BEENOW 2017

The Bee Health Magazine

Intensive Agriculture – Intensive Debate
Pollinator Health in Belgium and the Netherlands

Bee health in Australia and New Zealand
Pollinators in the Southern Hemisphere

Safety First!
Bee Safety Testing in Pesticide Development

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bee care

EDITORIAL

Pollinators and their health not only impact the livelihoods of farmers, beekeepers and pollination service providers but also the quality of life and healthy lifestyle that so many of us enjoy.

As the world population continues to grow, we need to contribute to the protection and conservation of pollinators and, at the same time, help farmers optimize their agricultural productivity in a sustainable manner. This is, naturally, an area in which Bayer is highly interested in contributing to progress. Pollinators need us to join forces to ensure their health and safety. It is important that we exchange knowledge, seek understanding, discuss options and take appropriate action.

In 2017, the Bayer Bee Care Program celebrates five years of dedication to promoting excellence in pollinator science, communication and dialog with stakeholders. The program comprises over 30 collaborative research projects worldwide, addressing some of the main threats and opportunities for pollinators and pollination and helping farmers optimize their harvests.

In this edition of the BEENOW magazine, we cover a selection of the projects and collaborations, showcasing tailor-made local and regional approaches.

These include examples from each of the three key areas of our program, namely **Feed a Bee, Healthy Hives** and **Sustainable Agriculture**.

We see it as a crucial part of our mission to contribute to bee and pollinator health via cutting-edge research and educational activities.

As such, we are fully committed to continuing to invest in pollinator health in line with our mission:

Science For A Better Life.

Liam Condon
Member of the Board of Management of Bayer AG and Head of the Crop Science Division

CONTENT

At Bayer, we take a keen interest in promoting and protecting the health of pollinators and do so via our Bee Care Program. This focuses on three key areas: Feed a Bee, Healthy Hives and Sustainable Agriculture. Partnerships and collaboration with bee experts around the world are key, to advance pollinator health in a tailored way. This edition of our BEENOW magazine demonstrates some of our undertakings.

COMMUNICATION AND DIALOG

Feed a Bee
- ✓ Foraging and nutrition
- ✓ Pollinator biodiversity

Healthy Hives
- ✓ Control of honey bee pests and diseases
- ✓ Hive management

Sustainable Agriculture
- ✓ Responsible product use
- ✓ Beekeeper – farmer relations
- ✓ Crop pollination

FEED A BEE

HEALTHY HIVES

SUSTAINABLE AGRICULTURE

Can Flower Strips Enhance Fruit Pollination?

Flowering strips in fruit orchards not only offer a more varied diet to honey bees but also provide flowers which are essential for other pollinators to forage there, so promoting pollinator biodiversity in some crops. But does an increase in pollinator biodiversity actually translate into enhanced fruit pollination in orchards? A three-year study near Lake Constance, in southern Germany, began in spring 2017 to better understand which of three selected flower seed mixtures is most appropriate to best support pollinator diversity. Also, whether flowering strips in the crop translate into better pollination services. Bayer is working together with Professor Alexandra-Maria Klein from the University of Freiburg in Germany to answer these questions.

“So far, many research projects have only analyzed the effects of ecological enhancement measures on pollinator biodiversity in general, but haven’t necessarily connected that biodiversity to actual pollination services for a crop,” explains Dr Juliana Jaramillo, Global Scientist at Bayer Bee Care. “In this study using apple orchards as a model case, we also want to determine the potential value of increasing biodiversity for the farmer, in terms of apple fruit set, fruit yield and quality.”

In addition, flowering strips can also attract and host beneficial insects that could help to naturally control apple insect pests. Researchers of this project are working in orchards that use typical Integrated Pest Management practices so this can be taken into account as well. The project’s results will help in giving recommendations on suitable yield enhancement measures in the agricultural setting.

Planting flowering strips in apple orchards may support pollinator diversity. Does it also bring additional benefits for farmers?

Barbados Bees Have Adapted to Survive

On the island of Barbados, honey bees have seemingly become resistant to the *Varroa* mite (seen here on a honey bee).

In 2003, beekeepers on the island of Barbados faced the worst-case scenario. The *Varroa* mite had devastated honey bee colonies to such an extent that both feral and managed colonies were almost wiped out. Beekeeping was virtually not possible any longer and many beekeepers saw their hives abandoned. Yet within six to eight years of *Varroa* arriving on the island, the number of colonies and swarms sharply increased – the surviving bees which were apparently resistant to *Varroa* had passed on this resistance to their descendants, so that beekeepers can now keep their bees without the need of *Varroa* treatments.

The key question remains, how were these bees adapted to survive? A question that scientists at the Arista Bee Research Foundation in the Netherlands and the Bayer Bee Care Center are eager to answer, with Barbados as their ‘Darwinian Evolutionary Laboratory’. Together they will analyze the evolution of the *Varroa* resilience on the isolated island, with beekeepers that did and do not use chemical treatments against *Varroa* on their bees – a rare opportunity. BartJan Fernhout, the study’s project leader and founder of Arista Bee Research, adds: “Our aim in this project is to determine the mechanism behind *Varroa* resistance. Which trait(s) did the bees on Barbados develop to become resistant and is the known behavioral trait Varroa Sensitive Hygiene (VSH) the dominant one?”

This collaboration project started in the summer of 2017 and preliminary results are expected by 2019. The gained knowledge may prove vital for beekeepers particularly in Europe and North America in their fight against *Varroa*.

Survival of the Fittest

Can we select for *Varroa*-resilient bees? The answer may be yes. Yet conventional apicultural practices such as the continuous treatment against *Varroa* mite are impeding natural selection for honey bees which can cope with *Varroa* infestation. Plant Research International of Wageningen University in the Netherlands has, via natural selection of some of their own honey bee colonies, introduced traits that make the bees more resistant to the *Varroa* mite, which include behavioral and physiological characteristics.

Introducing *Varroa* resilience through natural selection of honey bee colonies may be a way forward.

Led by Senior Scientist Dr Tjeerd Blacquière, at Wageningen University the future aim of the project "Natural selection for *Varroa*-resistant honeybee colonies" is to develop a verified and evaluated protocol for bee-keepers based on the methods used in selective breeding. Interested beekeepers in Germany and the Netherlands will be assisted through this process by Wageningen University and their partners in this project, including the Bayer Bee Care Center. Despite the program's promise, Blacquière says there is much work ahead: "We still need to learn why and how some bee colonies cope with *Varroa*, and how or why *Varroa* no longer impacts these particular honey bee colonies."

For Peter Trodtfeld, bee expert and bee-keeper at the Bayer Bee Care Center, it is worth the effort: "Breeding *Varroa*-resistant bee strains may be the more sustainable option in the long-term".

Understanding Vegetable Pollination in Kenya

Roughly one-third of Kenya's gross domestic product depends on agricultural crops, such as vegetables. Some of these crops depend on a diverse range of insects to provide pollination services that help increase crop yield in terms of quality and quantity. To improve the understanding of the pollination of indigenous and other vegetables in Eastern Kenya, Bayer is working on a new project in collaboration with the National Museums of Kenya (NMK), two local counties women's groups, a geographic information system (GIS) specialist and two local universities. The aim is to gain fundamental information about diversity and abundance of pollinators throughout the year and their contribution to vegetable production, including better seed production, for enhanced quantity and quality yield of these vegetables in two dryland counties (Machakos and Makueni). In these arid and semi-arid counties, surveys and fieldwork are being conducted to provide smallholder farmers and local communities with better knowledge about pollinators, their habitats, conservation and enhancement. Dr Juliana Jaramillo, Global Scientist at Bayer Bee Care, explains another aspect of the project: "Good pest management practices to protect crops, while maintaining pollinator health, are of great importance for enhanced crop yields in vegetable farming. We are showing how these can work together for the benefit of farmers and the environment in Kenya." The project, which began in June 2017, is set to run for two years.

In Machakos and Makueni, Kenya, crops such as vegetables are mostly grown by women on smallholder farms.

INTERESTING FACTS ABOUT OUR TOPICS:
HEALTHY HIVES, SUSTAINABLE AGRICULTURE AND FEED A BEE.

FACTS AT A GLANCE

WORLDWIDE **INCREASE**

65%

OF MANAGED HONEY BEE COLONIES

Since 1961, the overall number of managed honey bee colonies worldwide has inceased by some 65 percent.

Source: FAO

BILLION-DOLLAR POLLINATORS

Worldwide, about 75 percent of the most important food crops depend, at least in part, on pollination by insects. Every year, insects, including bees, in this way contribute around 235 – 577 billion US dollars to the global economy. That is up to eight percent of the global crop production.

Source: IPBES pollination report, 2016

OVER 20,000 DIFFERENT BEE SPECIES

There are over 20,000 different species of bees in the world; most of them are wild bees. Approximately 80 percent of the pollination of crops worldwide can be attributed to the activities of only 2 percent of wild bee species.

Sources: IPBES pollination report, 2016
Kleijn et al., 2015 (Nature communications)

Uninvited Guests

The Small Hive Beetle (*Aethina tumida*), a bee pest originating from Africa, is present today in many parts of the world, including the USA and Australia. An adult beetle is 1/3 the size of a worker bee.

126 Partners

AND A BOUQUET OF FLOWERS

Did you ever wonder why bees collect pollen AND nectar? Pollen grains are a source of protein and therefore provide a key element of the nutrition for the bees' brood. Nectar is a source of carbohydrates and provides energy for bees. To help bees and other pollinators find plenty of both, 126 partners in the US support Bayer's Feed a Bee initiative to create additional pollinator forage and habitat.

Source: Bayer Feed a Bee data
www.feedabee.com

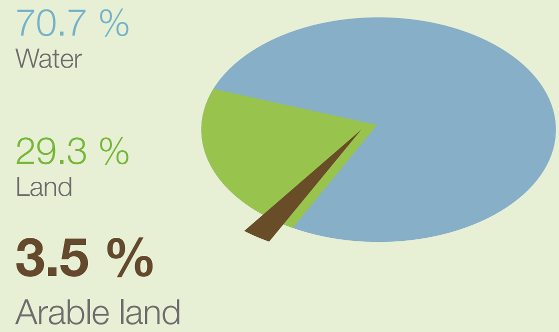
Feeding the World

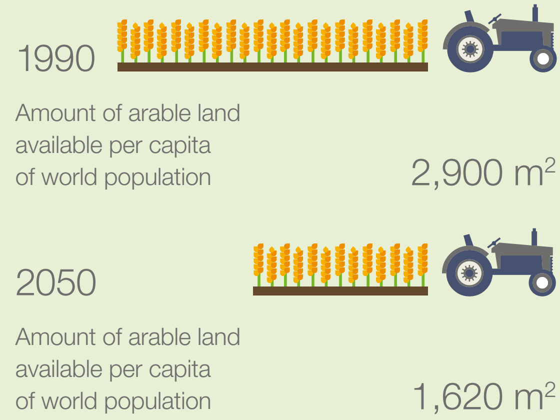
The human population is growing but the amount of arable land available is not.

Forecast growth of the global population

While the world's population is growing, available agricultural land remains, at best, stable. Globally, 1.5 billion hectares of land are used for farming. To fulfill the rising demands for nutrition, crop yields have to rise constantly. According to the FAO, yields from oleaginous fruits – such as sunflowers and oilseed rape – need to increase by 89 percent by 2050. This requires good pest management and pollination services.

Source: FAO





UNDER THE SEA

The first thing we may think of when we hear "pollination" is flying insects. But pollinators also work at the bottom of the sea: Small crustaceans transfer the pollen of sea grass plants which provide nutrition for many underwater creatures.

Source: https://www.nature.com/articles/ncomms12980

INTENSIVE AGRICULTURE – INTENSIVE DEBATE

In Belgium and the Netherlands, there is a high environmental awareness. Citizens expect the agricultural sector to not only produce sufficient and healthy food at acceptable prices, they also want this to be done in an attractive-looking, rural area fit for recreation, to enjoy leisure and value nature. With this, the task of managing the agricultural land has become broader. This article demonstrates Bayer's commitment to sustainable agriculture, introducing two of Bayer's ForwardFarms and showing a variety of activities and initiatives in Belgium and the Netherlands to enhance crop pollination and safeguard pollinator health.

High population density is a key factor that contributes to the increased level of awareness for sustainable agriculture, biodiversity and pollinator health in Belgium and the Netherlands. Consequently, there is a high interdependence and interaction between farming and the population in both countries. "Agriculture impacts very directly on the Dutch and Belgians," says Patricia Smet, Marketing Communication & Excellence Manager at Bayer Belgium.

Intensive land use

The Netherlands ranks among the top countries worldwide when it comes to agricultural productivity per hectare. "There are no outputs without inputs!" says Hinse Boonstra, Public & Government Affairs Manager, Bayer Netherlands. "Only through intensive land use can Dutch agriculture be so productive." The situation in Flanders in northern Belgium, where intensive farming is the agricultural norm, is no different.

New technologies and scientific crop research have combined to produce greater yields. Innovation has allowed for the modernization and expansion of farming and has led to an increase in scale and specialization in agriculture. High productivity has benefits but also comes with costs, and these costs are debated more and more in the Netherlands and Belgium.

New technologies and scientific crop research have combined to produce greater yields.

Hinse Boonstra (right), Public & Government Affairs Manager, Bayer Netherlands, talks to visitors on the farm.

The Netherlands is the 27th most densely populated country in the world, with 503 people/km^2 (2015). Only Taiwan is smaller and has a larger population. Even though the country is so densely populated, it has no municipalities with a population of over one million. In other words, the 17 million Dutch men, women and children are spread fairly evenly across the country. Belgium, as a whole, is less densely populated than the Netherlands with some 373 people/km^2. This country-wide statistic, however, hides the fact that Flanders is much more crowded than the national average at 480 people/km^2 in the Flemish region.

AT A GLANCE

- // The high population density in Belgium and the Netherlands leads to a high interdependence and interaction between farming and the citizens in both countries.
- // There is a high environmental awareness in both countries, and the agricultural sector is expected to produce sufficient and healthy food in a sustainable way.
- // Bayer is committed to sustainable agriculture, and its ForwardFarms are living examples of how this can be practiced.
- // Bayer is involved in a broad variety of activities and initiatives in both countries to ensure that crop production and safeguarding of pollinators are promoted alongside each other in a sustainable way.

ForwardFarming is about biodiversity and finding out how it can be better integrated into real-life, daily farm management.

ForwardFarming Belgium

Hof ten Bosch, Huldenberg, Belgium

Sustainable agriculture and pollinator biodiversity

Bayer's position regarding pollinators in sustainable agriculture is unequivocal. Sustainable agriculture needs both the latest crop production technologies and pollinators to produce the extra food required to feed a growing global population, while at the same time preserving natural resources, including land, water and wildlife. State-of-the-art crop protection products (pesticides) and other plant science innovations help to boost crop yields, minimize harvest losses and enhance agricultural sustainability by conserving soil, water and energy.

By making land use more efficient, sustainable agriculture preserves and creates space for natural habitats, helping to maintain the biodiversity of plants and wildlife, including pollinators.

Bayer is committed to protecting pollinators. Ways to do this are demonstrated in our ForwardFarming Program where we aim to combine bee protection and agriculture.

Typical farms in Belgium, France, Germany, the Netherlands and other countries are taking part in the program, each with a different focus in crops and balance of key elements being implemented. This includes measures to stimulate pollinator biodiversity and studies investigating how to enhance pollination efficiency in order to maximize crop production.

ForwardFarm in Belgium

One example of sustainable agriculture in practice is Hof ten Bosch, a Bayer ForwardFarm situated in Huldenberg, just 15 km from Brussels. Two brothers, Jan and Josse Peeters, grow wheat, sugar beet, corn, oilseed rape and pears on around 100 hectares and potatoes on some 40 hectares.

Besides instigating sustainable measures to tackle the challenges of land erosion on their potato fields, the Peeters brothers have worked to increase biodiversity and reduce the ecological impact of their farming activities. Mixed hedges providing flowers throughout the year in the farm's orchards, earwig shelters as well as grass buffers and flowering strips on their arable fields are just some of the successful measures they have implemented.

The work undertaken in the pear orchard clearly supported the needs of mason bees, for instance. This became obvious after collecting the bees' offspring in the nesting boxes: 2,500 cocoons were found in 2016. In an on-farm study, Bayer is monitoring the benefits to pollinators of different flowering strips suitable for the agricultural setting. The initial findings revealed that the so-called 'Tübinger mixture' was ten times more attractive and the arable flower mixture three times more attractive to bees than a natural grass border. Appropriate recommendations will be passed on to interested farmers at the end of the study.

Three hives of honey bees and several nesting sites for solitary bees near the Hof ten Bosch orchards are providing shelter for honey bee colonies and breeding places for wild bees. Studies are undertaken to investigate whether solitary bees have a positive impact on pear production. Showcasing these measures and findings supports a constructive dialog with visitors to the ForwardFarm who take this opportunity to see how the farm's orchards are being made more attractive for pollinators. Interest in how sustainable agriculture is practiced at Hof ten Bosch has been high. In 2016 alone, 2,146 visitors – amongst them farmers, NGOs and universities – were shown round the farm.

The Belgian Bee Care Team (from left to right): Anke de Landtsheer, Veerle Mommaerts, Hilde van Dyck and Patricia Smet.

Bayer ForwardFarming

Bayer ForwardFarms in different European countries are living examples of how sustainable agriculture can be practiced. The farms involved in Bayer ForwardFarming make use of three basic components:

// **Integrated Crop Solutions** with high-quality seeds and crop protection products (chemicals and biologicals) to protect the yield and quality of agricultural commodities. These solutions are backed by tailored services ranging from agronomic support, field demonstrations, diagnostics and prediction tools to documentation.

// **Proactive Stewardship** to ensure product integrity (for seeds and crop protection products), protect human health and preserve the environment. Trainings are offered to raise standards of handling and usage, as well as to minimize any possible risks to human health and the environment.

// **Partnerships** to enhance the quality of life for farmers, communities and society. Mutually beneficial partnerships that include all players in the value chain and help to leverage the potential for collaboration in modern agriculture.

ForwardFarming Netherlands

Het Groene Hart, North Holland, the Netherlands

ForwardFarm in the Netherlands

At Bayer's ForwardFarm in the Netherlands, Het Groene Hart, Jasper Roubos grows winter wheat, potatoes, onions and sugar beet on 83 hectares of very fertile clay soil in North Holland. A local beekeeper has placed nine hives on the ForwardFarm for his honey production, fostered by the diverse, non-crop vegetation. Several measures were taken to stimulate biodiversity, amongst others diversity of pollinators, including the introduction of nesting sites and food sources like flowering strips. In addition, measures were taken to improve the quality of soils, water and plant diversity at field edges. “A good environmental quality is the basis for healthy biodiversity and at the same time vital to agricultural production,” Boonstra states.

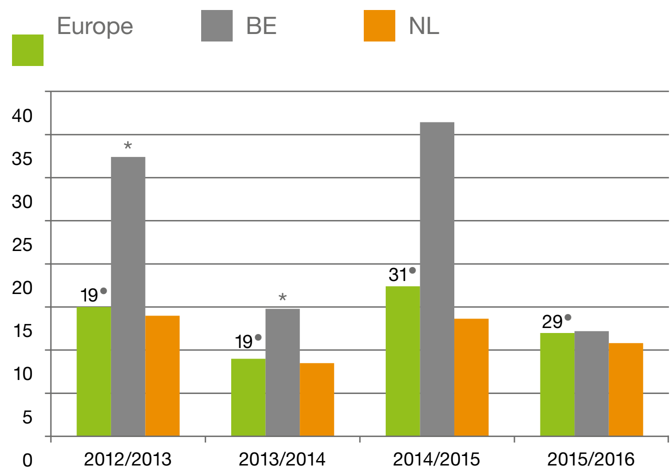
On our ForwardFarm we show, in practice, that beekeeping and modern farming can coexist. The honey bees are doing very well, despite the fact that tulips are flowering right next to the beehives and need intensive crop management to flourish. This example shows that as long as prescribed management practices are followed, bees and agriculture can thrive. Of course, managed honey bees are farm animals and, therefore, poor indicators for biodiversity.

However, besides these measures to demonstrate the compatibility of intensive agriculture with beekeeping, ForwardFarming is likewise about all biodiversity and finding out how this can be better integrated into real-life, daily farm management. One can think of stimulating natural predators of pests, pollinators or soil organisms like earthworms. It is clear that farmers can benefit from biodiversity, which offers various so-called ecosystem services. It is therefore interesting to enhance integrated crop management with measures that are beneficial for farmers and which support biodiversity at the same time. “This is a challenging task. Working with nature is complex and requires a lot of knowledge. In scientific literature, many promising ecosystem strategies are described for farmers. Making them work in practice is a whole different ball game. Nature can be unpredictable and the outcome is not always what a farmer needs,” Boonstra explains.

