smagghe, 2011). Vector-mediated biological control using pollinators started in the 1990s to transfer microbial control agents in the management of plant pathogens in North America, Australia and European countries but it is still being developed in several countries (Kevan *et al.*, 2003). Menzler-Hokkanen first introduced the term 'entomovector technology' from which the concept of apivectoring has been derived which refers to the utilization of insects as vectors for carrying microbial agents for plant protection (Hokkanen, 2007) (Table 1).

This technology proves particularly valuable for a wide range of pollinator-dependent crops. Managed bees, including honey bees and bumble bees, have been employed to transport the inoculum of fungi, bacteria, and viruses from the hive to the flowers (Kevan *et al.*, 2003). However, no such studies had been done under Indian conditions to disseminate BCA using entomovector technology until recently Vakaliya and Borad (2017) conducted research on pollinator biocontrol vector technology at Anand Agricultural University, Gujarat.

ELEMENTS OF APIVECTORING

Apivectoring has been utilized globally to manage crop pests and diseases for a long time, but its success depends upon several factors. The microbial agent used must be effective against the target pest without posing any harm to bee vectors. The bees should be able to disperse a sufficient amount of the agent on the target plant without affecting the yield and quality of the crop. An efficient dispenser needs to be designed in such a way as to ensure the dispersibility and precise dosage of inoculum at the target site without adversely impacting the health of the vector and non-target organisms, and it must be safe for consumption by both people and livestock. (Kevan *et al.*, 2008).

Therefore the elements involved in apivectoring technology benefiting the crop in need of protection from several pests and diseases including:

Pollinators as vector

Managed bees such as honey bees, bumble bees and mason bees have been employed to transport inoculum, including fungi, bacteria, and viruses, from the hive to the specific target flowers (Kevan *et al.*, 2003). Honey bees and bumble bees (*Bombus terrestris*, *B. impatiens*) have mostly been used as the vector in apivectoring followed by

Table 1. Apivectoring in the management of crop diseases

Microbial agent	Pathogen/Pest	Pollinator/ Vector	Crop	Location	References
Gliocladium roseum	Gray mold	Honey bee	Strawberry	Ontario, 1992	Peng *et al.* (1992)
		Bumble bee		Ontario, 2012	Sutton and Kevan (2012)
Pseudomonas fluorescens	Fireblight	Honey bee	Pome fruits	USA, 1992	Thomson *et al.* (1992)
Pantoea agglomerans				New Zealand, 1998, 2002	Vanneste *et al.* (2002); Cornish *et al.* (1998)
Trichoderma harzianum	Gray mold	Honey bee and/ or bumble bee	Strawberry	Italy, 1999	Maccagnani *et al.* (1999)
				USA, 2000	Kovach *et al.* (2000)
				Israel, 2006	Shafir *et al.* (2006)
				Quebec, 2009	Albano *et al.* (2009)
(*T. harzianum T. polysporum*)	Cucumber rot	Bumble bee	Greenhouse cucumber	Sweden, 2000	Svedelius (2000)
T. harzianum	Sunflower head rot	Honey bee	Sunflower	Argentina, 2002	Escande *et al.* (2002)
B. subtilis	Mummyberry	Honey bee	Rabbiteye blueberry	USA 2005	Ngugi *et al.* (2005)
B. subtilis	Fire blight	Honey bee Mason bee	Pear	Italy, 2006	Maccagnani *et al.* (2009)
Coniothyrium minitans and *T. atroviride*	Alfalfa blossom blight	Alfalfa leafcutting bee	Alfalfa	Alberta, 2005	Li *et al.* (2005)
T. harzianum + *G. virens*	None indicated	Bumble bee	Greenhouse	Italy, 2005	Maccagnani *et al.* (2005)
Gliocladium catenulatum	gray mold	Bumble bee	Strawberry	Belgium, 2011	Mommaerts *et al.* (2011)
Clonostachys rosea + *Bt*	Sunflower head rot + sunflower moth	Bumble bee	Sunflower	Ontario, 2012	Sutton and Kevan (2012)
Streptomyces griseoviridis	Blueberry blossom blight	Bumble bee	Rabbiteye blueberry	USA, 2011	Smith *et al.* (2012)
Clonostachys catenulatum	Monolinia brown rot	Honey bees	Cherry	S. Australia	Hoogendoorn (2014)