Yet these are not the only activities Bayer is undertaking to promote pollinator health in Belgium and the Netherlands. The company also contributes to a number of country-wide, multi-stakeholder projects looking specifically at the honey bee.

Beekeeper Erik Dolstra introduces school children to the world of honey bees on the Dutch ForwardFarm.

Mean winter colony losses (%)



• Number of countries surveyed (COLOSS).

* EPILOBEE data (due to non-availability of COLOSS data).
All other data: COLOSS.

EPILOBEE: pan-European study on honey bee colony losses in the years 2012–2014.

COLOSS: scientific network that has been conducting surveys on honey bee colony winter mortality since 2004.

BeeHappy project

While yearly colony losses of five to fifteen percent are considered normal by many professional beekeepers, significantly higher losses around 30 percent had been seen in Belgium over a number of years, implied by some to be linked to the use of pesticides. In 2013/2014, the average overwintering losses across Europe were the lowest for many years at nine percent according to COLOSS, whereas Belgium was still seeing relatively high winter loss rates above the European average (14.8 percent according to EPILOBEE, see graph above right).

The BeeHappy project initiated in 2013 by Phytofar, the Belgian plant protection industry association, aimed to discover why many honey bee colonies in different parts of Belgium did not survive recent winters and to develop solutions to help weakened bee colonies make a good recovery. Besides Bayer and other agrochemical companies, a wide range of stakeholders were involved in the project, including agricultural machinery manufacturers, seed companies, academic scientists, a beekeepers' association, an NGO, farmers' unions and public authorities. Scientists have been researching factors such as air pollution, weather conditions, biodiversity, use of pesticides and beekeeping practices and connecting them with the extensive pathological, mortality and health data from 360 honey bee colonies previously collected by academics from Ghent University and Belgian officials of the Food Safety Agency.

The conclusions, published in early 2017, show that *Varroa* infestation is the main factor correlated with the honey bee colony mortality. These findings tie in with the recent drop in overwintering losses seen in the country (COLOSS, 2016, see graph top right); Belgium experienced a much better winter in 2015/2016 with bee colony losses down to around twelve percent (similar to the European average) compared to the winter of 2014/2015 where losses as high as 36 percent were found (compared to the European average of 17 percent). This is assumed to be partly thanks to an increased awareness of *Varroa* and improved *Varroa* control measures.

Bee surveillance program

In the Netherlands, interest in pollinator health is also high with beekeeper and other stakeholder groups being actively involved in the discussions around this topic and, in the past particularly, the role that pesticides may play in colony losses. Overwintering losses in the Netherlands have come down to 8.5 to 14 percent in the last four winters, after in previous years up to 25 percent losses were recorded (COLOSS, 2016). The Nederlandse Bijenhoudersvereniging (NBV), the Dutch beekeepers assocation located in Wageningen, indicates even lower numbers, with 6.5 percent in 2015/2016 (NBV, 2016). The causes of this welcome decline are unclear. To study all the main influences on honey bee health, the Dutch government initiated a four-year program (2014 until 2018) to measure the relevant parameters. Now two years into the program, it is too early to draw scientifically sound and detailed conclusions, yet so far, correlations have been found between winter mortality and, amongst others, *Varroa* control, pollen sources and landscape characteristics.

In the meantime, the public debate on bee health has become more nuanced. It is generally acknowledged that, apart from possible side effects of pesticides, other factors influence bee health. Pests and diseases get more attention and also beekeeping practices are frequently discussed.

The public interest in providing not only bees but also other pollinators with good forage and nesting is very positive, as well. The Netherlands is literally covered with stakeholder initiatives: Bee Deals, a Honey Highway, Green Circles and many others.

Several measures have been taken on the farms to enhance biodiversity, including pollinator diversity: nesting sites and food sources like flowering strips, mixed hedges as well as grass buffers and earwig shelters.

Dialog is key to pollinator health

Veerle Mommaerts, Sustainable Development Expert Bayer Belgium, outlines the most important measures for preserving and improving pollinator health: "First of all, it is vital to have an ongoing dialog with beekeepers, the food chain, farmers and other stakeholders. Being aware of each other's requirements and constraints is important. Take beekeepers and farmers: They clearly have a common interest, namely healthy honey bees. Farmers benefit from the bees' pollination work and beekeepers harvest the honey. However, farmers do need to protect their crops against pests and diseases, using pesticides responsibly in doing so. Beekeepers need to combat *Varroa*. For this, we need to increase awareness of *Varroa* control measures and improve beekeeping practices through dedicated training programs." Since numerous factors, individually or in combination, have an effect on pollinator health, it is important to see this as a shared responsibility, and something that has to be collectively promoted. Boonstra adds: "The ForwardFarm is an excellent place to do this. It is a platform where sustainability measures in farming are put into practice and can be discussed in the field. This is very valuable when you discuss complicated issues like biodiversity decline."

We have seen that, even in areas of intensive agriculture, there are many initiatives that can and are being put in place through stakeholders working together. This ensures that crop production and safeguarding of pollinators are promoted alongside each other in a sustainable way. In Belgium and the Netherlands, Bayer is continuing its awareness-raising and outreach work, addressing people's concerns, encouraging public debate and expert discussion and proactively promoting an understanding of how best to preserve and improve pollinator health.

Dialog is of key importance: The health of bees and other pollinators is a shared responsibility.

Veerle Mommaerts, Sustainable Development Expert Bayer Belgium, explains the studies undertaken in the pear orchard to stakeholders.

AT A GLANCE

- // Australia is one of the few countries in the world that is still free from the parasitic *Varroa* mite.
- // In neighboring New Zealand, beehive numbers are skyrocketing despite the presence of the *Varroa* mite.
- // Initiatives are carried out in these two countries in the areas of pests and diseases and foraging habitat to sustain bee health.

Bee on pear blossom

POLLINATORS IN THE SOUTHERN HEMISPHERE

BEE HEALTH INITIATIVES IN AUSTRALIA AND NEW ZEALAND

Bees have an important role to play in countries of the southern hemisphere. Take for instance the Pink Lady apple, probably one of the best-known Australian horticultural exports, which relies on the pollination of mainly honey bees to secure fruit set and quality. Honey aficionados may also think of mānuka honey, produced by honey bees foraging on the mānuka or tea tree, which grows naturally in New Zealand. We would like to shed some light on the situation of bees in Australia and New Zealand, two countries that are very passionate about their bees. We highlight some of the activities in these countries that contribute to bee health and initiatives, targeted at better understanding the multiple factors influencing the health of bees, such as pests, diseases, and the availability of foraging habitat.

AUSTRALIA

Besides the managed and unmanaged (feral) European honey bees, Australia is home to some 2,000 different native bee species, including both social and solitary species. Australia has over 13,000 registered beekeepers operating around 448,000 hives. Pollination in Australia is provided by a range of animals, including managed and unmanaged European honey bees, native bee species, small mammals, flies and other insects. Unmanaged European honey bee colony density is high and was recently estimated at three to six colonies per km^2.

Varroa is on the doorstep

Australia is one of the few countries in the world that is still free from the parasitic *Varroa* mite which is thought to be a major factor behind widespread honey bee colony losses in North America and Europe. However, there is a high chance that the disease-transmitting *Varroa destructor* mite will also permeate Australian territory. It is present not only in the neighboring islands of New Zealand, but even closer, in Papua New Guinea. Australia's very strict quarantine measures may be one reason why the entry of this mite has been avoided so far.

An adult bee showing symptoms of Deformed Wing Virus (right circle), which can be transmitted by the *Varroa* mite (left circle).

Experts do expect the parasitic mite to arrive sooner or later, and they are quite concerned about it. “While in Europe the majority of honey bee colonies are managed, in Australia there is a much bigger population of feral honey bee colonies – that is unmanaged colonies in the wild. These unmanaged bee colonies will be massively hit by the *Varroa* mite, whereas managed honey bee colonies can be sustained better,” explains Professor James Cook from Western Sydney University. The *Varroa* mite is considered to have the potential to cause a major decrease in feral honey bee populations whose ‘invisible’ pollination services are important for Australia’s horticulture sector, mainly for vegetables and fruits.

Preparing for the arrival of the *Varroa* mite

Just how seriously the Australians are taking this latent *Varroa* threat is demonstrated by an elaborate two-tier strategy. The ‘National Bee Pest Surveillance Program’ is an early warning system, jointly funded by the Australian government, Horticulture Innovation Australia (see box page 18), and the grains and honey bee industries. It detects new incursions of exotic bee pests and involves a range of surveillance methods conducted at likely entry points into Australia. Inside Australia, the “National Bee Biosecurity Program” is targeted at beekeepers to help them prepare for dealing with the potential *Varroa* mite incursion and how to safeguard their beehives. One of the projects is a series of 12 videos produced by Plant Health Australia (PHA), the coordinators of the government-industry partnership for plant and bee biosecurity in Australia, and Plant & Food Research New Zealand, with the support of a partnership of public and private sector sponsors, including Bayer. “If the *Varroa* mite establishes in Australia, many crop producers will find they need to use managed hives to pollinate crops for best quality and yield. This applies to many horticultural crops including almonds, cherries, strawberries, apples, pears, avocados, melons, some vegetables and more,” says Dr Jenny Shanks, Project Officer with PHA. “Beekeepers will need to change their beekeeping practices. For example, it will require them to visit hives more often to check for mites and to control them, which will put up the cost of pollination services.”

The short videos (two to five minutes), specifically targeted at Australian beekeepers and horticultural crop growers, cover a broad range of topics including the honey bee biosecurity and surveillance programs. Additionally, a hypothetical *Varroa* incursion in the country and what it might mean for beekeepers and horticultural crop producers is included. Further topics are the life cycle of *Varroa*, hive inspections and ways in which the mite can be controlled if it enters and becomes established in Australia. The videos are available on YouTube and on the BeeAware website (www.beeaware.org.au/videos). “Beekeepers find it really helpful since many of them did not know much about the *Varroa* mite and the videos provide just enough information to get them to think: yes, I can do that next time,” Jenny is happy to see.

Professor James Cook from Western Sydney University (right) and Richard Dickmann, Head of Public and Government Affairs, Bayer Australia, inspect new climate controlled glasshouses in which environmental impacts on pollinators will be studied.

Bayer has supported Plant Health Australia in producing 12 videos related to its National Bee Biosecurity Program:

http://www.beeaware.org.au/videos

Richard Dickmann, Head of Public and Government Affairs Bayer Australia, adds, “We supported this initiative to ensure that the beekeepers are fully informed about the range of issues they are confronted with, as well as the best way of controlling the *Varroa* mite if it arrives. At the same time, maintaining healthy hives is critical to supporting pollination and economic return for growers.” PHA also developed the “Australian Honey Bee Industry Biosecurity Code of Practice”, in consultation with beekeepers and governments, as a framework for best-practice biosecurity measures. It is based on the principles of good beekeeping practices which beekeepers should adhere to in order to minimize the impact of pests and diseases on their bees and the bees of other beekeepers. This includes actions such as appropriate training of beekeepers, regular inspections for pests and diseases, having response plans in place for potential pest and disease situations and good record keeping. Some of the requirements of the Code go beyond state and territory legislations and while compliance with those sections is still voluntary at the moment, the aim is to make more practices mandatory for a larger group of beekeepers.

Almond pollination
In Australia, the importance of almonds continues to grow. In 2015, this crop, which depends heavily on insect pollination, accounted for one third of Australian horticulture export sales.

From protection to pollination
In Australia, pollination-dependent horticultural crops including many fruit, nut and vegetable varieties are increasingly important. To address current and potential future challenges for the horticulture industry, currently worth an estimated 9 billion AU $, Horticulture Innovation Australia has recently invested 12 million AU $ in two major pollination research initiatives. The first initiative covers five different focus areas around bees and other pollinators in Australia. One of these projects is dedicated to improving knowledge around pollinators to horticultural crop growers and increasing their active engagement to collect pollinator data. As a project partner, Bayer will bring in its expertise and experience from its 'Feed a Bee' program, which aims to increase forage for bees and other pollinators by planting more flowers and establishing additional forage acreage. By working and partnering with individuals and organizations across various sectors, 'Feed a Bee' helps to provide pollinators with the diverse foraging habitat they need to thrive. A separate program being managed by Plant and Food Research, New Zealand, will strengthen and enable effective pollination for Australian horticulture industries.

In the context of the first initiative, Bayer Australia will help to connect with fruit growers to set up on-farm workshops and engage with them to collect pollinator data. "We want to educate growers about pollinators and the importance of pollination and involve them in the monitoring. We hope to motivate them to make their own contribution," explains Professor James Cook from Western Sydney University, the project leader.

FACTS & FIGURES

According to a 2012 report, insect pollination-dependent crops in Australia have been estimated to be worth **over 4.3 billion AU $**.

Source: Hafi et al. 2012, http://horticulture.com.au/co-investment-fund/pollination-fund/

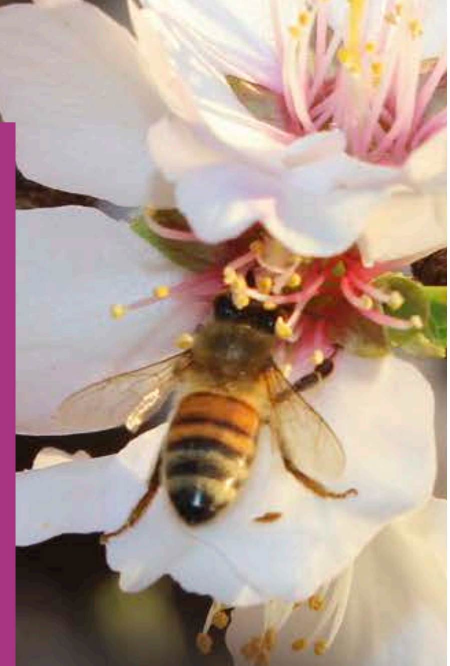
Healthy bee populations for Australia's horticulture

Horticulture Innovation Australia Limited (Hort Innovation) is a nonprofit, grower-owned Research and Development (R&D) and marketing company for Australia's 9 billion AU $ horticulture industry. Hort Innovation invests more than 100 million AU $ in R&D and marketing programs annually, with investment going into both applied research and long-term coordinated strategic research.

The company has recently developed a new strategic partnership model which looks at future-proofing the Australian horticulture industry by facilitating a range of long-term research projects in key areas. Sitting within this model is the Pollination Fund, supporting research that is dedicated to reducing the risks of insect pollination-dependent horticulture and to ensuring a sustainable future for Australian horticulture produce. Among the research groups and projects being funded by the Pollination Fund is the Pollination Plus consortium, comprising a range of partners including Western Sydney University, Plant & Food Research New Zealand, Bayer, Syngenta and Greening Australia. Each partner contributes different skill sets and operates in parallel to the All India Coordinated Research Program (AICRP) of the Indian Council of Agricultural Research on Honey Bees.

The consortium has recently embarked upon the "Healthy bee populations for sustainable pollination in horticulture" project. This five-year project is worth 7 million AU $ and will focus on characterizing and securing alternative pollinators, increasing the availability of pollen and nectar on farmland, investigating the effects of climate change on pollinators, bee virus research and grower education, training and adoption. These areas were identified based on recommendations by Western Sydney University, a key research provider for the Australian horticultural industries and close partner of Hort Innovation. "We want to better understand the importance of native pollinators for pollination of key crops in Australia, learn more about what they feed on and know more about diseases of our bee species apart from the honey bee," says Professor Cook, the research leader of the project.

Hort Innovation Chief Executive John Lloyd says the company is driving results through its projects: "Pollinators are important and are facing some challenges," he explains. "Bees pollinate a large percentage of Australian crops, so it is vital we dedicate more resources into their health. It is also crucial that we explore and strengthen alternative pollination options such as self-pollinating varieties of plants, alternative insects or automatic or robotic aids. The aim is to safeguard the future of our horticulture products for years to come."



If the *Varroa* mite establishes in Australia, many crop producers, who currently benefit from feral honey bee pollination, will find they need to use managed hives to pollinate their horticultural crops, such as almond (photo top right, previous page), in future.

Apple orchard

Highly prized and desirable
The demand for mānuka honey is contributing to an increase in the number of professional beekeepers in New Zealand.

Feral nest in tree
In New Zealand, the *Varroa* mite was first discovered in April 2000. It is considered responsible for the virtual elimination of feral honey bees there.

NEW ZEALAND

The European honey bee *(Apis mellifera)*, bumblebees (which were imported into the country) and solitary bee species can be found in New Zealand – but no native social bees.

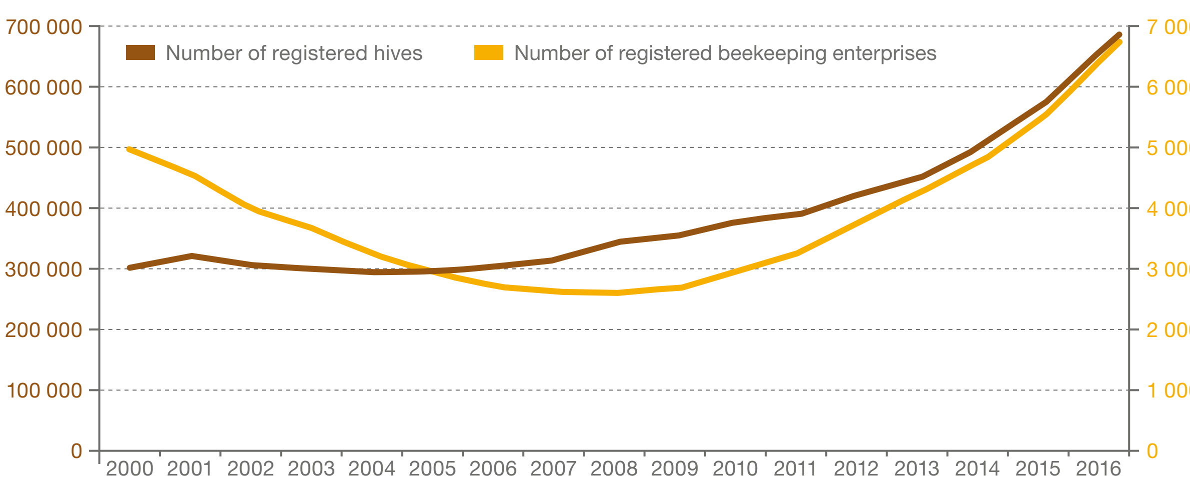
In New Zealand, the *Varroa destructor* mite was first discovered in April 2000. It is considered responsible for the virtual elimination of feral honey bees. After its introduction, registered hive numbers remained relatively steady at around 300,000 between 2000 and 2005. However, they have been increasing ever since, reaching 575,000 colonies in June 2015, an increase of 13.5 percent compared to the previous year or close to double pre-*Varroa* numbers. In June 2016, numbers were even up to a total of 684,000 colonies. The number of registered beekeeping enterprises has also seen continual growth since the late 2000s, reaching 5,550 in 2015, which is also more than pre-*Varroa* levels. The increase in managed honey bee populations is driven by strong market demand for mãnuka honey (honey exports increased from 7,150 tons in 2010 to 9,050 tons in 2015) and led by investment in beekeeping enterprises.

Also, an increasing ability to manage *Varroa* (often with the help of various varroacides) is accredited to contributing to rising hive numbers on the South Island.

"Current estimates see beehive populations already at 700,000 and we expect them to exceed 1 million in the near future," says Tonde Kaitano, Crop Science Regulatory Affairs Manager at Bayer New Zealand. Average beehive density per square kilometer of land area is also very high here, much higher than in, for example, the United States.

While the apiculture industry is growing, in terms of honey production and thanks to increasing honey prices, the industry also faces ongoing concerns over bee health. In 2010, Apiculture New Zealand (ApiNZ), the key body representing the beekeeping and honey products industry, launched the "Bee Aware Month" campaign, which over time has progressed to a week-long media awareness campaign devoted to making New Zealanders think about the honey bee and its important role for New Zealand's economy and agricultural ecosystems.

Hive numbers and registered beekeeping enterprises in New Zealand*



* According to registered beekeeping enterprises and hives under the National Pest Management Plan for American Foulbrood. *Varroa* was discovered in hives in New Zealand in 2000. Source: Ministry for Primary Industries (MPI) New Zealand, http://www.mpi.govt.nz/document-vault/16621.

Kiwi bees get a boost from Kiwi kids

In light of the increasing awareness regarding the challenges bees are facing, William Malpass, Communication Manager with Bayer in New Zealand, and his colleagues founded an internal "Bee Interest Group" (BIG). As he explains, "We are a small team with limited resources but we really wanted to do something to address the important topic of bee health."

They started in 2013 with an initiative educating employees around bees and distributed flower seed packages to them. The initiative was well received, which gave impetus to take it to another level in 2016. In order to obtain a greater impact, it was crucial for BIG to find partners who could help provide essential elements to the project, such as seeds. "Each one in the team had their specific part in the project based on their role and network," Malpass says. The idea was pitched to ApiNZ and Enviroschools, an action-based education program where young people plan, design and implement sustainability projects and become change agents in their families and community. Both of the organizations were easy to win over for this project. "Enviroschools was an important partner because they have a network of regional coordinators to engage with the schools," he explains. In total, 1,040 schools, ranging from early childhood centers to secondary schools, were supplied with packets of bee-friendly plant seed mixes that were sponsored by Yates, a seed company. Furthermore, a localized educational booklet created by the Bayer Bee Care Center was provided, containing information about honey bees and how planting seeds can help them.

September is the dedicated "Bee Aware Month" during which many bee-related activities are taking place all across the country, including this project. "It all happened really quickly," Malpass continues, "and we couldn't have done it without the help of our partners. This initiative showed us how collaboration between Bayer and different stakeholder groups can work. It went really well the first time, so we would like to do it again, and secure even more flower seed packages for distribution."

INSPIRING PROJECTS

The high level of commitment and scope of cooperation shown in these projects in Australia and New Zealand are inspiring. "These great initiatives in the area of bee research and education show that by working together we can contribute to safeguarding pollinator health and promoting sustainable agriculture. And this is what the Bayer Bee Care Program is all about," says Coralie van Breukelen-Groeneveld, Global Head of Bayer Bee Care.

Young pupils plant seeds of bee-friendly flowers in their school garden.

MORE INFORMATION

Information for beekeepers and growers about honey bee biosecurity and pollination of agricultural and horticultural crops:
http://beeaware.org.au/

Australian national Bee Pest Surveillance Program
http://www.planthealthaustralia.com.au/national-programs/national-bee-pest-surveillance-program/

Australian national Bee Biosecurity Program
http://www.planthealthaustralia.com.au/national-programs/national-bee-biosecurity-program/

Australian Honey Bee Industry Biosecurity Code of Practice
http://www.honeybee.org.au/wp-content/uploads/2016/07/Australian-Honey-Bee-Industry-Code-of-Practice-July-2016.pdf

“Our initiative to improve pollinator health with 1,040 schools, where young people plan, design and implement measures to safeguard sustainability, developed very successfully. So, we would like to do it again, and secure even more flower seed packages for distribution.”

William Malpass
Communication Manager, Bayer New Zealand

AT A GLANCE

- // Most bee experts believe honey bee health is affected by multiple factors, including climate, parasites, diseases, food availability, genetics and beekeeping or agricultural practices.
- // Although pesticides are usually not seen as the primary cause of colony losses, some believe they could play a contributing role, especially in combination with other factors.
- // Some claim that sublethal concentrations of pesticides may negatively impact honey bee colonies, but most of these studies have looked at individual bees – not colonies – under unrealistic exposure conditions.
- // FIT BEE, a five-year, public-private collaborative research project conducted in Germany, approached bee health from a holistic perspective with a focus on maintaining healthy, vital honey bee colonies in the field.
- // One research area investigated by the FIT BEE project examined the effect of sublethal exposures of a neonicotinoid insecticide, thiacloprid, on honey bee colonies under field conditions.
- // This three-year study found that long-term dietary exposures of thiacloprid – at realistic or exaggerated dosages – had no measurable adverse effects on honey bee colony health and performance.

COLONY FEEDING STUDY WITH THE INSECTICIDE THIACLOPRID

SAFETY IN THE FIELD

Most experts acknowledge there are multiple factors that can affect honey bee health. Yet pesticides, especially neonicotinoid insecticides, get an uneven amount of attention in the scientific and public arena. Some scientists have raised concerns that exposures to less than lethal doses (often called sublethal exposure) of these pesticides might impact bee colonies in ways that may not be obvious.

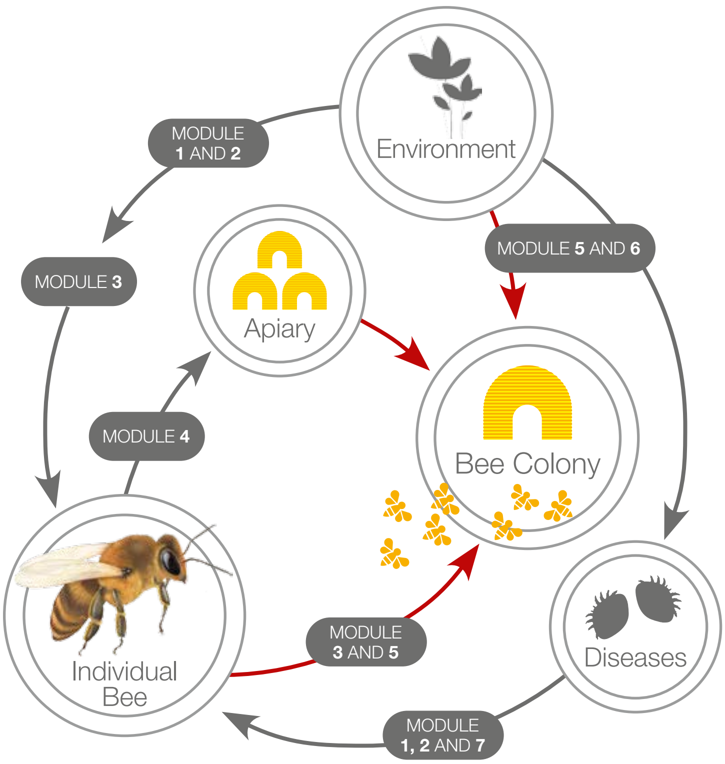
In a three-year study undertaken as part of the FIT BEE project, scientists examined the effect of exposures of honey bee colonies to sublethal concentrations of the neonicotinoid, thiacloprid. The results of this recently published research provide good news for farmers and beekeepers alike: long-term dietary exposures of thiacloprid – at realistic or even exaggerated dosages – were shown to have no adverse effects on honey bee colonies.

Most people think of honey bees as an integral part of our natural world. While this is true, it is also true that these insects have been domesticated and managed to help produce many of the foods that we enjoy, even in areas where they are not a native species. So when high winter colony losses in Europe and North America were seen in the early 2000s, it raised concerns among beekeepers, farmers and the general public that a critical resource was in trouble. Since then, a significant amount of research has been devoted to understanding the issues affecting honey bee health. Unfortunately, rather than finding a single "silver bullet" solution, scientists instead found greater complexity.

Today, the consensus among bee experts is that honey bee colony health is impacted by multiple factors, including climate, parasites, diseases, food availability, genetics as well as beekeeping and agricultural practices.

FIT BEE

A collaborative five-year, multi-partners umbrella project*that ran from 2011 to 2015 in Germany with focus on maintaining healthy, vital bee colonies.



PROJECT OBJECTIVES:

- Understand the interactions between the individual bee, the colony, bee diseases and other environmental parameters
- Define the conditions of a healthy bee colony
- Improve these conditions by specific measures

Different modules were developed and assigned to various researchers to evaluate these factors.

INTERACTION OF THE FACTORS:

Influence of and interaction between different factors impacting the health of the bee colony. The **environment**, the **beekeeping practise** and **individual bee health** influence the vitality of the bee colony directly (red arrows). The modules investigate harmful effects and measures to reduce them.

MODULE **1**

Impact of multifactorial influences on individual bees: investigation of immune response and injury thresholds

MODULE **2**

Innovative tools for the assessment of altered learning and orientation behavior due to crop protection products and bee pathogens

MODULE **3**

Quantification of the crop protection products brought into the bee colony and reduction in the colony's influx of active substances by agricultural measures

MODULE **4**

Spread of pathogens between bee colonies and their prevention via apicultural measures

MODULE **5**

Multifactorial influences on bee colonies and establishment of a GIS-based specialized data information system

MODULE **6**

Effects of the local climate on food availability, *Nosema* infestation and vitality of bee colonies

MODULE **7**

Development of a biological control method against the *Varroa* mite based on sexual pheromones

*Funded by the Federal Ministry of Food and Agriculture (BMEL), the Federal Office for Agriculture and Food (BLE) and private partners, and conducted in collaboration with various research institutions.

Table 1

A superorganism: Honey bee evolution has produced a society in which most individuals have given up the role of reproduction and, instead, devote themselves to the care and well-being of their collective family.

Due to the serious implications to food and agriculture, the protection of honey bees should not be restricted to any one group of stakeholders. This need for a broader response became the genesis of a collaborative five-year, multi-stakeholder umbrella project that ran from 2011 to 2015 in Germany, known as FIT BEE. With its central focus on maintaining healthy, vital bee colonies, FIT BEE was a public-private collaboration funded by the Federal Ministry of Food and Agriculture (BMEL), the Federal Office for Agriculture and Food (BLE) and private partners, and conducted in collaboration with various research institutions. FIT BEE approached honey bee health from a holistic perspective and several distinct research modules were identified as fruitful areas of study *(Table 1)*. Bayer provided both financial and expert input to various areas of the work undertaken under the FIT BEE umbrella project.

Pollination is a critical part of modern farming, so that protecting crops and maintaining honey bee colony health are not an "either-or" option … they have to go hand in hand. From agriculture's perspective, a more holistic approach to better understand the interactions of factors influencing pollinator health is both welcome and necessary. While the agriculture and pesticide industry remains fully committed to exploring ways to reduce potential pesticide exposures to pollinators, it is also important to note that this effort alone will not solve the far broader issues affecting honey bee populations.

Understanding the potential effects of crop protection products on honey bee health may be difficult when using laboratory experiments alone, which involve individual bees. This is because each honey bee is part of a superorganism, the colony, which through evolution has developed its own way of coping with its environment. A colony's response to external stressors, such as parasites, diseases, toxicants, restricted food availability or adverse weather, can effectively mitigate potential harm through a variety of ways that are not feasible to observe when only individual bees are studied. That is why the goal of honey bee protection has always focused on assessing the viability of the colony, not the individual, as formally recognized by European (EPPO Guideline No. 170) and North American (Guidance for Assessing Pesticide Risks to Bees, US Environmental Protection Agency EPA & Health Canada Pest Management Regulatory Agency, 2014) regulators.

Prior to registration, all pesticides must be tested to determine their toxicity to honey bees and to evaluate whether their application may pose a risk to bees. If there is evidence from laboratory experiments that a product may potentially impact individual bees, additional testing is required under more realistic circumstances. This involves entire functional bee colonies to assess whether a pesticide will harm bees when used on a crop under practical conditions and in accordance with the label instructions. This process provides a reasonable assurance that the product can be safely used on crops and it has proven to be quite predictive and protective over many years of observations.

Different tiers of honey bee testing

TIER 1 TESTING

LABORATORY STUDIES

Highly standardized tests conducted under controlled conditions for acute and/or chronic toxicity studies of individual bees (adults and larvae).

EXAMPLE TESTS:

- acute oral adult toxicity
- acute contact adult toxicity
- acute larval toxicity
- 10-day adult chronic toxicity
- 21-day larval chronic toxicity

TIER 2 TESTING

SEMI-FIELD AND COLONY EXPOSURE TRIALS

Semi-field studies incorporating caged bee colonies (bee tunnels) and colony feeding studies, designed to more closely reflect real-world exposures and effects on the colony. Complemented by specific crop residue studies to determine potential exposure of bee colonies.

EXAMPLE TESTS:

- semi-field study
- colony feeding study (artificial feeding in the field)
- studies to measure residues in pollen and nectar

TIER 3 TESTING

FIELD TRIALS

Most complex and realistic of all bee studies, with colonies placed in experimental fields and exposed to crops that are treated under typical agricultural conditions.

EXAMPLE TESTS:

- field study with free-foraging bees

Study complexity and relevance →

Source: U.S. EPA – Guidance for Assessing Pesticide Risks to Bees, 2014.

The science of evaluating the impact of crop protection products on pollinators can range from relatively simple to extraordinarily complex test designs, following a stepwise, hierarchical approach:

1. Laboratory tests on adult bees and larvae
2. Semi-field and colony feeding tests
3. Field studies

With hundreds of studies conducted and a long commercial-use history, we know more about neonicotinoids and bees than any other class of pesticides. Despite this, some scientists have raised concerns that even exposure to lower concentrations of neonicotinoids that may not be high enough to cause death (so-called sublethal exposure), might nevertheless impact honey bee colonies in ways that may not be immediately obvious and impair the colony's overall performance and health. While many recent studies have claimed sublethal effects, most of these tests have been conducted on individual bees in the laboratory or under otherwise unrealistic exposure conditions, making it uncertain as to whether or not the same effects would be seen at the colony level under realistic field conditions.

The goal of FIT BEE's module 1 was to explore the potential interactions between the health of a honey bee colony and its environmental influences. This involved experiments designed to investigate the impacts of pesticides, nutritional deficiencies and pathogens – alone and in combination. With this goal in mind, Bayer worked with scientists of the Kirchhain Bee Institute and the Oberursel Bee Institute (affiliated to the Goethe-University of Frankfurt). The project was designed to explore a colony's response to long-term exposure to thiacloprid, a neonicotinoid insecticide mostly used as a foliar spray on some million hectares of oilseed rape each year. Thiacloprid is considered a "bee-friendly" insecticide because of its low intrinsic bee toxicity. The reason: The bee's enzymatic system is capable of rapidly degrading the active ingredient. This is partly why thiacloprid is classified in Germany as "Not Harmful to Bees (B4)" so that even treatments during full bloom in the daytime, when bees are actively foraging in the crop, are permitted. Therefore, residues of thiacloprid are regularly found in bee hives, yet at levels far below the lethal concentration.

Creating a sublethal colony exposure study

Due to its widespread use in a highly bee-attractive crop, thiacloprid is a good candidate for studying what effect – if any – chronic exposures to sublethal levels might have on honey bee colony health. In a long-term colony feeding study conducted over a three-year period, a team of researchers, led by Dr Reinhold Siede, scientist at the Kirchhain Bee Institute and study director of the research outlined here, was able to monitor a series of experimental colonies exposed to both field-realistic and exaggerated dietary exposure concentrations of thiacloprid, which could then be compared to an untreated control group. All colonies were fed with a sugar-syrup solution which was spiked with thiacloprid in the treatment groups to simulate chronic exposure.

The dynamics of running a study in the field are quite different than that of a laboratory test. Selecting a suitable site for conducting research involving multiple colonies was just the first of many key considerations. "One of the biggest challenges we faced in this study was managing a large number of colonies over a long-term duration," explains Siede. "Ten colonies per treatment, replicated over three years, added up to 90 colonies in total – all of which had to be continuously monitored, sampled, evaluated and cared for. We had to maintain these high numbers so that we could achieve the statistical power necessary to make meaningful comparisons between the different treatment groups."

In defining the dietary concentration for the first treatment group (T1), the researchers created a worst-case, but still field-realistic exposure of 0.2 mg/kg, based on actual high-end concentrations of thiacloprid residues found in bee bread samples collected from honey bee hives, as part of an ongoing multi-year monitoring study in Germany, the German Bee Monitoring (DEBIMO).

Dr Reinhold Siede, scientist at the Kirchhain Bee Institute and study director for the thiacloprid long-term study, on the importance of this research:

"As one who has been a 'backyard beekeeper' for some 30 years, this was an opportunity to connect my professional career with my personal passion. Working with the multiple stakeholders associated with the FIT BEE project has helped to deepen our understanding of the relationship between honey bee colonies and their environment."

The dynamics of running a study in the field are quite different from that of a laboratory test.

Over the course of the three-year study, all colonies were regularly monitored and evaluated using a wide variety of different parameters to assess overall colony performance and health. These included:

- number of adult bees per comb
- number of worker brood cells per comb
- number of drone brood cells per comb
- colony weight
- number of dead bees in front of the hives
- residues of thiacloprid in stored bee bread
- number of *Varroa* mites per bee sample
- viral infection (CBPV, DWV, ABPV)*
- number of *Nosema* spores per bee
- overwintering colony mortality and survival
- queen failure
- expression of the polypeptide hymenoptaecin as an immune defense parameter

* Bee viruses monitored: Chronic Bee Paralysis Virus (CBPV), Deformed Wing Virus (DWV) and Acute Bee Paralysis Virus (ABPV).

RESULTS:

No adverse effects on colony performance and health

In this colony feeding study in the field, realistic and exaggerated thiacloprid dosages were shown to have no measurable impact on honey bee colonies compared to the untreated control hives.

Bee experts take samples to analyze the exact amount of residues of thiacloprid in stored nectar.

One measurement used to assess the honey bee colony strength was to estimate the number of adult bees in the hive.

The second treatment group (T2) received a worst-case, exaggerated concentration of thiacloprid of 2.0 mg/kg, a 10-fold increase when compared to the T1 group. The colonies were fed syrup spiked (treatment groups) or non-spiked (control group) with the test-substance from early July onwards until the end of the beekeeping season. During the feeding/exposure period, no major bee-attractive crops were flowering within the flight radius of the hives to ensure each colony would feed predominantly on the syrup solution provided to it. Further hive management of the colonies was done according to good beekeeping practices (e.g. disease and parasite control, honey harvest, overwintering feeding etc.). The trial was repeated over three subsequent years, which provided a time-staggered replication to account for year-to-year environmental variability.

After three years of observations, the study concluded that the tested sublethal exposures of thiacloprid had no adverse effects on honey bee colony health. In reviewing the results of the different parameters evaluated, scientists found no indication that field-realistic or even the tested exaggerated sublethal exposure concentrations produced a biologically significant impact on colony performance, when compared to untreated control colonies. “Frankly, I was a little surprised that we found no effects, considering the high dietary and long-term exposures in the treatments when compared to the control colonies,” notes Siede.

In all measurements used to assess colony strength (numbers of adult bees and brood cells, mortality, colony weight, winter survival, queen loss and rate of *Varroa* mite infestation), no significant differences between the treated and untreated colonies were found over the duration of the study *(Table 2)*.

While the incidence of Chronic Bee Paralysis Virus (CBPV) and Deformed Wing Virus (DWV) was rare or absent throughout the study, another important honey bee virus, Acute Bee Paralysis Virus (ABPV), was frequently detected. However, no apparent difference between treated and untreated colonies associated with ABPV’s presence was observed. Similarly, spores of the microsporidian parasite, *Nosema* spp., were frequently found in all colonies during the study, but no significant differences in incidence were observed between treatment and control colonies.

To help combat microbial infections, honey bees rely on their immune system and the regulation of the genes to produce antimicrobial compounds. One of these compounds is a peptide (hymenoptaecin) which is involved in the bee’s defense against bacteria. To measure the effect of thiacloprid exposure on the bees’ immune defense response, the researchers removed a small number of individual bees from the colonies and brought them to a laboratory for further investigation.

Colony performance: three-year overall average measurements*

	Group		
	Control	**T1**	**T2**
Thiacloprid dietary exposure concentration (mg/kg)	none	0.2	2.0
Average number of adult bees per colony (average per assessment)	13,151	13,645	12,277
Mean number of worker brood cells per colony	11,918	12,571	11,344
Mean number of drone brood cells per colony	3,121	2,846	2,555
Mean number of dead bees in front of the hives (mean per assessment)	19.8	20.4	19.8
Hive weight (kg)	37.2	38.0	36.4
Number of *Varroa* mites per bee sample weight (g)	0.032	0.033	0.040

* No statistical differences between treated and untreated colonies were found in any of the comparisons listed above.

Table 2

"In contrast to the sometimes emotional conversations about pesticides and pollinators, our study showed that thiacloprid did not affect honey bee colonies – even at high oncentrations over extended periods of time."

Dr Reinhold Siede

Individual bees exposed to thiacloprid in the laboratory showed a slight, but statistically significant modification in their gene expression pattern (i.e. less hymenoptaecin mRNA production as a response to bacterial challenge) when compared to the control. However, in evaluating the honey bee colony's defense response to threats in the field – such as parasitization or disease infection – the researchers did not observe any differences between the control and treatment groups. "The lack of effects seen in the field shows that the colony's response to an external stressor can be very different from that of an individual bee in a laboratory, but we don't really know why," explains Siede. "Perhaps the colony's ability to compensate by adjusting its reproduction or food intake plays a role. Regardless, I think this is an important area for future research."

There have been few tests in the field involving honey bee colonies that examined the potential sublethal effects of dietary exposure to pesticides over multiple years. By any of the many metrics used to assess colony health in this study, long-term dietary exposures of thiacloprid – at high-end realistic and exaggerated dosages – were shown to have no measurable impact on honey bee colonies when compared to the untreated control hives. No statistically significant adverse effects were seen in colony strength and weight, mortality, brood production, overwintering and queen survival, parasitism or viral infection.

Siede believes this research can help contribute to a greater understanding of the interrelationship between beekeeping and agriculture. "In contrast to the sometimes emotional conversations about pesticides and pollinators, our study showed that thiacloprid did not affect honey bee colonies – even at high concentrations over extended periods of time."

Nonetheless, he also believes agriculture must continue its efforts to reduce pesticide exposure, especially in bee-attractive crops. "Farmers can take appropriate precautions and use best management practices to reduce potential exposures to bees whenever possible when they are protecting their crops," he concludes.

This research provides important evidence in support of the safe use of modern agricultural tools, even in crops that are bee-attractive and frequently visited by honey bees.