Table 2. Apivectoring in the management of insect pests

Microbial agent	Pathogen/Pest	Pollinator/ Vector	Plants	Location	References
Heliothis NPV	Corn earworm	Honey bee	Crimson clover	USA, 1994	Gross *et al.* (1994)
Metarrhizium anisopliae	Pollen beetle	Honey bee	Canola (rape seed)	UK 1998, 2007	Butt *et al.* (1998), Carreck *et al.* (2007)
Bt	Banded sunflower moth	Honey bee	Sunflower	USA, 1999	Joyoti and Brewer (1999)
Beauveria bassiana	Coffee berry borer	Honey bee	Coffee	Australia, 2002–3	Urena and Chuncho (2003)
Beauveria bassiana	Tarnished plant bug (TPB)	Honey bee	Canola & Sweet Pepper	Ontario, 2006	Al-mazraawi *et al.* (2007)
Metarrhizium anispoliae	Pollen beetle + cabbage seed weevil	Honey bee	Canola	UK, 2007	Carreck *et al.* (2007)
B. bassiana + *Clonostachys rosea*	TPB, Green peach aphid, whitefly, Western flower thrips,	Bumble bee	Greenhouse tomato and pepper	Ontario, 2008	Kapongo *et al.* (2008)
HaNPV	Pod borer	Honey bee	Pigeon pea	India, 2017	Vakaliya and Borad (2017)

solitary bees such as *Megachile rotundata*, *Osmia bicornis*, *O. cornuta, O. lignaria* and *O. cornifrons* (Maccagnani and Sgolastra, 2020).

Honey bees and bumble bees collect pollen on their hairy bodies and transfer it to the pollen basket or corbicula (plural corbiculae) of the tibia on the hind legs. Unlike other bees, mason bees carry pollen on their abdominal scopa (pollen-carrying hairs) through which it lands on the flower collecting the most pollen, i.e., why their pollination rate is better than honey bees as they do not have a hive so all of the pollen they collect stays with them and are used by them whereas, honey bees have a colony to support and carry most of the pollen they collect back to the hive (McKinney & Park, 2012).

Selection of a vector

Matching the synchrony between foraging activity or availability of the pollinator with the blooming period of the protected plant is the primary step for considering a pollinator as a vector in this technology (Mommaerts & Smagghe, 2011). Selection is done according to the crop in need of protection and the crop visitation rate of the vector, e.g. crops belonging to the Asteracee and Brassicaceae family are better pollinated by honey bees and wild bees but mostly disliked by solitary and bumble bees. Fabaceae family is seen as particularly attractive to bumble bees and the Rosaceae family is frequently visited by mason bees which are efficient pollinators of apples, pears and almonds (Maccagnani & Sgolastra, 2020).

Choice for the most suitable vector also depends on weather conditions which affects the flying capacity of the pollinator and further its ability to transfer microbial agents. Honey bees visit more plants on a good weather day and have mostly been used but do not fly under rainy conditions. Whereas bumble bees perform better under cold or rainy weather as they can fly at lower temperatures and in conditions with reduced light intensities. (Mommaerts *et al.*, 2010a). Therefore, prioritize using locally available pollinators wherever feasible and exotic species, if needed should always be used after proper risk assessment as they threaten biodiversity by outcompeting the local species.

Biological control agents

Selection of biocontrol agents

Bee Vectoring Technology (BVT) only works with those biological control agents that are registered and authorized by the respective country. Commercial formulations to be used in the technology need to have several properties (Kevan *et al.*, 2020):

- Should be Capable of adhering effectively to the bodies of insect vectors, yet able to dislodge upon reaching the target flowers.
- Should not be overly irritating to the vectors, preventing them from grooming the material off their bodies before reaching the target flowers.
- Should not induce health problems or mortality in the vectors.
- Must maintain a dry and flowable state in the dispensers for the duration of application despite becoming moistened by faeces.
- Should be easily applicable.