Perhaps most significantly, this study affirms that in order to understand the potential effect of crop protection products on honey bee health, aspects that involve individual bees and the dynamic of the colony need both to be taken into account.

"Because a colony's response to potential stressors can be much different than that of an individual bee, the results of this research make an important contribution to our body of knowledge, while also providing some very good news to both farmer and beekeeper alike."

Dr Christian Maus
Global Lead Scientist
at the Bayer Bee Care Center in Germany

CONCLUSION

In one of the few, multi-year colony feeding studies investigating honey bee colonies and the potential sublethal effects of long-term dietary exposure to pesticides over multiple brood cycles, thiacloprid was found to have no measurable effect on colony strength and performance. No significant adverse effects were seen in colony strength and weight, mortality, brood production, overwintering and queen survival, parasitism or viral infection.

This research shows that modern crop protection products can be safely used around honey bee colonies in agriculture, which is certainly good news for farmers and beekeepers alike.

Several honey bee hives are stationed at the Centro Apícola de Castilla-La Mancha in Marchamalo, Spain. Bee experts there regularly check the bees' health.

AT A GLANCE

// Beekeeping and honey production are an important part of the Spanish economy.
// However, parasites and infectious diseases, which are harmful to honey bee health, are common and further spreading.
// This could lead to economic losses for Spanish beekeepers, unless new strategies to deal with these challenges can be implemented.
// Bayer experts are working with Spanish bee researchers to jointly contribute to the improvement of honey bee health, by strengthening research and better understanding of these threats.

JOINT RESEARCH ON HONEY BEE HEALTH IN SPAIN

PATHOGENS AND PARASITES: AN INVISIBLE THREAT

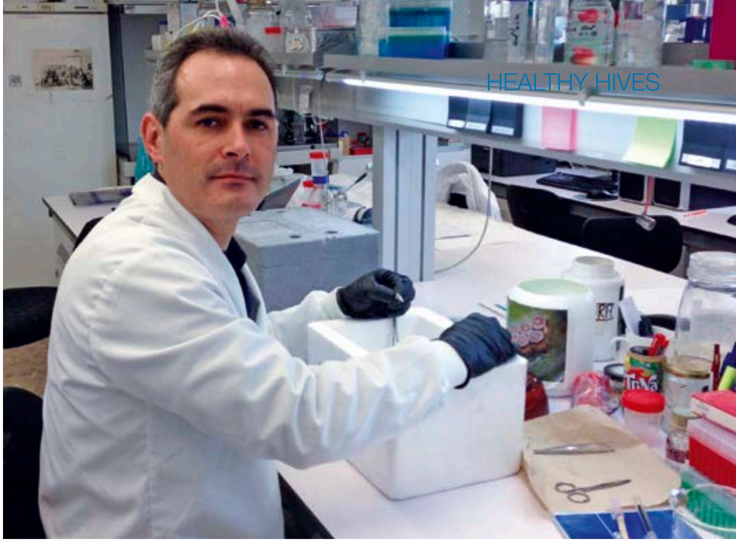
While the beekeeping industry is strong in Spain, the honey bee colonies themselves are frequently weakened by the presence of bee pests and pathogens such as Nosema *species. Products to control such pests are not yet readily available. In addition, bee experts suspect that in some regions in Spain the parasitic* Varroa *mites have become resistant to treatments currently used in the country. This is seen as a rising threat for honey bee health and Bayer is working with Spanish bee researchers to promote healthy hives in the country.*

Spain is the principal honey producer in Europe: Beekeepers there harvest around 33,000 tons each year for local and export markets. Therefore, beekeeping and honey production are an important part of the economy of this southern European country. However, the sustainability of the beekeeping sector is challenged because the bees that produce this honey are threatened: "Almost every honey bee colony in Spain is infested with some level of parasites," says Dr Joel González-Cabrera, a molecular biologist at the University of Valencia in Spain. "Beekeepers are tremendously worried about the health of their honey bees because they lack effective strategies to protect them from pests, such as the *Varroa* mite," explains González-Cabrera. The threat that he and other experts observe: This bee parasite passes on viruses, which weaken the honey bees – and can even be deadly for them.

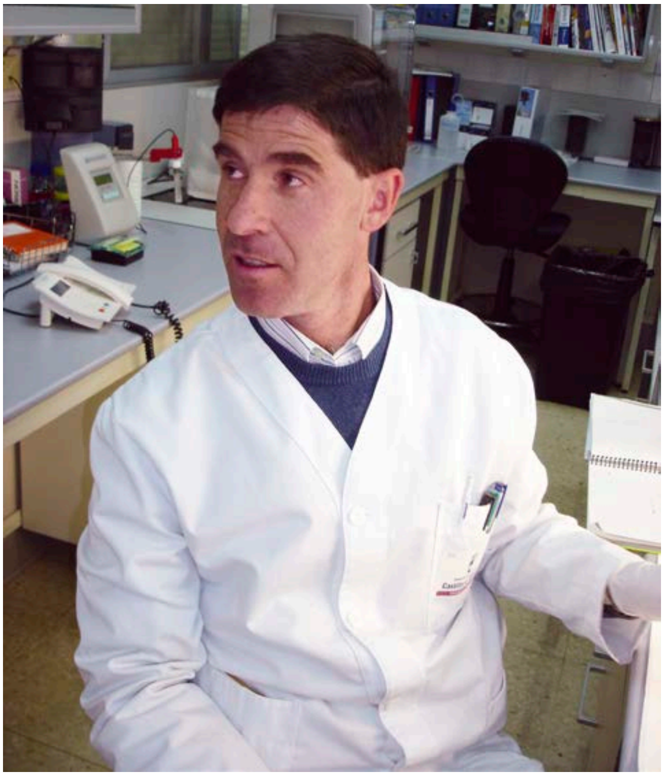
Renowned researchers, including Dr Mariano Higes, are supporting Spanish beekeepers by analyzing honey bee health. Heading the laboratory of bee pathology at the Centro Apícola de Castilla-La Mancha, Higes studies bee diseases and their possible causes and he is concerned about the lack of bee disease awareness: "Many beekeepers don't even know what is wrong with their own bees, as many diseases are almost invisible to the untrained eye." To address this, the Centro Apícola helps make the correct diagnosis for each diseased beehive: "Local beekeepers can send us bee samples and we examine them to see if they are infected and with what," he explains.

However, even bee experts sometimes struggle to give the right diagnosis. In the past, they could not pinpoint the cause of increased honey bee losses which had been seen in some Spanish regions. Initially, farming practices and use of pesticides were among the factors suspected of impacting the honey bees' health. In particular, the neonicotinoid insecticides that had been used on sunflower fields were thought to be the cause. However, not everyone was convinced and so, during his research at that time, Higes looked in more detail at the honey bee loss problem in these regions. "What I found was that the increased mortality rate of honey bee colonies did not occur in regions of sunflower cultivation," he states, summarizing the results of his earlier research. Despite the ongoing debate, he does not believe neonicotinoids to be relevant to the problems affecting Spain's honey bees.

Instead, Higes dealt increasingly with infectious diseases, which are presumed to have the greatest influence on honey bee health. He works closely with Bayer as an industrial partner to not only support beekeepers through research analyses to correctly diagnose the reason for their honey bee colony losses, but to also offer them concrete solutions. "Our collaboration is extremely important, as Bayer might be able to develop bee health solutions based on our research," says Higes. "These solutions may then support us to better control parasites and diseases."



Dr Joel González-Cabrera
Molecular biologist at the University of Valencia, Spain



Dr Mariano Higes
Head of the bee pathology laboratory at the Centro Apícola de Castilla-La Mancha, Spain

FACTS & FIGURES

Infection doubles and loss rates increase:

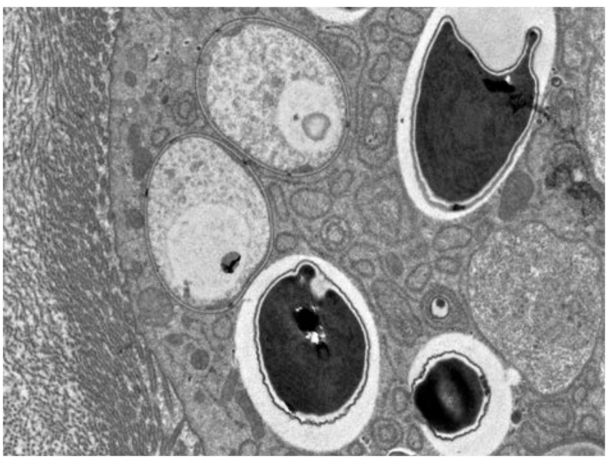
Between 2006 and 2015, the *Nosema ceranae* infection level of Spanish honey bee colonies more than **doubled from 40 % to 85 %**. During the same period, loss rates of up to 50 % were seen, partly due to *Nosema* species.

Source: Dr Mariano Higes, Centro Apícola

Bee doctor: Using a microscope, Dr Higes can see if a bee is infected. Here he is observing the microsporidium *Nosema ceranae* which is increasingly infecting honey bees in Spain.

> *"I think that* Nosema *has become one of the biggest problems for honey bee health in the Mediterranean region, due to a lack of veterinary products to control it."*

Dr Mariano Higes



Highly contagious: The fungal pathogen *Nosema ceranae* can rapidly spread within a honey bee colony. It weakens the bees' immune system.

A contagious intestinal infection

A single-celled pathogen, invisible to the naked eye, is responsible for nosemosis, the most frequent epidemic infection of adult honey bees in Spain. There are two different species of the microsporidian genus *Nosema*: *Nosema apis* has existed in Europe for at least a century, while *Nosema ceranae* was imported from Asia in the past 20 years.

Honey bees can come into contact with this fungal pathogen through contaminated food or water. Even a small number of *Nosema* spores can trigger an infection in the bee's mid-gut that weakens the bee. Due to the honey bees' social behavior, the infection can spread rapidly within a weak colony.

Dr Higes has observed a frequent increase of severe gut infections while examining Spanish honey bees under his microscope. The microsporidium *Nosema ceranae* is the cause of these intestinal diseases. "It is known that this pathogen weakens bees' immune system, changes their behavioral patterns and shortens their life span," the scientist explains. In the last decade, the number of infected colonies has more than doubled. However, this fungal disease has been underestimated for a long time. The reason: A closely related *Nosema* species named *Nosema apis* was thought to be the sole trigger for nosemosis (see also box left). It has existed in Europe for a long time already, without being overly harmful for honey bee health. "Host and parasite even seem to have adapted to each other," says Dr Klemens Krieger, Global Head Bee Health Projects within Bayer Animal Health. However, a few years ago, scientists discovered *Nosema ceranae*, a related type of fungus, originating from Asia. "Unlike with *Nosema apis*, the Western honey bee has not yet developed any defense mechanisms against *Nosema ceranae*," says Krieger.

Moreover, this intestinal infection is highly contagious: Although a strong honey bee colony may be able to compensate for a certain number of infected bees, *Nosema ceranae* spreads rapidly due to the bees' social behavior, impacting the entire colony. The infection expands particularly quickly in warmer climates. "Hence, *Nosema* species have become a fundamental problem in Mediterranean countries," Higes explains, adding, "In my opinion, it has become the biggest problem for honey bees in Spain." Higes states that 85 percent of the local honey bee population was infected with *Nosema ceranae* in 2015. Spain's beekeepers are defenseless against the fungal disease as they lack effective treatments. In a joint effort, Higes and Krieger are working intensively to find answers to this problem – hoping to be able to provide alternative treatment options to beekeepers in the future.

The experts also collaborate on the control of *Varroa destructor* with the Veterinary Faculty at the Universidad Complutense de Madrid, where Professor Aránzazu Meana Mañes, Director of the research group Epicontrol at the Animal Health Department, works. She states: “As in other animal husbandries, medical treatments against bee parasites are only available by prescription. In fact, measures against *Varroa* in Spain require a treatment in fall that must be prescribed by veterinarians. Therefore, veterinarians play an important role in honey bee health in Spain.” The goal of the cooperation of Bayer and the Centro Apícola is to work with veterinarians and involve them in current research, utilizing their expertise to search for suitable treatments and medications.

Joel González-Cabrera is also part of this research network. He is involved in activities trying to control the *Varroa destructor*. There are few treatment options to control the mites and prevent the related disease called varroosis, such as formic acid and synthetic acaricides. Beekeepers from different regions of Spain have been reporting that some products no longer seem to work. According to González-Cabrera, “some mites are no longer controlled by available *Varroa* treatments – they are, possibly, resistant.” Many bee experts in Europe and North America see the *Varroa* mite as the biggest threat to the health of the Western honey bee.

Dr Klemens Krieger, Global Head Bee Health Projects within Bayer Animal Health

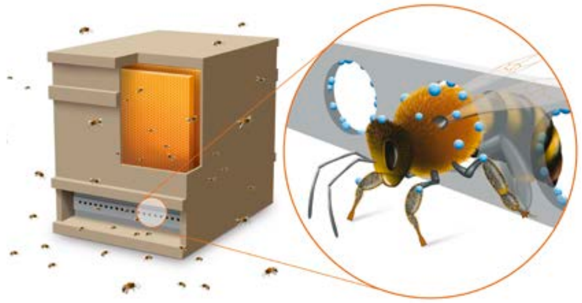
MOST WANTED

The Spanish authorities have established a list of bee pests and pathogens against which new treatment options would be required. What is most needed in Spain are agents to protect honey bees against:

1. *Varroa destructor*
2. European and American Foulbrood
3. *Nosema* species
4. Wax Moths

Dr Higes holds a *Varroa* diagnosis box containing a few hundred bees, taken from a hive. An acaricide kills susceptable mites on the bees and these fall to the bottom of the box where they can then be counted.

Varroa mites are not much larger than a millimeter, have four pairs of legs and piercing and sucking mouthparts. The parasite orients using numerous sensory hairs all over its body.



Weapon against *Varroa* at bee hive entrance:

Bayer researchers have developed a plastic strip containing an acaricidal active substance, which is fitted over the entrance to the beehive and designed to prevent mite infestation. The product is now available in several countries for use by beekeepers as part of their integrated *Varroa* management programs.

Dr Joel González-Cabrera first worked with Bayer when he contributed to a three-year study, looking at *Varroa* resistance to some synthetic pyrethroid insecticides, in England. He then came to Valencia, Spain, in September 2015 to work on a large-scale study analyzing the worrisome phenomenon of resistant mites. He explains: “Here in Spain, we also have to find out for certain whether resistance has developed and to establish a monitoring system to evaluate this.”

Moreover, in another study, he intends to look at preventive measures to maintain the efficacy of the acaricides approved for *Varroa* control. Concrete information and training courses are being developed to assist apiaries, beekeepers in avoiding apicultural practices that would foster the build-up of resistances. “They should not use active ingredients with the same mode of action for the *Varroa* treatment in two consecutive years, as this may lead to resistance build-up,” the expert explains *(see also “Combating Varroa“ BEENOW 1_2015)*. Through a rotation of products with different modes of action, beekeepers should be able to avoid resistance.

The list of factors potentially harmful to honey bees is quite long: Pests, diseases, adverse weather conditions, a lack of nutrition and particular agricultural and apicultural practices can all challenge honey bee health. However, González-Cabrera stresses that “most urgently, we need more information about bee pests and diseases.” Together with his research partners he has already initiated important studies on topics including how to survey the development of resistant mites and how to develop strategies for efficient control. With their expertise, the scientists intend to help maintain the economic strength of this leading European beekeeping region. Overall, Higes remains optimistic: “I am confident that we will contain the spread of infectious diseases with the results of intensive research and dialog with other stakeholders involved and restore bee health in Spain.”

FACTS & FIGURES

65 % of the managed honey bee colonies in Europe are found in the Mediterranean area. Unfortunately, this warm climate region favors the spread of *Nosema* species.

Source: Dr Mariano Higes, Centro Apícola

Dr Joel González-Cabrera analyzes for possible *Varroa* mite resistance and also advises Spanish beekeepers on how to prevent this occurring.

A variety of other pests relevant to Spain

The Asian hornet *(Vespa velutina)*

American Foulbrood, caused by a bacterium, *Paenibacillus larvae.*

Small Hive Beetle *(Aethina tumida)*

Greater Wax Moth (*Galleria mellonella*): larva on a honey comb (top), cocoon where the larva pupates (bottom left), and adult insect (bottom right).

The **Asian hornet** is currently spreading throughout northern Spain. As a predator of insects, including honey bees, it can be a threat to apiculture. This invasive species has unintentionally been imported from East Asia and was first found in Europe in France *(see also "Enemies on the Wing", BEENOW 1_2015).*

Spanish beekeepers particularly struggle against a bacterial disease called **American Foulbrood**. The spores of the bacterial pathogen that cause the disease can remain virulent for more than 60 years. To effectively eradicate the disease in affected apiaries, beekeepers have to burn their infected hives, along with all their equipment that has been in contact with these hives.

Experts are preparing for the possibility that the **Small Hive Beetle**, currently introduced into Italy, may eventually also migrate to Spain.

Wax Moths lay a few hundred eggs inside a beehive. Once hatched, larvae feed on the wax combs in the hive, spinning a thin web that sticks to the combs and may cover the bee larvae. During this process, the moths destroy the combs and the bee brood.

CONCLUSION

Beekeeping is important for the economy in Spain due to the country's extensive honey production. That said, many professional beekeepers see their livelihoods at risk because pests and diseases are threatening the health of their honey bee colonies.

With the strength of shared knowledge, Bayer experts and local Spanish bee researchers are working to address these current problems. They hope to expand their research network in the coming years, collect important data about bee pests in different countries and develop new strategies to effectively combat honey bee pests and diseases in Spain.

SPRING FEST FOR BEES

Japanese cuisine is characterized by healthy, seasonal and vibrant foodstuffs, its visual presentation an art form with great attention to every little detail. This article introduces the artists behind the scene when it comes to fruits and vegetables, showing the key role honey bees and other bees play in pollination, the challenges they face and ways to ensure bee health. Regarding the latter, Bayer is working on a 'Japanese cuisine for bees': a seed mixture for flowering strips as a source of nectar and pollen with flower species native to Japan – to create flowering areas on unused land.

Every year, when the first days of spring trigger the buds of plum, peach and cherry trees to open up as flowers, people in Japan celebrate a spring fest named Hanami. The colorful cherry blossoms – known as Sakura – not only draw in the Japanese and tourists with their beauty; they also attract honey bees, butterflies and other insects, who visit the blossoms for their nectar and pollen.

Although thousands of people marvel at the natural spectacle of the Hanami, many may not be so aware of the important insect activity going on in the background and how this plays a crucial role for food production. For many of those agricultural crops which are pollinated by insects, bees play an important role, and their visit to the blossoms is vital for the development of fruit. Yet it was exactly the significance of these pollination services which triggered one of the pioneering bee scientists in the country, Professor Okada at Tamagawa University in Machida near Tokyo, to intensify bee research. He led one of the first honey bee research teams in Japan in the early 1950s and in 1979 the university's Honeybee Science Research Center was opened. His initial aim was to increase agricultural food production through scientific knowledge. "After the Second World War, we had a big food shortage here in Japan. As a consequence, many universities and research institutions were studying pests – among them insects – in their laboratories to help protect the crops," reflects Professor Jun Nakamura, a bee scientist at the Center since 1993. "Professor Okada recognized a significant research gap in terms of beekeeping and pollination studies and started to focus on honey bees, which play a key role for food security, as they increase the productivity of many crops through the pollination services they provide." Today, the main focus of the research group at Tamagawa is still the honey bee. "Our activities range from basic to applied research, both laboratory and field studies and the improvement of beekeeping practices and evaluation of bee health products," says Nakamura. He wants to help local beekeepers to keep their colonies healthy.

Professor Jun Nakamura
Bee scientist at the Honeybee Science Research Center, Tamagawa University in Machida, Japan.

AT A GLANCE

- // In Japan, there are two different species of honey bee, the Japanese honey bee (*Apis cerana japonica*) and the European honey bee (*Apis mellifera*).
- // Problems due to pests and diseases are the major cause of reduced bee health, and this applies to both species.
- // The few bee research institutions in Japan mainly focus on honey bees, developing various studies to look at honey bee biology and health.
- // In Japan, there are about 390 native bee species. Although data is limited, it is clear that many wild bees are effective pollinators of wild plants and crops.
- // Good nutrition has been identified as a key factor for good health of managed honey bee colonies, and availability of appropriate forage is likewise a prerequisite for the existence of wild bee species.
- // Bayer is working on a seed mixture as a source of nectar and pollen with native Japanese flower species that are already part of the local ecosystems, creating flowering areas on fallow land.

When cherry trees bloom in Japan, honey bees will find nectar and pollen. However, the cherry blossoms only last for one to two weeks and these honey bees need varied nutrition throughout the season.

Honey bee colony numbers in Japan

In recent years, worldwide discussions about bee health have increased – and thus also received media attention in Japan. At times, this has led to an overreaction: "Many people were concerned, relying on misinformation regarding alleged honey bee colony decline," says Dr Keiko Nakamura from the Research Institute for Animal Science in Biochemistry and Toxicology (RIAS) in Kanagawa, Japan.

"Similar to the situation in Europe and North America, the managed honey bee population has declined in Japan over the past decades but during the last ten years, the population has stabilized," she explains.

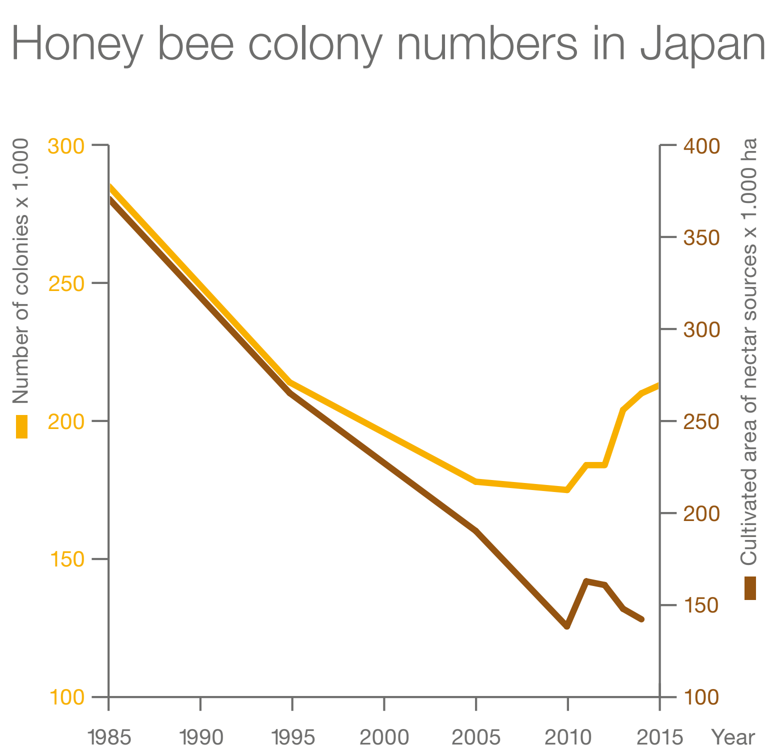
Specific to East Asia is that there are two different species of honey bee; the Asian honey bee (*Apis cerana*), in Japan represented by the subspecies *A.c. japonica*, and the European honey bee (*Apis mellifera*). This situation makes bee research and beekeeper advice more complex. Professor Jun Nakamura explains, "There are big problems with the high rate of transferred parasites between our two different honey bee species." While the *Varroa* mite (*Varroa destructor*) is the biggest problem for the European honey bees, the native Japanese honey bees are better adapted to this parasite.

However, the Japanese honey bees have been faced with another big challenge for the last five years: "Today around 40 percent of Japanese honey bee colonies are infected with tracheal mites (*Acarapis woodi*), which produce their offspring inside the tracheas of honey bees," he explains. Many beekeepers are concerned about this because the mites, which likewise are parasites of the European honey bee, might also transfer viruses to the bees. In recent years, tracheal mites have caused significant losses in honey bee colonies. "Problems due to pests and diseases are the major cause of reduced bee health and have increased with the rising number of hobby beekeepers. Unfortunately, many of them do not have enough experience to successfully fight these various pests," explains Keiko Nakamura.

The few bee research institutions in Japan today mainly focus on honey bees, developing various studies to look at honey bee biology and health. Yet Dr Tomoyuki Yokoi, an assistant professor at the University of Tsukuba, Japan, highlights the importance of wild bee species in agriculture.

"Problems due to pests and diseases are the major cause of reduced bee health and have increased with the rising number of hobby beekeepers."

Dr Keiko Nakamura
Research Institute for Animal Science in Biochemistry and Toxicology (RIAS), Kanagawa, Japan



Source: J-MAFF, Situation On Beekeeping, Youhou Wo Meguru Jousei, 2015 (in Japanese), http://www.maff.go.jp/e/

His research ranges from basic ecology for instance elucidating the interactions of insects and their environment, to the research on the agricultural relevance of pollination by insects, studying the interaction between flower-visiting insects and plants in satoyama woodland environments. This is the border zone or area between mountain foothills and arable flat land. Literally, 'sato' means arable and livable land or homeland, and 'yama' means hill or mountain. Another focus area in his research is the evolution of foraging strategies and reproductive strategies of native bees, for instance bumblebees and Japanese honey bees. "In Japan, we have about 390 native species including solitary and social bees," he indicates. As he explains: "From spring to autumn, many wild bees visit flowers in the field. Although most people do not notice their presence, most wild pollinators for wild plants and crops. For example, farmers in some areas of Japan use *Osmia* bees for the pollination of apple and cherry trees." The data on crop pollination by wild pollinators is limited, although their contribution to crop production is estimated to be 330 billion Yen (which equals 2.7 billion EUR) – accounting for 70 percent of total insect pollination services.

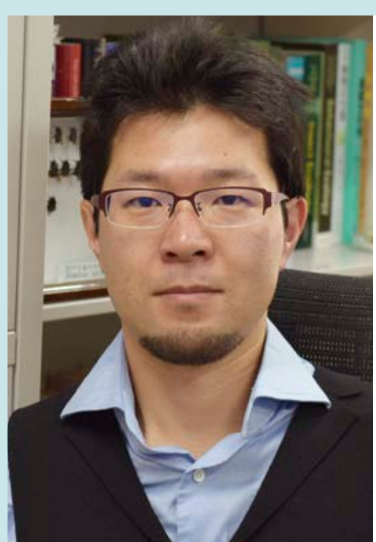
Good nutrition has been identified as a key factor for good health of managed honey bee colonies, and availability of appropriate forage is likewise a prerequisite for the occurrence of wild bee species. Honey bees need varied diet, and they need forage throughout the season, whereas most plants just have a limited flowering window. "Take the Sakura: The spring blossom in Japan only lasts for one or two weeks and the nectar and pollen sources in the summer are too short for bees," explains Professor Nakamura. Wild bees frequently depend on one of a few plant species, but they are many in number, and they all have different needs, so in sum they also depend on floral diversity. Professor Nakamura is now tackling this issue in Japan by planting bee-attractive flowers in the agricultural landscape in areas where crop production has been abandoned. He knows that nutrition is critically important for bee health.

Wild carpenter bees are one of the important pollinators. This bee species has strong mandibles, helping them to make holes in dead wood in which to nest.

Locust acacia with European honey bee.

Female *Halictus* bee visits Creeping Smartweed.

Plasterer bee (*Colletidae*) collects pollen from wild flower.



"Although many people do not notice their presence, most wild bees are effective pollinators for wild plants and crops."

Dr Tomoyuki Yokoi
Assistant professor at Tsukuba University in Japan, specializes in research on wild bees.

Yasuo Araki
Biologist and expert for pollinator health at Bayer in Tokyo, Japan

Inspired by Professor Nakamura's idea and as part of the Bayer 'Feed a Bee' Program, Yasuo Araki, biologist and expert for pollinator health at Bayer in Tokyo, started his project to develop a suitable flower mix specifically for Japan. "Blooming strips with bee-attractive flowers, specifically designed for the conditions in Japan, which supply a sufficient amount of nectar and pollen for a long period, can contribute to improved health of honey bees, and provide wild bees with additional nutritional sources," says Araki. To develop a suitable flower mix (not limited to annual plants) specifically for Japan, he is searching for useful flower species including native ones which are already part of local ecosystems for bees as a source of nectar and pollen.

In spring 2015, Bayer in Japan cultivated these flower species on test fields and positioned a colony of honey bees close to the blooming field. "From early July to late September, we studied the bees' visits to the flowers and analyzed if the bees collect pollen, nectar or both," explains Araki. "In the laboratory, we could assess the nectar in the bees' honey stomach and, based on the sugar content, define the nectar quality."

From the 64 flower species planted in the test field, 34 species flowered during the screening period. Some of these plants have already been reported as attractive for bees in other countries. Not only the tested Western honey bees but various insects including social and solitary bees, butterflies, beetles and hoverflies visited all of these blooming flowers and some competition was seen. Honey bee visits could only be confirmed for nine of the tested flower species.

"This does not necessarily mean that the other flowers are not attractive to honey bees as it could very well be due to the small scale of the test plot and planted flowers," Araki says. "It may also be due to the abundance of flowers and other factors." With this initial information, the researchers wanted to confirm the usefulness of cultured or wild flowering plants surrounding the test fields to provide nutrition for bees. "Since the spring of 2016, we began to document the quality and amount of pollen carried by the honey bees, in order to identify the visits of bees to blooming plants. The pollen study confirmed bees visited 71 kinds of plants, of which 15 were test plant species and 68 kinds of bee collected pollen were identified by November. In addition, Japanese honey bees visited 30 species of flowers including seven of the test plants, and other bees (at least 12 species) visited about 90 species of flowers including 35 of the test plants."

In Japan, the understanding of which flowers, trees and other plant species are beneficial for the health of pollinators is still developing, yet the idea is to cultivate native flowers alongside agricultural fields. "We have a lot of agricultural land that is not being used at the moment," states Professor Nakamura. "Both farmers and beekeepers could benefit from using this land for flowering strips. Honey bee colonies feeding on a mixture of pollen from different plants get a more diverse nutrition, which makes them healthier than those fed on only one type of pollen. And healthy colonies can provide better pollination services."

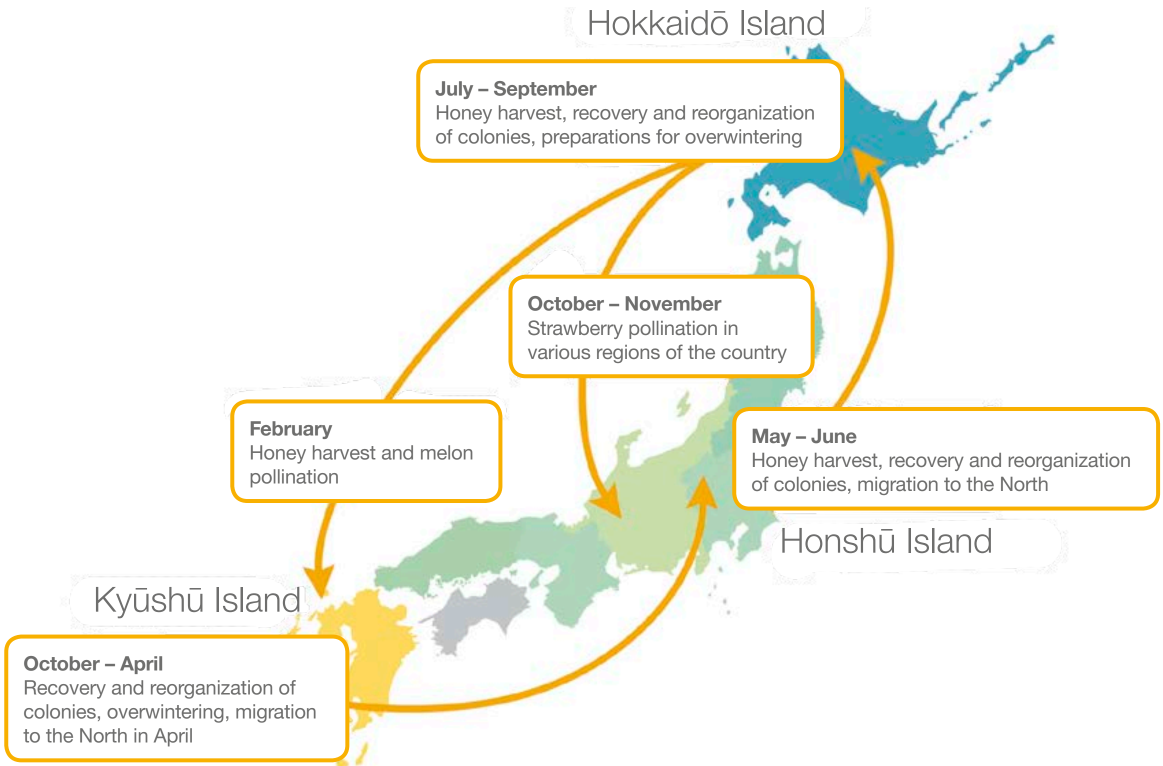
Japanese Snowbell (*Styrax japonicus*)

OUTLOOK

Once a suitable Japanese flower mix (specifically developed for the conditions found in the country) is in place, planting flowers alongside fields and on land which is not being used for agriculture will become a real option. An improved understanding of which flowers, trees and other plant species are beneficial for honey bees and other pollinators will help ensure better pollination services, benefiting both farmers and beekeepers in Japan (in the future).

The Japanese pollination journey:

Tenshi and Teishi



Important nectar sources of honey bees in Japan are Satsuma orange, apple, Locust acacia (*Robinia pseudoacacia*), Japanese snowbell (*Styrax japonica*), horse chestnut (*Aesculus turbinata*), Japanese linden (*Tilia japonica*), Chinese milk vetch (*Astragalus sinicus*), Oilseed rape and White clover, and many others.

Most apiculture in Japan takes place with Western honey bees, which are used for both honey production and pollination services. The hives are moved to an equal extent, either over short or longer distances and the term used in Japan is 'Tenshi' (= moving apiaries). Strict regulations are in place for migration and positioning of bee hives.

Colonies move from the south to the north from **April to July**, following the flowering seasons, for efficient honey production. The northern island of Hokkaidō is the perfect place for the honey bees to spend the summer, offering a relatively cool climate and, consequently, it can get quite crowded.

Colonies are restructured, i.e. consolidated or split, when necessary, after honey harvest and move mainly for pollination of greenhouse-cultivated crops from **autumn to winter**, from the north to the south.

The leasing and selling of colonies for pollination services can be quite a lucrative business. This brings the colonies to the warmer climate in the south of the country for overwintering.

Professional beekeepers manage hundreds of colonies that could not be fed without moving under the conditions prevailing in Japan.

This is different for the Japanese honey bees; beekeeping is very minor and is carried out locally called 'Teishi' [= static apiaries]. The honey produced is typically coming from various flowers within the area. This beekeeping practice works with colonies built from captured swarms. The Japanese honey bees are not used for managed pollination services.

DEVELOPING NEW TREATMENTS

As the threat of the Varroa *mite continues, scientists are keeping up their search for effective ways to help beekeepers protect their colonies from this destructive pest. But developing new treatments isn't easy.*

AT A GLANCE

- // Even though the parasite, *Varroa destructor*, is widely regarded as the greatest individual threat to honey bee health, new tailored pest management solutions to replace long-standing older chemistries have not entered the market and are not foreseen in the near future.
- // Registration of a new varroacide is similar to that of any new pesticide, which can involve more than a hundred basic studies and an average of eleven years to take it from concept to market introduction.
- // Bayer scientists are working collaboratively in private-public partnerships to amplify the search for new *Varroa* solutions.

Approximately 20 years separate the invasion of the *Varroa* mite in Europe and its spread to North America. Beekeepers in both continents have suffered equally the losses of honey bee colonies caused by this destructive pest. In the 30 years since its introduction to the USA, the *Varroa* mite *(Varroa destructor)* has quickly become the most dangerous pest of the Western honey bee, earning the label "Public Enemy Number 1" from US bee-keepers. Worldwide, this pest is estimated to have killed millions of colonies, resulting in billions of dollars of economic loss.

Unlike the Asian honey bee *(Apis cerana)*, which is the original host of the *Varroa* mite, the Western honey bee *(Apis mellifera)* has few natural defenses against this invasive parasite which affects bees by direct feeding and by vectoring infectious viral diseases. It only takes a few mites per hundred bees to severely weaken a colony. Without prompt human intervention, these infestations can cause major colony losses. Many successful beekeepers use an Integrated Pest Management (IPM) approach in dealing with *Varroa*. This involves rigorous monitoring of hives to assess the problem, use of apicultural practices to control population build-up, and the application of chemical varroacides to reduce the number of mites or prevent re-infestation.

Acaricides are chemical agents to combat mites and ticks. The picture shows a male brown dog tick *(Rhipicephalus sanguineus)*.

Substances specially developed to combat the *Varroa* mite are called **varroacides**. The picture shows mites in a brood cell of a bee colony.

Until such time as the Western honey bee develops a natural tolerance to *Varroa*, or new *Varroa*-resistant strains are commercially available, the use of chemical control will remain a critically important component of beekeeping IPM. And yet, despite the obvious need for effective varroacides, there are no guarantees that enough new treatments will be available to help address this existential threat. To better understand the situation, it is helpful to first look back from where we've come.

Beekeepers have always dealt with numerous pests and predators in managing their hives, but it is no understatement to say that everything changed after the introduction of *Varroa*. Finding appropriate chemical treatments to help them manage this new pest is no easy matter. Perhaps no one understands this better than Dr Klemens Krieger, Global Head Bee Health Projects within Bayer Animal Health. "At the time of the *Varroa* introduction there were no readily available treatments," he explains. "Today, even after 30 years of intense research effort, only four synthetic varroacide active ingredients are approved for *Varroa* control, two of which were developed by Bayer."

Given the magnitude of the threat, it is easy to wonder why more treatments are not readily available. Fact is, there are several reasons why finding and developing an appropriate chemical candidate to fight *Varroa* is anything but easy.

The inherent difficulty of controlling a "bug on a bug" (without harming the host species) is a biological challenge requiring a level of chemical specificity that is hard to find. For example, many products that are used to control agricultural insect pests also have some acaricidal activity. Similarly, it is not uncommon that acaricides used for mite control in crops have some level of activity on insects, too. Scientists searching for an effective *Varroa* treatment must find the narrow "sweet spot" that provides reliable control of the parasitic mite without causing harm to its honey bee host.

Dr Klemens Krieger, Global Head Bee Health Projects within Bayer Animal Health, has long experience in developing varroacides to protect honey bees from the Varroa mite.

Scientists who screen new molecules for apicultural uses know that there is more to this process than just finding a chemical that controls the mite without harming the bee. Dick Rogers, Principal Scientist and Expert of Bee Health and Integrated Apiculture Research at the Bayer Bee Care Center in the USA, is a longtime beekeeper who evaluates potential new candidates. “The difficulty in finding a bee-friendly varroacide is compounded by the fact that we’re looking for one that has a different mode of action to the currently registered products,” he notes. “Effective IPM programs require a rotation of chemical modes of action to minimize the potential for pest resistance.”

Identifying an acceptable candidate for a chemical control product for *Varroa* is a huge step, but it’s only the first of many in a complex and multilayered path to the marketplace. Establishing proof of efficacy is just one part of the registration process. A potential candidate must meet stringent safety parameters to show it will not have adverse effects on people, wildlife or the environment. Registering a new varroacide is similar to that of any new pesticide, which typically involves more than a hundred basic studies and an average of eleven years to take it from concept to commercialization.

Not only is this path long and arduous, it is also expensive. The cost of developing a new varroacide can easily reach 100 million Euros (without including the substantial investment in a manufacturing facility). New medicinal products, developed for use in food-producing animals like honey bees, require a costly infrastructure to evaluate their molecular, biological, and toxicological properties and clinical assays to ensure their efficacy and safety when used. Additional costs involved in developing stable formulations, evaluating metabolic pathways, and field performance trials only add to this investment.

“Because the development is associated with honey consumption, additional scrutiny and risk assessment is required of a new varroacide used in honey bee hives,” notes Stu Nibbelink, Project Manager at Bayer’s Animal Health Business Unit. In smaller markets such as products for commercial beekeeping, the decision to develop a stand-alone varroacide can be a significant financial hurdle because the return on investment is relatively low. As Nibbelink explains: “The most cost-efficient path to development is to find a product that has a broader pest potential in crop protection uses to complement its use in hive pest management practices.”

There’s no question that a long and costly registration timeline is an impediment to the development of new varroacides.

Currently there are few, if any, incentives in place to help expedite these ‘minor use’ products through the registration process. Despite the urgent need for new solutions, the regulatory requirements for a new data safety package have only continued to increase.

FACTS & FIGURES

Through the use of bee health products from Bayer to combat the *Varroa* mite in the USA for nine years, economic losses amounting to some **1.5 billion US dollars** were prevented in the period between 1999 and 2007.

Source: Michigan State University, 2009

The average number of veterinary medicines authorized per EU member state:
bees: 3 pigs: 426 dogs: 592

The uneven distribution of bee product registrations among the EU Member States results in little or no choice for beekeepers in some countries.