Carrier material

The diluent or the carriers are significant for biocontrol agent formulation to have maximum particle loading and better dispersal. In bee vectoring technology, several carriers have been tested with different biocontrol agents *viz.,* wheat, barley, oat flour, maize meal, potato starch, potato flakes, talc and maize flour. The carriers, such as corn flour and wheat flour resulted in more efficacious transport of the agent. However, some carriers especially scented talc have been found irritating to the vectors and they groomed the formulation off their bodies before reaching the flower (Israel & Boland, 1993).

Registered biocontrol agent for bee vectoring technology

The Pest Management Regulatory Agency (PMRA) has announced the approval of Botanigard® 22WP (*Beauveria bassiana* strain GHA) to be used in novel pollinator biocontrol vector application method on greenhouse crops to control whitefly, aphids and thrips at lower application rates through continuous delivery of bioinsecticide to the target on January 17, 2013, at Ottawa. In this, 1/4th of the recommended dose of fungus is thoroughly mixed with dry corn starch of particle size less than 125 µm To ensure minimal mortality of bees and maximize mortality of pests.

Pre-Stop Mix® (*Gliocladium catenulatum* Strain J1446) earlier known as Lalstop G46^{WG} was registered in 2009 to be used against seed-borne and soil-borne plant diseases such as damping-off, root or stem rot and wilt. It was 1st developed for the protection of strawberries against gray mould and is deemed safe for Honey bees and bumble bees. Two hives equipped with dispensers of Prestop Mix are recommended to be used per hectare for the 1st week and the number is further increased or decreased depending upon the bee activity (Hokkanen *et al.*, 2015).

Dispensers for apivectoring

In apivectoring technology, bees traverse a dispenser containing microbial inoculum, collecting the biocontrol product on their legs and body hair. As they engage in foraging and grooming activities, they deposit the loaded biocontrol agent onto plant foliage and fruits. Therefore the dispenser is known as a "means of dosing the vector", i.e., ensuring an effective transfer of the biocontrol agent by the vector.

A dispenser is found suitable if it has the following properties (Mommaerts & Smagghe, 2011):

- Loading of a vector with sufficient biocontrol agent e.g. honey bees exiting the hive through a dispenser carry 58 per cent propagules on the legs, 23 per cent on the thorax, 14 per cent on the abdomen and 5 per cent on their head capsule to be deposited on the target (Kovach *et al.*, 2000).
- low dispenser reloading interval: should be two times a week in bumble bees and once every 10 days in honey bees.
- Should be easy to mount.
- Should not affect pollinators' food-searching capacity.

TYPES OF DISPENSERS

One way dispensers

These dispensers have only one slot made at the bottom for bees to come and go out, making them Pass through the powder during both exit and entry from the hive.

Honey bees

A Harwood dispenser designed for honey bees consists of a wooden trough placed at the bottom of the hive to hold BCAs whereas A tub dispenser comprises dual wooden blocks enclosing a pliable acetate sheet, shaping a container capable of receiving powder for transport by the bees. There is only one chamber or slot for the vector to enter as well as to leave. Such dispensers used for biological control were not successful as they caused a lot of wastage of BCA and less quantity of particles were carried by vectors which led to the development of 2-way dispensers (Smagghe *et al.*, 2013).

Bumble bees

In the SSP dispenser, Two adjacent pathways are created, one featuring a zig-zag design with inclined walls, filled with inoculum, which is normally illuminated to attract outgoing bees and the second one forms a linear pathway designed for bumble bees returning to the nest. However, this dispenser proved ineffective in segregating outgoing and incoming bees, as only 12.5 per cent of bumble bees exiting the dispenser carried powder, that too of low concentrations as only one slot is present to enter or to exit. Moreover, caking and crusting of inoculum due to the secretion of fluids by bumble bees could also occur (Maccagnani *et al.*, 2005).

Two-way dispensers

The chambers for exit and entrance are entirely segregated, ensuring that only vectors leaving the nest come into contact with the powder in the case of two-way dispensers.

For honey bees

The Peng dispenser comprises a wooden platform supporting a plexiglass tray containing the microbial agent. Positioned vertically at the bottom of the hive, the light passing through attracts bees to traverse the powder and move onto the panel, leading towards an exit slot. Returning honey bees access the hive through a slot beneath the wooden platform, avoiding contact with the powder upon entry (Peng *et al.*, 1992). The Peng dispenser was utilized for the dispersion of *B. bassiana* by honey bees to manage tarnished plant bugs (*Lygus lineolaris*) on canola flowers. The percentage of mortalities in adults collected from bee-delivered living *B. bassiana* conidia was significantly higher compared to the heat-inactivated or non-*B. bassiana* canola blooms (Al-mazra'awi *et al.*, 2007).

The Gross dispenser, devised by Gross *et al.* (1994), is crafted to fit into the front centre of a modified bottom board of a honey bee hive. It features a removable tray for loading powder into the dispenser, which can be inserted from the side. Vakaliya and Borad (2017) evaluated honey bee as entomovector of HaNPV in Gujarat, India for the control of *H. armigera* on pigeon pea flower, which showed that the distance between the dispenser and target field/ flower influenced the mortality rates of the pest and resulted in maximum mortality at 10 m distance (20.0%) followed by 50 m (14.64%) and 100 m (10.01%) distance from dispenser.

The Triwaks dispenser contains an extended wooden dispenser fitted to the Langstroth hive. The dispenser is bisected at an angle, forming two triangular sections, the exit compartment with dry formulation and its longest side facing the hive and concluding with the shortest side away from which light comes inside and attracts the bee leaving through that portReturning foragers encounter a spacious landing platform, concluding with its briefest side facing the nest. This design ensures that honey bees enter the hive through the section of the dispenser without powder (Albano *et al.*, 2009).

Bumble bees

The OP dispenser has two overlapping passageways and a hole present between the upper and lower passageways to communicate. In this, Bees accessed the hive through a distinct entrance hole on the nest wall, while departing bees traversed the upper passageway. Upon reaching the lower hole, they moved through the inoculum towards the exit (Maccagnani *et al.*, 2005). Mommaerts *et al.* (2010b) dispenser, tailored for bumble bees, features two rectangular sections: an exit compartment with a bottom grid housing the powder formulation and a smaller entrance compartment.

The Houle dispenser, crafted for both honey bees and bumble bees, is horizontally partitioned. It comprises an upper compartment housing a powder tray and a lower compartment free of powder. Departing bees follow a zig-zag path through the inoculum before exiting the hive through the upper compartment. Returning bees get entry from different openings through the lower compartment. One major limitation of this dispenser occurs in open field trials, causing the powder formulation to clump. This, in turn, may lead to a reduced loading of the bees. (Albano *et al.*, 2009).

Mason bees

The solitary bees are emerging as an appropriate vector in entomovector technology for which several two-way dispensers have been designed. MB 13 dispenser could not attain much success, because bees were not adapting well to this dispenser, i.e., why it was modified to MB14 (mason bee) dispensers by Maccagnani *et al.* (2014) for *Osmia cornuta.* The dispenser is placed at the top of the hive. Returning bees quickly learn to enter by flying above the dispenser, while the exit path requires mason bees to walk on the bottom of the dispenser to reach the exit slot. The Biological Control Agent (BCA) is distributed on a horizontal plastic support positioned at the bottom of the dispenser.

Nest tube Dispenser has proven to be suitable for *O. cornifrons* bees, and is modeled after the dispenser designed for the European orchard bee, *O. cornuta*. Constructed from wood, it features an exit ramp made of transparent plastic with a shallow station at the base for holding the biocontrol product in either fine powder or granular form and a flap which only allows bees to exit but not to enter. Above the exit point, a transparent screen Permitting light to enter solely from above attracts the bees upward towards the exit ramp. They colour-coded entrance tubes so that upon returning, the bees could remember and enter through the respective entrance tubes. Joshi *et al.* (2020) carried out the study to test the amount of *Bacillus subtilis* carried by the orchard bee, deposited on crabapple flowers, which ranged from 9×10^6 to 1.3×10^7 CFU/bee.

The OP and SSP dispensers have been compared by Maccagnani *et al.*, (2005) in which, the load of biocontrol agent *Trichoderma harzianum* transferred by the vector leaving through OP dispenser was higher (100%) with135.3 CFU/ flower as compared to the SSP dispenser (12.5%) with 69.7 CFU/ flower. In addition to the OP dispenser, Mommaert's dispenser is proved to be better than the SSP dispenser in terms of loading of vector (Mommaerts *et al.*, 2010b).