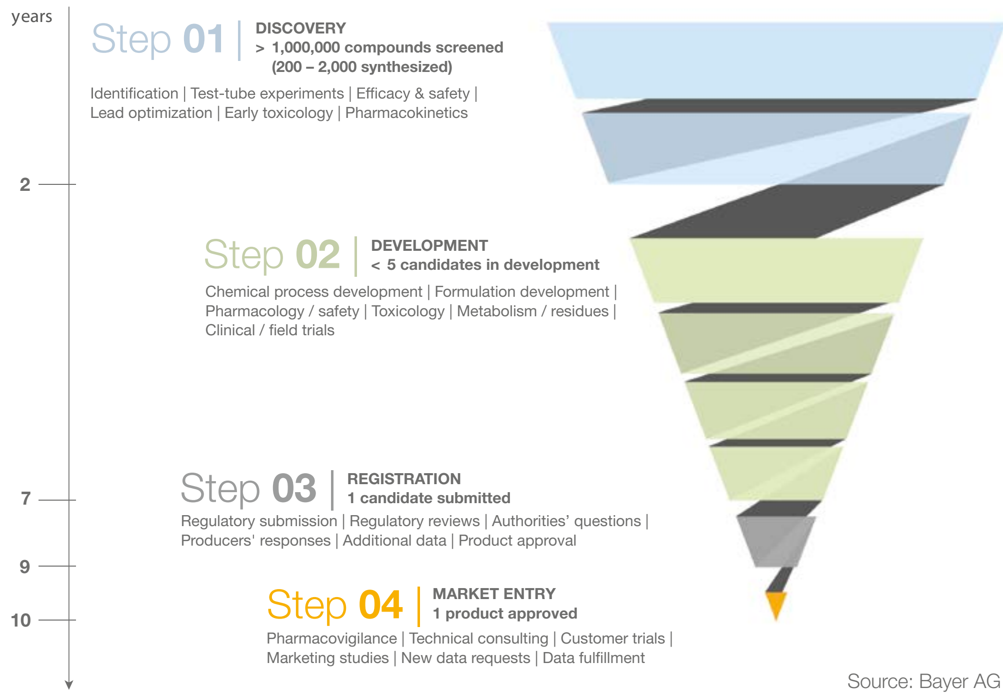
EU financial support for beekeeping:
33,100,000 EUR / year

Source: European Commission Fast Facts, 2014
http://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/COM-2016-776-F1-EN-MAIN-PART-1.PDF

From idea to market maturity

Development of a new varroacide

Costs: up to 100 million EUR (excluding cost for production facilities)



Source: Bayer AG

THE MOST IMPORTANT REQUIREMENTS FOR AN EFFECTIVE VARROACIDE

Efficacy

- Highly effective on *Varroa* mite
- Highly selective (effect on mites versus bees)
- Low risk of resistance development by the pest
- Good formulation properties
- Nice to have: control of other pests such as tracheal mite, Small Hive Beetle, Wax Moth, while the honey is still in the hive

Human safety

- Low toxicity to humans
- No oncology or reproduction classification
- Low / no residues in honey
- Safe packing
- Easy to use

Environmental compatibility

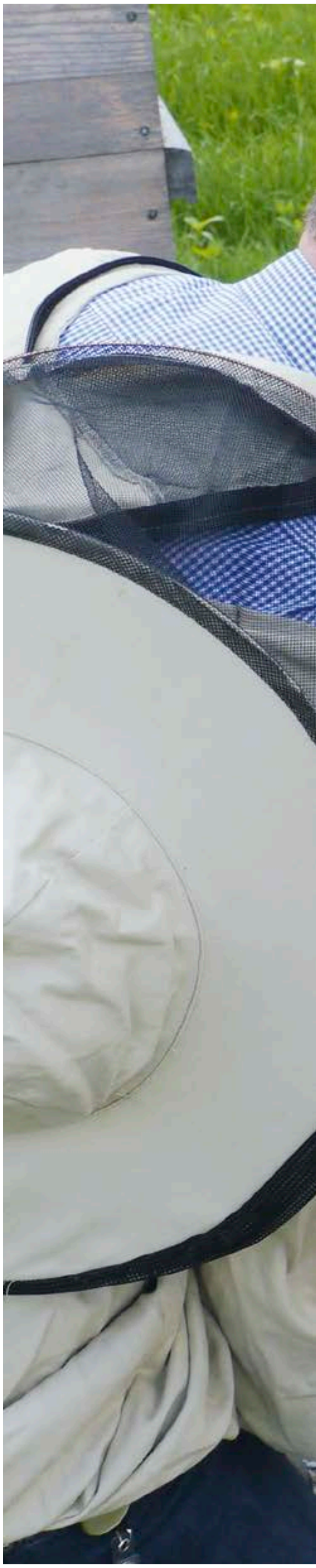
- No harmful effects on bees and bee brood
- No residue build-up in wax
- No disposal issues

Profitability considerations

- Favorable cost-benefit ratio for the beekeeper

Mark Drewes manages the substance library at Bayer in Monheim (Germany). Around 2.5 million substances identified in our research efforts are stored there.

Testing the contact effect of the polymer matrix with active substance during the development of the Varroa Gate.



While the search for new modes of action continues, scientists are doing all they can to make the best use of the tools they have available – in some ways almost reinventing them to meet the challenges of today's hive management practices. Dick Rogers is pouring through Bayer's vast chemical archives to see if candidates evaluated for crop protection uses might have acaricidal properties that were previously unnoticed. "It's not just about finding the right chemical, it's also about finding the right delivery system for the chemical," he notes. "Contact activity or volatility is greatly affected by the solvents or formulations used and can make a huge difference when evaluating varroacide products."

When it comes to new delivery systems, Bayer's Animal Health Business Unit is exploring cutting-edge innovations to help bring relief to the world's beekeepers. For the past few years, Krieger has led the development of a new concept known as the "Varroa Gate", a plastic strip impregnated with a varroacide and affixed to the entrance of the hive. Honey bees entering or leaving the colony receive a tiny dose of chemical which they distribute in the hive. It is sufficient to control the mite population but harmless to the bee.

"One of the biggest problems beekeepers face is the mite's ability to spread between colonies, carried by foraging workers returning to the hive after having picked up this parasite," Krieger explains. "The Varroa Gate technology provides a novel way of minimizing another *Varroa* infestation, which is especially important for vulnerable colonies preparing for the winter season." The performance of the Varroa Gate has been evaluated in one of the largest and most comprehensive field efficacy trials of its kind ever conducted in Bayer's Animal Health Business Unit. Applications for registration have been submitted in 24 countries in Europe and this has been granted in several countries already.

Having access to a new technology to help manage the *Varroa* mite is certainly a rare occurrence. But for beekeepers who have struggled with this destructive pest over the past 30 years, it is also one that cannot come soon enough.

Hanging a *Varroa* mite control strip with a varroacide between the combs in a beehive is one of the methods used to apply a varroacide.

To keep honey bee colonies healthy, beekeepers need to monitor and control the *Varroa* mite in their beehives. This includes periodic inspections to determine the infestation level before taking appropriate control measures.

CONCLUSION

Despite being critically needed by beekeepers, the process of discovering, developing and registering a new varroacide is extraordinarily difficult. Finding the right product not only requires years of research and development and a significant financial investment, but also demands a long-term commitment to pollinator health. For 30 years, Bayer has been an industry leader in honey bee research and this effort extends well beyond its own laboratory doors.

REDUCING DUST DRIFT TO PROTECT POLLINATORS

For over 3,000 years, seeds have been treated to protect them against pests and diseases and, ultimately, improve yields. More than a century of unmatched experience and expertise in seed treatment technologies distinguishes Bayer's portfolio. However, innovation at Bayer does not stand still and the portfolio is being continuously adapted to address market needs and safety requirements. To this end, Bayer has been working intensively with the seed industry to reduce the risk of dust drift from seed treatment products, which has the potential to negatively affect pollinators and other organisms in the environment during sowing. As a result, significant progress has been made in minimizing the risk of dust emissions from treated seed.

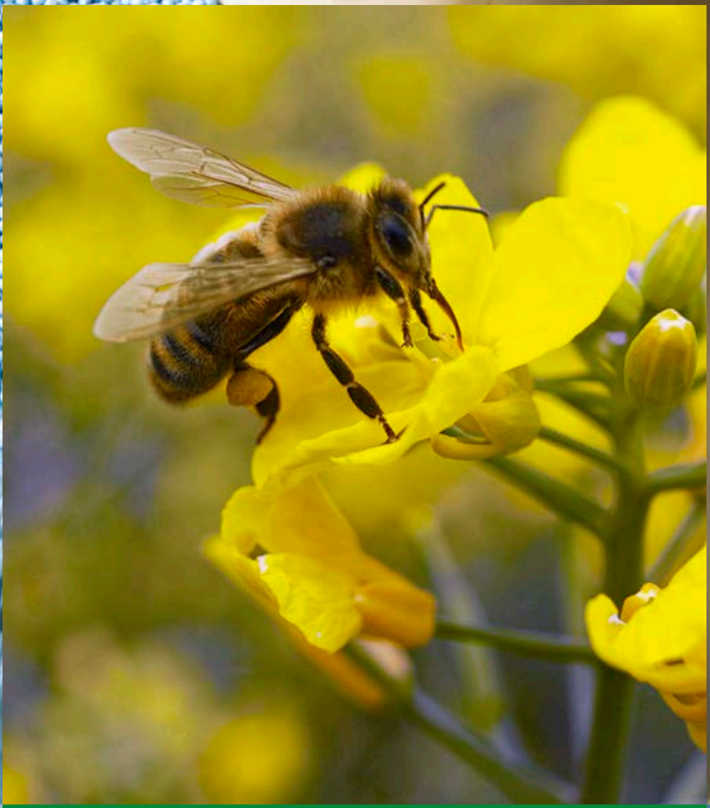
Ash, pulped olives, copper carbonate, liquid manure, copper vitriol, arsenic: All sorts of weird and less than wonderful substances were used to protect seed against pests and diseases in centuries past. A decisive breakthrough in the search for effective seed treatments came in 1914 when Bayer launched Uspulun, a fungicide that finally broke the curse of fungal diseases that had devastated cereal crops since time immemorial. This heralded a century of Bayer-driven innovations in seed treatment products that have brought benefits to farmers, consumers and the environment: secure field emergence, uniform and healthier plants, reliable and sustainable yields and, first and foremost, protection against pests and diseases.

Widespread benefits

For farmers, the benefits of seed-applied solutions are mainly economic. Take oilseed rape, for instance. A seed-applied insecticide protects the crop from the significant losses caused by pre- and post-emergence pests (e.g. Cabbage Stem Flea Beetles) and ensures higher yields. For consumers, it is not only the delightful sight of bright-yellow oilseed rape fields in spring but also the benefits of the harvested product, the processed oil, which is a great source of polyunsaturated fatty acids. Last but not least, oilseed rape fields are an important component of agro-ecosystems in temperate zones since the flowers serve as a source of early-season forage, providing nectar and pollen for honey bees.

Without protection against pests such as the Flea beetle (picture shows a larva), farmers can lose a substantial part of their harvest.

In 2015/2016, some 68 billion tons of oilseed rape was harvested worldwide from which we get, among other things, edible oil.



AT A GLANCE

- // Treating seeds protects them against pest and diseases and, ultimately, improves yield.
- // Bayer's expertise in seed treatment technologies is based on over a century of know-how.
- // Stewardship measures, improved coatings, certification of seed treatment sites and technical innovations (e.g. deflectors, AirWasher, SweepAir or the Bayer Fluency Agent) have significantly reduced environmental exposure due to dust drift from seed treatment products, also protecting pollinators.

Seed treatments are nothing new

Seeds have been treated to protect them against pests and diseases for over **3,000 years**. Seed treatment has come a long way since the 1930s when mercury was used to stave off seed-borne diseases. Mercury treatments were stopped in the 1970s due to health issues.

QUALITY STANDARDS

for a high level of application quality at seed treatment plants:

RECOMMENDATIONS on recipes, best management practices and tested modifications for sowing machines (e.g. deflectors), as required by some authorities (for implementation by seed treaters and farmers).

Close follow-up and on-going **MONITORING** of treatment quality and implementation of best management practices in the field.

INFORMATION AND TRAINING of customers in best management practices, incl. **CERTIFICATION** SUPPORT (for seed treaters) and good sowing practices (for farmers).

Unique protection

Systemic seed treatments, which move upwards from the roots into the plant and outwards towards the tips of new leaves as they grow, protect an entire plant during its early growth stages. This dramatically reduces environmental exposure to the necessary plant protection treatment as the insecticide, for example, is applied at the seed level, exactly where it is needed. This reduces the number of foliar applications required in the plant's later life. A greatly reduced proportion of the field area is exposed to the plant protection treatment. An additional benefit is the efficacy of seed-applied solutions against otherwise hard-to-control soil pests and diseases.

Dust drift

If, however, the seeds of certain crops (e.g. corn or sunflowers) are treated in a manner which is not compliant with the recommended quality standards for seed dressing, a significant amount of dust particles from the seed treatment can be abraded during handling, storage or sowing. These particles can then be emitted into the air, especially when vacuum-pneumatic planters, a type of sowing device that accurately places seeds into the soil using a negative pressure system, are used. In 2008, serious incidents occurred in Germany and Slovenia when a combination of factors (poorly treated seed, the type of sowing machine used, landscape structure and weather conditions) resulted in dust from treated corn seed drifting onto neighboring flowering crops and flowers around the planted fields, causing honey bee mortalities in the vicinity of the field.

Since then, Bayer has been working intensively with the seed industry and other stakeholders to reduce the risk of dust drift impacting bees and other pollinators during sowing. The outcome has been a number of effective safety measures. "Stewardship is the responsible and ethical management of a product throughout its life cycle, the maximization of the benefits derived from the use of our products, and the minimization of potential risks to human health and the environment," says Dr Peter Ohs, Senior Global Stewardship Manager at Bayer's Crop Science Division. "Bayer is working with agricultural communities worldwide to ensure that its products are used in an environmentally responsible manner."

Enhanced stickability

The starting point for reducing dust drift is to increase the 'stickability' of the seed treatment product in order to prevent abrasion of dust particles. Here, coatings play a decisive role. At the Bayer SeedGrowth Center of Excellence in Méréville, France, a team of specialists develops, produces and markets a wide range of film coatings to improve seed treatment quality and support the performance of seed-applied solutions. Marc Andrieux, formerly Global Head of SeedGrowth Technology, Services and Coatings at Bayer's Crop Science Division, explains what matters most: "It's a constant challenge to develop coatings to protect the seed, ensure the additives stick to it, and make sure seed germination, sowability, flowability, i.e. smooth mobility of the seeds in the machinery, and dust control are all tackled. Balancing stickiness and flowability is one of the main aspects in the development of film coatings." The results of Méréville's work are impressive: Bayer's Peridiam® coatings have been shown to reduce dust emissions by up to 95 percent and improve the flowability of treated seed in the sowing machine by up to 15 percent.

Developing coatings to protect the seed, ensure the layers stick to it, make sure seeds don't stick together, can be sown easily, don't create lots of dust and will still germinate, is a constant challenge.

Certified seed treaters

An important step in reducing the risk of dust emissions is to ensure seed is treated at certified sites. Compliance with an industry-driven certification scheme, such as the European Seed Treatment Assurance (ESTA), proves that a specific seed treatment process and the treated seed meet the operator- and environment-related quality and safety standards of regulators and the industry. One ESTA quality criterion, for example, is compliance with pre-defined Heubach dust values (grams of dust per unit of treated seed, following a pre-defined handling procedure). The Heubach test is generally recognized as the standard method to determine the loss of dust from treated seed. Certification proves seeds have been treated professionally and sustainably and thus contributes significantly to higher-quality seed treatment products. The higher the quality of the seed treatment, the less dust is generated.

Improved in-field safety

Once the treated seed has been loaded into the sowing machine, several technological advances in which Bayer has been a key player have made a critical contribution to minimizing the risk and levels of dust emissions. Field tests have shown that deflectors fitted to a pneumatic vacuum sowing machine reduce dust emissions by as much as 90 percent through directing the outlet air stream of the machine that may contain abraded seed treatment particles onto the soil. Having deflector technology available is one thing; investing in the actual equipment is another.

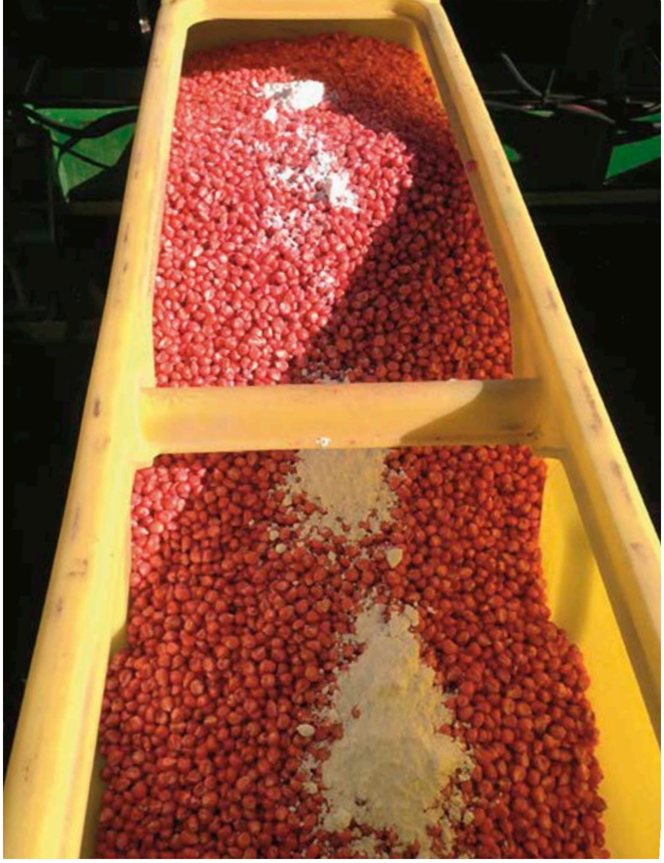
Bayer is working with agricultural communities worldwide to ensure that its products are used in a responsible manner.

FACTS & FIGURES

3.9 billion US dollars

The global chemical seed treatment market was worth around **3.9 billion US dollars in 2015** and is expected to cross **6 billion US dollars by 2020**.

Source: www.researchandmarkets.com



Tests with **Fluency Agent**, a polyethylene wax lubricant, show up to 90 percent total dust reduction from vacuum sowing machines.

Fortunately, the deflectors have already been widely implemented in several European countries since 2008, as for instance Germany or Slovenia. In Hungary, Bayer has been proactively involved in a campaign to raise awareness of the need for deflectors. A standardized deflector kit was developed to fit the planting equipment commonly used in Hungary and discounts of 50 to 70 percent are encouraging farmers to purchase the kit. In Romania, it will hopefully become mandatory soon and, in Spain, Bayer has been working with machinery suppliers to make the necessary technology available. In Italy, deflector technology is being implemented in collaboration with seed companies. Additionally, in North America, specifically certified deflectors came onto the market in January 2016.

A seed-box lubricant, the **Bayer Fluency Agent**, also greatly reduces dust emissions from vacuum sowing machines. In corn, for instance, emissions were reduced by up to 88 percent compared to talc, which is widely used as a seed flow lubricant in planting equipment. Lubricants like talc or graphite are used in planters to decrease wear in mechanical seeding mechanisms by reducing friction or as drying agents to prevent seeds sticking to machine parts or clumping together. The Bayer Fluency Agent is a polyethylene wax lubricant which is thus the ideal replacement for conventional lubricants. It can be used with all makes and types of sowing machines, and has no impact on planting accuracy. It has been readily taken up in Canada and in the corn growing regions of the USA.

SweepAir is a prototype technology based on a cyclone system that separates the dust from the outlet air of vacuum-pneumatic planters.

Sometimes, the inspiration for an innovation comes from an unusual source. After noticing how construction sites heavily douse dust with water to prevent drifting, Bayer specialists in Austria co-developed a technology they christened **AirWasher** with Lechler, a German machinery manufacturer. The exhaust air from a seed planter is sprayed in a tube with a fine mist of water and the water droplets mix with the dust particles before draining into the field. Tests at the renowned Julius Kühn Institute (JKI) in Germany revealed that an AirWasher kit fitted to a deflector reduced dust emissions by up to 97 percent, i.e. significantly more than the already impressive results achieved by deflector technology alone.

Another Bayer development, **SweepAir**, is a prototype technology based on a cyclone system that separates the dust from the air. Here, JKI tests have shown that SweepAir can reduce in-field dust emissions from pneumatic corn-sowing equipment by up to 99 percent.

The advances in seed treatment and sowing technologies in recent years have been made possible by close collaboration between stakeholders along the entire value chain. The beneficiaries have been pollinators, people and our environment.

CONCLUSION

There have been significant advances in seed treatment and sowing technologies in recent years. Bayer has made a major contribution to these beneficial developments through close cooperation with the seed industry and sowing equipment manufacturers, as well as through its own technical innovations. Where these advanced technologies have been implemented, the potential risk to pollinators and the environmental exposure to dust drift from seed treatment products has been greatly reduced.

Project 'Zero Dust'

We talked to Dr Björn Schwenninger, when he was the head of Bayer's 'Zero Dust' project, about the latest developments in dust reduction technologies.

"BaySTEP"
Via a microphone attached to the seed treatment tank, a computer program recognizes the exact time when the seed treatment process must stop.