Commercially Available Dispensers

Currently, some companies have established business models centred around entomovectoring technology and are commercially available to be used in different countries, such as:

BeeTreat Dispenser® (Finland, Europe)

It is a dual-purpose dispenser developed by Hokkanen *et al.* (2011) to safeguard organic strawberries from gray mold using a fungal antagonist. Initially designed for Langstroth-type beehives, it has proven compatibility with all hive types. The frame easily attaches to beehives using a straightforward rubber strap. Once attached, the landing platform is set in place. After a brief acclimation period for the bees, the microbial formulation (5g) is positioned at the dispenser exit, requiring daily refilling. Departing honey bees traverse the powder beneath the plexiglass plate to exit the hive. Upon return, they land on the top of the plexiglass plate and enter the hive through a separate entrance, preventing contact with the BCA formulation.

Flying Doctors®by Biobest (Belgium, Europe)

It is a commercial dispenser for *Bombus terrestrispented* by Biobest Company and is based on the Mommaert's dispenser. Bees depart from the dispenser via a loading tray and access the hive through a distinct entrance. A transparent sealing flap is there on the top of the exit which guarantees that bees will return to the hive by hive entrance only. The additional benefit of this dispenser is that the tray can be loaded with either a biological control organism (BCO) for crop protection or with commercially available pollen to enhance crop pollination. with refilling twice a week to maintain the viability of either BCA or pollen (www. biobest.com).

BVT Inoculum Dispenser® (Canada, N. America)

It is a commercially available two-way dispenser for bumble bees patented by Bee Vectoring Technologies International Inc. It consists of disposable trays (Vectorpak™) to hold the biocontrol agent along with a special lid that allows easy and safe replacement of the Vectorpaks. A flap is present at the entry point that compels exiting bees to traverse the dispenser, ensuring that they interact with the content so that it gets smeared with formulation and carries it to flowers. An additional cap is present near the entry and exit point which closes fully to keep the bees inside the hive in case of pesticide application in the field.

STEPS FOR SETTING UP A DISPENSER

Select a crop in need of protection, Pollinators visiting the crop flower can act as a vector, BCA is effective against pests but safe for non-target organisms Dispenser as means of dosing the vector

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Attach a suitable microbial product dispenser to the beehive at low bee activity, i.e., early morning/late evening

↓

Allow bee to adapt to entry and exit points of the dispenser for 1 week

↓

Evenly fill inoculum of BCA in dispenser up to 3-5 mm depth

↓

Weekly monitor the dispenser for bee activity. If low, should be removed immediately

↓

Change of inoculum in the dispensers weekly or sooner, to keep it in powder form as caking and crusting can happen or it can become very hard for the bee to pick it

↓

Discard microbial contents according to disposal instructions

↓

Dispensers should be rotated randomly amongst the hives

↓

Check for pest density and plant damage, after 3-4 weeks

↓

If required, the amount of hives with dispensers can be increased, decreased or remain the same

VECTOR, HUMAN AND ENVIRONMENT SAFETY

The potential risk a substance poses to humans or other organisms depends on two factors: its toxicity and the extent of exposure to the organism. Bee Vectoring Technology exclusively employs Biological Control Agents (BCAs) authorized by the respective country. The fungus used in this technology thrives only at temperatures lower than the human body temperature, and no infection is anticipated e.g. *Beauveria bassiana* has successfully met the registration requirements in numerous countries including India with no side effects found with the application of this fungus as it is known to grow at 8-35°C temperature and not beyond that range (Keswani *et al.*, 2013).

The biological control agents tested thus far appear to be safe for Honey bees and bumble bees, except when present in extremely high concentrations, as seen in commercially sold formulations of powders or liquids. To guarantee the absence of adverse effects on humans, vectors, or the environment, comprehensive risk assessments, including safety and product registration procedures, must be conducted. Therefore, additional topical tests play a crucial role in establishing a system that does not harm the vector (Al-mazra'awi, 2004; Kevan *et al.*, 2020). The effect of different BCAs has been tested on bumble bees by feeding them with treated pollen or artificial food materials. Mortality rates of bumble bee workers were higher when fed with treated sugar syrup than in treated pollen. *Bt* var. *kurstaki* and azadirachtin were classified as highly toxic, *Paecilomyces fumosoroseus* PFs-1 was weakly toxic and *Beauveria bassiana* Bb-1 and *Lecanicillium lecanii* V1-1 were non-toxic to workers of *B. terrestris* On the fifteenth day under the sugar syrup treatment (Demirozer *et al.*, 2022).