How do you define "zero dust"?
I would compare our project with "zero emissions" projects in the automotive industry, for example. Since it's scientifically impossible to achieve absolute zero in dust or exhaust emissions, I'd say we're striving to minimize dust emissions to the lowest technically feasible levels.

What are the most recent developments in your 'Zero Dust' project?
Our project has many different facets – SweepAir and AirWasher are just two of the better-known technological outcomes. In our formulation technology laboratory in the USA, for example, we are currently optimizing several seed treatment products for cereals, so products marketed from 2018 onwards will be characterized by even lower dust emissions. Another exciting development is the end-point determination technology we call "BaySTEP®".

What's a "BaySTEP" got to do with seed treatment?
Rather a lot actually. This new technology determines the precise point in time when the seed treatment process is to be stopped. Right now, an experienced operator at a seed treatment site listens and decides by ear when the process is finished. Now we can offer treaters an ultra-precise technical solution. A specially developed software tool translates the noises recorded by a microphone attached to the seed treatment tank into signals that automatically stop the seed treatment mixing process – independent of the experience level of an operator. If the mixing goes on too long, the treated seed will end up with less favorable dust values and particles of the treatment will be abraded during mixing. As a result, the seed treater will have higher costs due to wastage of seed treatment product which has been abraded, and will lead to a sub-standard seed which has not been correctly coated with the right amount of seed treatment to meet customer requirements. Our "BaySTEP" has been successfully tested in our laboratories and at various treatment sites for corn, cereals, soybean and oilseed rape seeds in Germany and Canada. The treaters were so pleased with its performance they would have gladly carried on using our prototype.

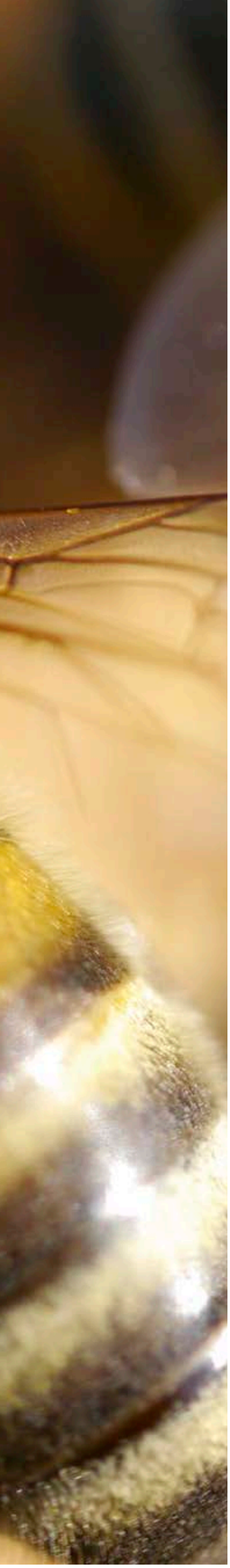
What progress has been made in putting these technological advances into practice?
In 2015 we had two most encouraging roundtable discussions in Germany involving representatives of the equipment manufacturers, regulatory bodies and crop protection industry in which it was agreed that it was key to bring further dust reduction technologies to the market. What we agreed on is a kind of 'letter of intent' to introduce a dust reduction classification scheme in Europe, an idea similar to the CO_2 emission classes for cars. The dust reduction level currently achieved by deflector technology, 90 percent, would be a kind of "Class I", and two new classes could relate to 95 percent and 99 percent dust reduction. We are currently working on translating this letter of intent into concrete common activities which will also extend to all types of planters and all relevant crops. Our ultimate goal is that authorities consider the dust reduction classes for registrations of seed treatment products. Today, we see that many planters in the market already fulfill "Class II" or "Class III" levels so, hopefully, these advanced technologies could soon actually be used in practice.

Varroa female mites are 1.1 millimeters long and 1.6 millimeters wide. For a honey bee, this is the equivalent of an average-sized human having a rabbit attached to their body.

Female *Varroa* mite, top right, and male shown, bottom left.

AT A GLANCE

// The parasitic mite *Varroa destructor* serves its name well; it is probably the most dangerous pest of the Western honey bee.
// The parasitic mite, *Varroa destructor*, originated in Asia and has been introduced to most of the world through human movement of honey bees.
// Unlike the Asian honey bee, the Western honey bee has not yet developed sufficient mechanisms to protect itself against the parasite.
// *Varroa* infests adult honey bees and their brood and, thus, weakens the entire bee colony. Additionally, the mite transmits deadly viruses to honey bees.
// *Varroa* is the main cause for regionally increased overwintering honey bee colony losses in Europe and North America.
// Bayer is actively involved and committed to monitor *Varroa* and develop strategies to control the mite, to improve honey bee colony health worldwide.



A DEADLY PARASITE THREATENS HONEY BEE HEALTH IN PARTS OF THE WORLD

FIT AGAINST *VARROA* – FIT FOR WINTER

In Europe and North America, honey bees are productive livestock which require intensive care by humans to stay healthy. The biggest threat beekeepers have to manage is the Varroa destructor *mite. This parasite weakens the bees and transmits viruses that cause deadly diseases. Bee experts see* Varroa *as the main reason for increased honey bee colony losses, especially over the winter season. Bee experts are working on new approaches to control* Varroa *and thus improve the overall health of honey bees.*

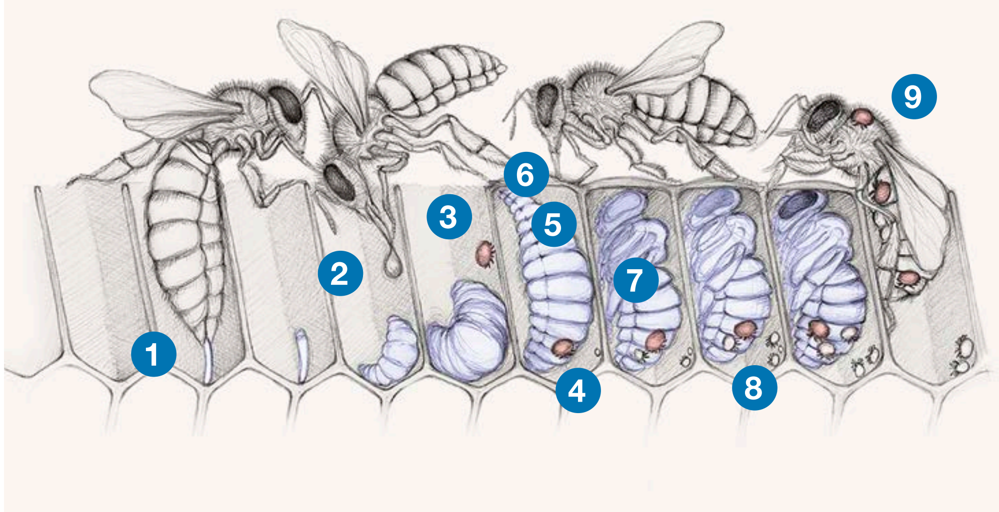
Unlike honey bees in many parts of the world, Ernst Caspari's bees remain calm when he removes their honeycombs from the beehive. He does not need to wear gloves or a net-like veil to protect his face. "These bees are calm – a direct result of quality breeding," the experienced beekeeper and breeder explains. 86-year-old Caspari, who keeps 20 honey bee hives, is a member of the beekeeper association of Leverkusen, Germany.

Ernst Caspari is 86 years old and has many years of beekeeping experience, having started as a teenager. Today, he still manages 20 honey bee colonies.

As a former Bayer scientist in the area of organic chemistry, Caspari continues to be in close contact with research colleagues and bee experts at the Bayer Bee Care Center located nearby, in Monheim. Bayer has been actively engaged in protecting and improving bee health for 30 years now and Caspari benefits greatly from this intensive exchange of expertise.

His enthusiasm for honey bees has not changed at all over the years – his tasks as a beekeeper, on the other hand, have changed tremendously: fighting bee pests is now much more a focus than it was when he started out as a beekeeper. The main threat is the *Varroa* mite. The parasite infests honey bee colonies and crawls into the bees' brood cells – before the worker bees cap these cells. Initially, the adult female mite that enters the cell will hide under the bee larva. Once the cell is capped and the larva has consumed all of its brood food and pupates, the parasite starts feeding on the newly formed bee pupa. Female mites can also live on adult honey bees, especially during broodless periods such as winter: they penetrate the chitin armor with their mouthparts and suck the hemolymph, a bees' blood-like fluid.

Development of *Varroa* mites in a honeycomb cell



1. Queen bee lays eggs.
2. Worker bee feeds larva.
3. *Varroa* mite enters cell with larva inside.
4. Reproduction: The female mite starts to lay eggs. The first egg is not fertilized and develops into a male.
5. Larva grows to final stage.
6. Worker bee closes cell with wax.
7. Pupation phase begins.
8. Female mites develop from the next 4 to 5 fertilized eggs.
9. Young bee hatches from the cell with adult *Varroa* mite and 1 to 2 mature daughter mites.

One of the viruses the mite transmits is the Deformed Wing Virus (DWV). Both brood and adult bees can be infested.

Symptoms may not be visible until infected bee pupae hatch as adult bees with deformed wings (see above). Such bees have a shortened life span.

In addition to the parasite itself, there is also a more severe danger for honey bees: the infection it can transmit. Like a tick, the *Varroa* mite transmits viral diseases. “The mites weaken the bees’ immune system, making honey bees more susceptible to diseases,” says Peter Trodtfeld, bee expert and beekeeper at the Bayer Bee Care Center. “Moreover, the mite transmits viruses directly into their hemolymph, so normally less harmful viruses can become deadly to bees.” *Varroa* is a vector for Deformed Wing Virus (DWV), for example. If bee pupae are infected with this virus, their wings do not develop correctly. Consequently, the hatching bee is not able to fly and will have a shortened life span. To spread from hive to hive, the *Varroa* mite depends on honey bees to transport it. This happens when bees are searching for food, as they may frequently come into contact with bees from other colonies, even those located several kilometers away. In this way, the mite can rapidly spread.

Keeping *Varroa* infestation in honey bee colonies as low as possible is a particularly important task for beekeepers especially in Europe and North America, where the mite can cause high colony losses. As such, one of Caspari’s tasks is to assess the extent of the *Varroa* infestation in his own honey bee colonies. To do this, he counts the number of mites that have fallen through an open grid onto a sticky board on the bottom of the hive. “From the number of dead *Varroa*, we can extrapolate the number of live mites in the bee colony,” he explains. Regular diagnosis is critical for the appropriate timing, frequency and choice of treatments to control *Varroa*.

The *Varroa* mite is native to Asia. The *Varroa jacobsoni* mite was discovered on the Indonesian island of Java more than 100 years ago and, at that time, it was associated with the Asian honey bee (*Apis cerana*).

Each colony requires intensive care. Special efforts are necessary to control pests and diseases to ensure that bees stay healthy and are, thus, more likely to survive the winter. Peter Trodtfeld, bee expert and beekeeper at the Bayer Bee Care Center in Germany, sees good nutrition and timely *Varroa* treatment as the most important elements in preparing a honey bee colony for winter.

Presumably, this bee had been living alongside the mite for hundreds of thousands or millions of years in a host-parasite equilibrium. When hives of the Western honey bee (*Apis mellifera*) were introduced to East Asia, it was not foreseen that, through direct contact with the native Asian honey bee, the newly introduced Western honey bee colonies would also become infested. Due to the speed with which this occurred, the Western honey bee did not have time to build up sufficient mechanisms to protect itself against the parasite. "Without man's help, an infested Western honey bee colony will normally die within a few years," Peter Trodtfeld, bee expert and beekeeper at the Bee Care Center in Germany, explains. Unfortunately, the detrimental effects of the *Varroa* mite on the health of the Western honey bee were discovered too late to prevent infested colonies from being returned to Europe, from where the invasive parasite has continued to spread since the 1970s.

In the following years, based on genetic analyses, researchers discovered that the mite that was carried to Europe is a different species than *Varroa jacobsoni*. This new species is today known as *Varroa destructor*. Nowadays, this mite populates most regions of the world: China, Russia and other Asian countries have confirmed finding the parasite in addition to Europe, Africa, North and South America and New Zealand. In almost all areas of North America and Europe, the mite is present in virtually every honey bee colony. This is why there are fewer feral honey bee colonies in North America than there were before *Varroa* arrived and almost no feral honey bee colonies in Europe any more. So far, Australia is the only continent to have been spared from a lasting invasion, primarily through intensive inspections and strict quarantine controls (see also page 15 ff). Although *Varroa* is prevalent worldwide, it does not show the same impact on bee colony health in each region because of the different behavioral and other features of the bees. In Africa and parts of South America, *Varroa* does not appear to be a key factor influencing honey bee health because the bees show a distinct tendency to swarm, leaving a part of the colony behind, along with the brood combs which contain a large number of the mites. Similarly, in some regions of Southeast Asia, no major problems appear to be known so far. That said, in many other countries beyond Europe and North America, specific information about the current situation regarding the prevalence and impact of *Varroa* is still missing.

To control the mite, there are synthetic products, so-called varroacides, as well as organic acids, such as oxalic acid and formic acid, which can be used: "I do the first treatment with formic acid immediately after the last harvest of honey," Caspari says. The liquid compound vaporizes and disperses throughout the hive in gaseous form. "The vapor bath even penetrates the sealed brood cells, killing the mites feeding in there," he explains. Temperature plays a decisive role in the effectiveness of the treatment: It influences how fast the formic acid vaporizes. So, products that require specific outside temperature and environmental conditions are only suitable under certain climatic conditions and, as such, can only be used in certain regions of the world. Beekeepers can also use synthetic varroacides which were developed and registered specifically to control the parasitic mites. Some of the synthetic active ingredients, such as amitraz, coumaphos or flumethrin, can be embedded into plastic strips that are hung between the honeycombs in a hive. "The active ingredient particles are picked up in the bee's hair and are passed onto other bees inside the hive through their social interaction. In this way, the female mites outside the brood combs and on the bees are also exposed to the substance and are killed," Trodtfeld says.

A *Varroa* population can double every three to four weeks during the breeding season. It can grow from **50 mites up to around 3,200 mites** from the beginning of February to the end of August under temperate climatic conditions.

However, a single *Varroa* treatment at the end of a bee season is not sufficient to protect the bee colony over the winter from these parasites. With the correct treatment earlier in the year, in summer or early fall, beekeepers can reduce the *Varroa* numbers but not completely eradicate *Varroa* from a honey bee colony. "A few mites always remain and will begin to reproduce again in spring," Caspari says. A *Varroa* population can double every three to four weeks during the breeding season. It can grow from 50 mites up to around 3,200 mites from the beginning of February to the end of August under temperate climatic conditions. The health and vitality of winter bees which developed during a high mite infestation in autumn are severely compromised. As a result "The *Varroa* treatments have to be timely as we are unable to subsequently treat or cure diseases that may have been transmitted by the parasite previously," Trodtfeld explains.

Dr Tjeerd Blacquière, Senior Scientist at Plant Research International of Wageningen University, the Netherlands

“The most serious pest is the Varroa mite together with the viruses it spreads.”

Dr Tjeerd Blacquière

Dick Rogers
Principal Scientist and Expert of Bee Health at Bayer Bee Care Center in North America

“Since its arrival in the USA, the Varroa *mite continues to be a tremendous challenge that has to be overcome – with the help of intensified monitoring and improved hive management. To prevent resistance problems, it is essential that beekeepers do not overuse effective products and rotate product use each year.”*

In addition, “Many environmental stressors in late summer can impair the development of vital winter bees: Bee diseases and parasites such as the gut parasite *Nosema*, lack of forage or adverse weather effects may reduce the quantity and quality of the winter bee populations”, explains Dr Tjeerd Blacquière, Senior Scientist at Plant Research International of Wageningen University in the Netherlands.

Ultimately, the lower the *Varroa* infestation at the end of a bee season – and the stronger the honey bee colony – the greater the chances are that the colony may survive the winter. “Honey bee colony losses of up to 10 percent are normal during the winter,” Caspari explains. The increased presence of *Varroa* mites has caused increased honey bee colony losses during winter in recent years, particularly in many European regions and in North America. Caspari has witnessed this himself, since mites first infested his honey bees in 1984: “Initially, 15 dead mites falling into the sticky board during a *Varroa* treatment in late summer were considered a lot. Today, I often count hundreds of mites,” he states.

Worldwide, the number of managed honey bee colonies has increased about 65 percent over the last 50 years. However, increased honey bee colony losses during winter mean beekeepers have to compensate by replacing their lost colonies in the spring. The “Bee Informed Partnership” (BIP) – supported by the United States Department of Agriculture (USDA) – reports preliminary results of up to 28 percent of US honey bee colonies lost during winter 2015-16. “This is above the loss rate of 15 percent, considered acceptable in the USA. Moreover, we did our own survey and talked to many beekeepers, who recorded losses up to 100 percent,” says Dick Rogers, Principal Scientist and Expert of Bee Health at Bayer Bee Care Center in North America. Rogers sees the *Varroa* mite as the main cause of honey bee colony losses in North America: “Virtually all colonies in the USA are infested to some extent,” he states. “A survey we conducted in 2015 showed that 78 percent of the checked honey bee colonies had more than three mites per 100 bees. Extrapolated to a colony of 40,000 bees, this means a minimum of over one thousand mites per colony – an alarming number.”

Professor Robin Moritz (right) and Alexis Beaurepaire

GENES: GOING BACK TO BASICS

Robin Moritz is a professor of molecular ecology at Martin Luther University, located in Halle-Wittenberg, Germany. Biologist Alexis Beaurepaire has been conducting research at the university since 2011, writing his dissertation on the host-parasite interaction of the Asian honey bee and the *Varroa* mite. Since 2014, Bayer has been supporting his study.

What is the background of your dissertation?

Beaurepaire: *If we want to control* Varroa destructor *efficiently, we have to first understand its biology. For a while now, scientists and beekeepers have noticed that* Varroa *mites are becoming resistant to acaricide products with the same active substance, if exposed to them continuously. We want to find out how these resistances develop. Our approach is to first learn more about the development of mite populations through genetic research.*

Moritz: *It is interesting to note that, at the beginning of their life cycle in the brood cells of bees, mites depend on inbreeding to be able to reproduce. Normally, this is bad for the genetic diversity of populations.* Varroa*, however, seems to benefit from it.*

In what way?

Beaurepaire: *During my year-long investigation of the dynamics within a* Varroa *population, I used genetic markers and observed higher genetic diversity than expected assuming inbreeding alone and also a rapid evolution. This may provide an explanation for* Varroa*'s fast development of insecticide resistance. My goal now is to examine mite reproduction more closely.*

How is your research connected to the Varroa Gate technology?

Beaurepaire: *The Varroa Gate helps kill the mites that have already entered the beehive – and targets others as they enter. The technology is very elegant. It is, however, rather useless if the mites become resistant to the active agent within a short period of time. Therefore, it is important to rotate different active ingredients and treatment options systematically.*

How does the collaboration with Bayer work?

Moritz: *Our collaboration with Bayer started in April 2014. Bayer's Animal Health Business Unit is testing the Varroa Gate through large field studies, under the supervision of Professor Nikolaus Koeniger and Dr Gudrun Koeniger at the University of Halle (Germany). They collect mites which have and don't have resistance. Alexis Beaurepaire then identifies the genotype of these mites and examines if, by the end of the season, the seasonal population dynamic of both types of mites is influenced by inbreeding as well as genetic recombination – in other words, by mixing genetic material.*

How can we combat resistant mites?

Beaurepaire: *By timing the treatments with the natural recombination phase of the mite. When the amount of bee brood in the colony is low towards the end of the season and if there was no treatment before, the few resistant mites in the colony have to mate with susceptible ones and will produce largely susceptible offspring. Hence there will be many more susceptible mites after this phase which can then be eliminated efficiently by the varroacide.*

For Europe, Blacquière sees a more positive situation: "In most European countries, including the Netherlands, Germany and Austria, bee losses were rather low over the winter 2015/2016," he says. "Only some beekeepers report high losses, which I would relate to a late or missing *Varroa* treatment." The research network COLOSS (prevention of honey bee COlony LOSSes) published their report on the winter losses in many countries in July 2016. In most countries, the honey bee colony losses were low with the European average around 12 percent. Dr Klemens Krieger, Global Head Bee Health Projects within Bayer Animal Health, believes that the mild winter of 2015/2016 could have long-term effects: "The warm temperatures may mean the honey bees continued breeding for a longer time span. This also means that the *Varroa* mites could reproduce inside the bees' brood cells throughout almost the entire year. As a result, their numbers will have increased significantly in the bee colony, making them even harder to control."

In cooperation with external research partners, Bayer has been working continuously to improve honey bee health and find strategies to effectively control the *Varroa* mite. Bayer researchers have developed the Varroa Gate, a plastic strip containing an acaricidal active substance (varroacide), which is fitted over the entrance to the beehive and designed to prevent mite infestation. It is being brought to the market in several European countries for use by beekeepers as part of their integrated *Varroa* management programs. Bayer has developed this technology in cooperation with Professor Nikolaus Koeniger and Dr Gudrun Koeniger at the University of Halle in Germany.