Advantages

- Apart from steering clear of chemicals with potential adverse effects on the environment or human health, bee vectoring presents various advantages over traditional spraying methods. It maximizes benefits by integrating pollination with pest control.
- Bees deposit the inoculum precisely within or on the flowers of the crop, thereby reducing the wastage of biocontrol agent into the soil or air as the inoculum is directly delivered to the flowers and leaves where the pest is located., hence minimizing the impact on non-target insects and reduced labour costs.
- This technology provides consistent dissemination of microbial control agents as bees pollinate the plants daily and deposit the BCAs onto the flower as compared to the single spray of biocontrol agent (Kevan *et al.*, 2003).

- Moreover, apivectoring is an environment-friendly approach as it uses no water and reduces the amount of active ingredients put into the environment.

WHY ISN'T EVERYONE USING APIVECTORING

Although this technology has been designed to address various plant diseases and pests, but it has mostly been effective on the pathogens, whose infection starts from the flower as the colony-forming units of biocontrol agent deposited on the leaves by the bee species are comparatively less than in flowers. Furthermore, the microbials are well known for their slow infection process on the target host, therefore for this technology to work, they must be applied early, as this cannot be a curative measure due to its vulnerability to several different variables such as bad weather affecting the flying capacity of bees and caking or crusting of the biocontrol inoculum.

CONCLUSION AND FUTURE PROSPECTS

Pollinator biocontrol vector technology represents a multidisciplinary pest management approach that integrates various ecosystem components, including pollinators, microbial control agents, and insect pests, into the crop production system. It provides dual advantages of crop pollination and crop protection. Therefore, apivectoring could be an important alternative to chemical methods of pest control as it minimizes pesticide usage while enhancing crop pollination. Despite the practical challenges faced by countries lacking local rearing facilities or pertinent research, the utilization of local species/populations for future entomovectoring mitigate transport issues. Furthermore, these investments may play a crucial role in preserving pollinator biodiversity at the local level. The biological control agents have only been registered on a country level that too in American and European countries with maximum research on the technique. Therefore, there is a requirement for international guidelines for the registration of biological control agents for bee vectoring technology to make it convenient for other countries that are currently working on this and are still developing the research. Manufacturers of biocontrol products should be incentivized to enhance the development of products and their formulations tailored specifically for entomovectoring. This is essential as current formulations are suboptimal, having initially been optimized for other purposes.

Although this technique has been proven safe for the bees used as vectors only a few studies on the fecundity of the queen and sub-lethal behavioural effects of the BCA on adult Honey bees have been conducted, which necessitate more testing on (sub)lethal effects on the vectors upon topical exposure. but the successful implementation of this technology on a global scale requires a unified global policy to regulate and standardize the application process. Continued research is needed to optimize the various components of the technology, including perfecting the design of the dispensers to ensure effective loading of the vectors and minimize the wastage of biocontrol agents. Additionally, in-depth studies on the safety of the vectors, the crops, and the environment are necessary to ascertain long-term impacts. Moreover, further research is also required to determine the long-term economic viability of the system compared to traditional chemical control methods. With the increasing emphasis on sustainable agricultural practices and organic farming, apivectoring offers a potential game-changer in the way we manage pests and diseases. As the technology becomes more refined and widespread, it could usher in a new era of eco-friendly and efficient crop protection. The promotion of apivectoring in developing countries can be supported by global partnerships and collaborations to share knowledge, technology, and best practices. Moreover, the setup of local research and rearing facilities can ensure the sustainable and successful adoption of this technology. In conclusion, while apivectoring offers a promising solution to some of the current challenges faced in sustainable agriculture, its effective global adoption requires collaborative efforts, extensive research, and an understanding of the local agricultural landscapes and pollinator populations. Pollinators other than the honey bees, bumble bees and mason bees should be explored which can be present and available throughout the year to enable year-round functioning of apivectoring technology.

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