As a general rule, beekeepers need to vary their treatment strategy: "If beekeepers continuously treat the *Varroa* mite with the same varroacide or another with the same mode of action, there is a risk that the parasite will become resistant to that substance," explains Trodtfeld. The development of such resistances has already been reported for all available synthetic varroacides. Through the rotation of various substances which work in different ways to control the mites, a fast development of resistance can mostly be prevented and existing resistances can be counteracted.

To test how far pyrethroid resistance was occurring, Bayer asked beekeepers in Germany to send in samples of *Varroa* mites. In a molecular biological test the mites were analyzed for resistance. "Luckily, we have found very few of these pyrethroid resistant mites in Germany," Trodtfeld reports. "This is a favorable tendency." Resistance monitoring has recently been extended to areas in Hungary, where no pyrethroid resistant mites were found. In cooperation with Valencia University (Spain) and Rothamsted Research (UK), Bayer scientists are developing a test to show if a mite is resistant against pyrethroids. They also aim to develop a similar test for other varroacides. "Our aim is to develop a fast, easy to handle and inexpensive method to detect all kinds of resistances," explains Krieger. In this way, beekeepers can immediately clarify if resistant mites appear in their bee colony and choose the most effective treatment option.

OUTLOOK

Helping honey bees help themselves: breeding *Varroa*-resistant bee populations would be a future solution for the mite problem.

Honey bees with a behavioral trait called *Varroa*-sensitive hygiene (VSH) can detect a *Varroa* mite in a closed brood cell. These bees pull out the infested pupa and remove it, thus, also removing the *Varroa* and slowing its proliferation in the colony.

Researchers are trying to strengthen this defensive capability through selective breeding among European bees, to create long-lasting protection against the parasites. Research and breeding programs have had some success and there is potential to significantly improve the health of honey bees in the future – however, more research is required (see also page 4).

Bayer has already discovered resistant mite populations in studies in the USA: "In some regions, only a few products available for beekeepers remain effective against *Varroa*," Bayer scientist Rogers says, summarizing the previous findings of an ongoing study. Therefore, the US Bee Care Team promotes the development of more effective *Varroa* management which includes a search for more effective treatments and management strategies. Among many other projects and initiatives, the Bayer Bee Care Center in North America provided funding for a Healthy Hives 2020 Initiative (HH 2020) in 2015. The program's goal is funding external projects that seek to better understand honey bee health in the United States and make measurable improvement by 2020 (see also page 72 ff).

Rogers is confident that by taking the right measures, *Varroa* can be controlled more effectively: "Beekeepers can minimize the infestation if they learn to take the right precautions at the right time," he says. The level of a *Varroa* infestation in bee colonies may vary significantly from one year to another, which is a good reason for Rogers to intensify monitoring activities: "Within our Smart Hive Program, we work with early warning and data collection systems that remotely monitor colony conditions. Hive monitoring sensors in and near the hive include acoustics, brood area temperature, relative hive humidity, and environmental and weather conditions. With the sensor data we are able to assess the condition of a bee colony from any internet-connected computer or mobile device," he says. "And in conjunction with systematic in-hive observations we can better understand colony health status and provide for the needs of the bees in a precise and timely way."

INFESTATION 5 – 10 TIMES HIGHER

To reproduce, a female *Varroa* mite enters a bee brood cell shortly before it is capped. Mites infest drone brood 5 to 10 times more often than worker brood because drone larvae need 2 to 3 days longer to develop into adult bees. The extra days allow more daughter mites to develop before the drones emerge from the brood cell.

Beekeeper Caspari is pleased with his *Varroa* diagnosis: The infestation in the bee colony is currently low. He will, however, keep an eye on the parasitic threat throughout the entire bee season. "We have to take measures early enough to keep the honey bees healthy. Only strong colonies have a chance to survive the following winter and to rebuild a strong colony in the spring," Caspari says. Bees are not only important to beekeepers worldwide who earn a living from honey, hive products and pollination services, but these insects ensure the pollination of many crops and are, thus, an essential part of sustainable agriculture.

INTERVIEW

"The *Varroa* mite is the main topic of conversation among beekeepers."

Udo Gensowski is the chairman of the Bienenzuchtverein Bechen e.V., a bee breeding association near Bergisch Gladbach, Germany. The association was established in 1930 and has currently more than 160 members. At monthly meetings, experienced beekeepers share their expertise with younger beekeepers. One important topic: the treatment of *Varroa*.

How much of an impact does *Varroa destructor* have on beekeeping?
The Varroa *mite has changed our job enormously over the last few years. It is no longer advisable – without training – to keep bees simply as a hobby. The spread of this parasite requires us to know more than we used to. We have to monitor more carefully and have to use new methods – for example, removing the drone brood. The male brood is particularly prone to mite infestation. Therefore, the removal of the drone brood reduces the proliferation of* Varroa*.*

In your opinion, how dangerous is this parasite?
The Varroa *infestation determines how well a bee colony survives winter, particularly because the mites also infect honey bees with secondary diseases that are potentially fatal. There are other bee diseases such as* Nosema *or American Foulbrood – however, the most prevalent issue in Germany is the* Varroa *problem.*

What do beekeepers say about *Varroa*?
The Varroa *mite is really the main topic of conversation among beekeepers. Every year we see heavily infested bee colonies – and others with very little infestation. The way the beekeeper handles the problem determines the extent of infestation. In my opinion, you need to be consistent and precise and be able to interpret even the smallest sign of a problem. If there is still increased bee breeding in the autumn, for example, this can be a sign of a bee colony's struggle with increased* Varroa *infestation. For the treatment, timing is crucial. Substances such as formic acid and oxalic acid are harmful to bees if applied incorrectly. Our workshops help to learn the correct application. My recommendation to every young beekeeper is to seek support from a beekeepers association.*

What are other factors that impact honey bee health?
It is important for honey bees to find sufficient forage. As a beekeeper, you have to consider different factors every year – like the weather and nearby flowering plants. Even if there are a lot of flowers in the surrounding areas, it does not mean automatically that there will be enough nectar. Many blossoms do not produce nectar when external temperatures are low. I always tell young beekeepers: monitor your bee colonies and nature closely.

Sustainable agriculture requires both the use of modern crop protection products and the protection of pollinators.

BEES IN FOCUS DURING PESTICIDE DEVELOPMENT

SAFETY FIRST!

With a world population expected to reach nearly ten billion people by 2050, the demand for innovative tools to help meet our future food security needs has never been more urgent. Sustainable agriculture requires both the use of modern crop protection products (pesticides) to help farmers manage destructive pests and the protection of pollinators that contribute to our food productivity. To better address this requirement, scientists at Bayer have extended the environmental safety assessment to the early phases of new candidate products' life cycle, to better understand its potential impact on bees. One of Bayer's newest insecticides, Sivanto® prime, is a perfect example of meeting this dual goal of protecting both plants and bees.

'**SAFETY** FIRST!' is a common slogan seen in many production facilities – and for good reason.

Manufacturers have long realized that a safe work environment is foundational to higher production and a happier workforce. In the absence of an emphasis on safety, accidents are more likely to occur and with them comes a greater potential for worker injuries and a disruption in long-term productivity. In agriculture, protecting the pollinator "workforce" is critical to greater farm productivity, just as the use of new technologies is needed to protect valuable crops from destructive pests. It's no stretch to say that safety is of paramount importance when it comes to developing new crop protection products. After all, the people who work in the crop protection industry are also consumers, eating the same foods and living in the same environment as do their friends and neighbors.

Nowhere is this emphasis on safety more evident than in the process underlying Bayer's development of new products. However, before discussing the steps Bayer takes to develop new products, it is worth discussing why new product development is so critical to agricultural sustainability.

AT A GLANCE

// With a world population expected to reach nearly ten billion people by 2050, the need to increase crop productivity depends both on crop protection products (pesticides) and the preservation of pollinators.

// Only one out of 160,000 potential new compounds for crop protection products reaches commercialization, a process that, on average, requires long-standing profound expertise, costs approximately 250 million EUR and takes eleven to fourteen years to meet today's standards of safety.

// Bayer is conducting honey bee and other environmental safety testing already during exploration of new chemistry, to more quickly evaluate a candidate's potential impact on pollinators and the environment. The company is also participating in the development of new test methodologies to better assess potential risks to honey bees and other pollinators.

// The number of new studies performed to evaluate a product's potential impact on pollinators is substantial.

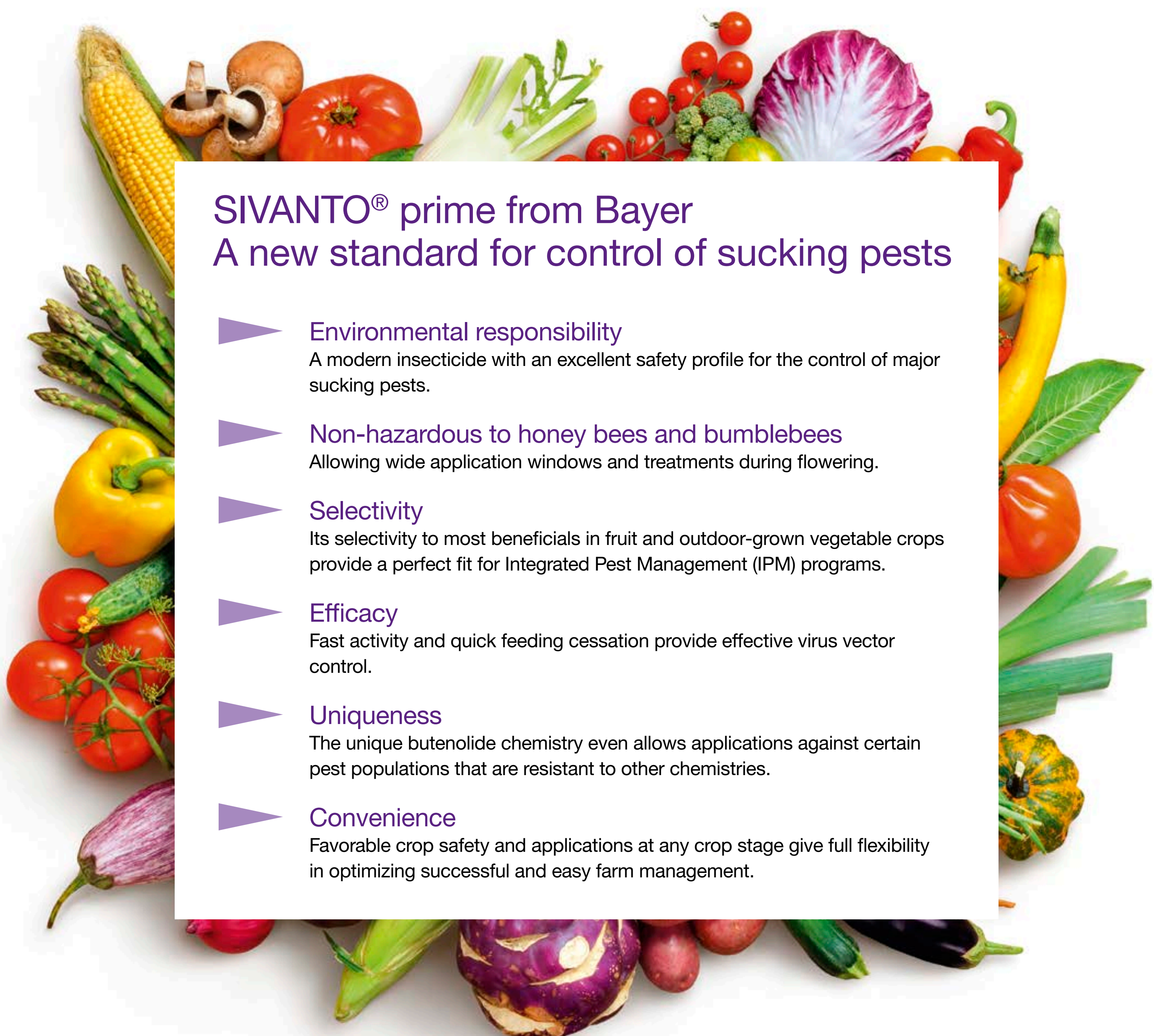
// With its excellent crop performance and bee safety profile, Sivanto prime, a novel Bayer insecticide belonging to the new substance class of butenolides, exemplifies Bayer's focus on pollinator safety during new product development.

// As part of its leading role in crop protection, Bayer continues to search for new products that meet high environmental compatibility standards and will help solve tomorrow's critical food challenges.

The development of innovative products is the life-blood of any Research and Development-based company, yet when it comes to food production, it's not just the company that benefits from these discoveries. The use of new products and integrated technologies, coupled with best management practices, has enabled more food to be grown on less land than ever before, providing a bounty for farmers and for everyone who enjoys nutritious food at an affordable price. Despite this remarkable progress, the UN estimates that agricultural production must increase by 50 percent to meet our future food demand.[1] With most of the world's suitable farmland already under cultivation, growth can only come from new innovations that can help farmers glean more from each existing hectare.

And yet sustainable agriculture is dependent on more than new growth-enhancing technologies. Producing more food on limited land must be accomplished without disrupting our natural resources and biodiversity. Preserving our environment includes safeguarding our soil and water, as well as the beneficial organisms that play a vital role in growing our food. Plant pollination is an essential component of crop production and no insect pollinator is more important to farming than the honey bee *(Apis mellifera)*.

Balancing the need for crop protection with the need to protect these critical pollinators is a key criterion of Bayer's product life cycle development.



SIVANTO® prime from Bayer
A new standard for control of sucking pests

Environmental responsibility
A modern insecticide with an excellent safety profile for the control of major sucking pests.

Non-hazardous to honey bees and bumblebees
Allowing wide application windows and treatments during flowering.

Selectivity
Its selectivity to most beneficials in fruit and outdoor-grown vegetable crops provide a perfect fit for Integrated Pest Management (IPM) programs.

Efficacy
Fast activity and quick feeding cessation provide effective virus vector control.

Uniqueness
The unique butenolide chemistry even allows applications against certain pest populations that are resistant to other chemistries.

Convenience
Favorable crop safety and applications at any crop stage give full flexibility in optimizing successful and easy farm management.

"I was lucky to be part of the agronomic development of the new compound, flupyradifurone. Later introduced under the trade name Sivanto prime, this was exactly the type of product that our regulators and customers had been talking about."

Dr Matthias Haas
Bayer Global Project Manager

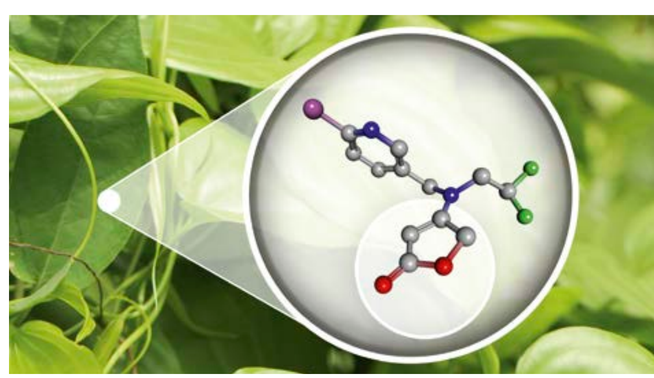
Finding the right balance requires an eye for observation and an ear to listen to what is needed. During a new product's development, feedback from all potential stakeholders is not only welcome, it is encouraged. As a global project leader, one of Dr Matthias Haas' primary goals is to help drive the development of promising new candidates from research to market entry and he recalls one such product as being particularly noteworthy. "I was lucky to be part of the agronomic development of the new compound, flupyradifurone," says Haas. "Later introduced under the trade name Sivanto prime, this was exactly the type of product that our regulators and customers had been talking about. The increased interest in protecting pollinators, coupled with our farmers' need for reliable tools to protect their crops, shows that Sivanto prime was ahead of its time in anticipating our future safety standards."

New product development: many are culled, few are chosen

The development of crop protection products is not for the faint-hearted. According to a recent study, only one out of every 160,000 compounds typically survives the grueling evaluation process to reach commercialization[2]. For those that do, the average development costs 250 million EUR and takes 11 to 14 years of testing to ensure it meets the highest standards of performance and safety before it can be sold. As part of a new candidate's registration process, a wide variety of potential human health and environmental effects associated with the use of the product are assessed. Scientific data regarding the chemical and physical characteristics, composition, potential adverse effects and environmental fate of each product must be generated by the manufacturer and reviewed by the regulatory authorities to determine whether it could harm non-target organisms, including honey bees.

What made the development of Sivanto prime so exciting was its excellent ecotoxicological and safety profile, which matched today's stringent regulatory requirements. In addition to its rapid control of some of the most destructive sucking pest species found in many crops, Sivanto prime was found to be fully compatible with honey bees and bumblebees. Field research showed that the application of Sivanto prime according to the prescribed, crop-specific application instructions does not interfere with honey bee health, specifically in terms of foraging activity, brood and colony development, colony vitality or overwintering success.

The development of a new crop protection product costs 250 million EUR on average and takes 11 to 14 years of testing to ensure it meets the highest standards of performance and safety before it can be brought to market.



The creation of flupyradifurone, the active molecule in Sivanto prime, was inspired by the natural compound stemofoline – an isolate from *Stemona japonica*, a medicinal plant that grows mainly in Southeast Asia.

[1] UN report: How to Feed the World in 2050: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

[2] Philipps McDougall (2016). The Cost of New Agrochemical Product Discovery, Development and Registration in 1995, 2000, 2005-8 and 2010 to 2014.

Dr Richard Schmuck, whose department is responsible for evaluating the environmental safety of crop protection products at Bayer, has been at the forefront of ecotoxicological research on honey bees for many years and has been a major proponent of how the company has shifted its approach to new product development. “While we have always checked new substances for inherent toxicity or persistence, today we already focus on optimizing the balance of new molecules between pest control efficacy and environmental compatibility during the synthesis phase,” Schmuck notes. “Pushing this screening and optimization forward by two years requires an earlier investment, but ultimately it reduces costs by allowing us to make a more informed decision about which molecule to select.” From a pragmatic research perspective, the sooner a company can eliminate a product that will not meet high performance and safety standards, the sooner it can invest in more promising ones.

This earlier screening of new candidates for bee safety is only part of Bayer’s extended development process with regard to environmental compatibility. New study protocols to assess bee health are evolving due to an increased public awareness of the importance of bees which made policy makers even more cautious when it comes to pesticide regulation. “It is not sufficient anymore to demonstrate that a product does not adversely impact bees under practical use conditions,” says Schmuck. “Today, regulators want to know the mechanism behind these new compounds in order to understand why they have a high margin of safety to bees.”

Understanding the complex mechanisms involved in insecticide toxicology and insect resistance has helped Dr Ralf Nauen, Principal Scientist at Bayer Pest Control, to gain insights into Sivanto’s selectivity to bees. “We were very interested to learn what enzymes produced by honey bees are responsible for their inherent resistance to certain insecticides, such as Sivanto prime,” acknowledges Nauen. “By defining these metabolic pathways, we can open the door to understanding how these products interact with other species.” For example, his team of scientists, together with external collaboration partners, identified the same detoxification mechanism present in honey bees in other pollinators, a promising discovery that could have profound implications for future environmental research.

Sivanto's strong efficacy profile allows the control of severe sucking pests such as aphids (above left), hoppers and whiteflies (above right), while being inherently safe to honey bees.

“We were very interested to learn what enzymes produced by honey bees are responsible for their inherent resistance to certain insecticides.”

Dr Ralf Nauen
Principal Scientist, Head of Resistance Management, Bayer

“Today, regulators want to know the mechanism behind these new compounds in order to understand why they have a high margin of safety to bees.”

Dr Richard Schmuck
Head of Environmental Safety, Bayer



Semi-field (tunnel) studies with honey bees: foliar application at full bloom. When applied at proposed label rates, Sivanto prime causes no adverse effects to honey bees – even on flowering crops.

Evaluating the mechanistic nature of a product's potential impact on bees is only one of a complex set of tools designed to facilitate today's ever more elaborate environmental compatibility assessment. While a certain amount of precautionary risk-avoidance can be useful, it can have negative implications for agriculture if taken too far. Beginning with the passing of Council Directive 91/414/EEC in 1991, which harmonized the registration of corp protection products across all Member States of the European Union, and continuing with more recent legislation, the number of compounds available to European farmers today has been reduced by more than half. The dramatic reduction in the tools available to EU farmers has increased the threat of pest resistance, as farmers are forced to rely on fewer products.

In addition to the loss of existing products, the emphasis on hazard over true risk assessment (which includes the consideration of hazard and exposure) is negatively affecting the development of new active substances. A recent report[2] found that since 1995, the number of new substances identified as potential candidates for the development of new pesticides screened by manufacturers has tripled, but the number of candidates in full development has declined by more than 60 percent. And the primarily precaution-driven extension of regulatory requirements is only adding to the difficulty in finding suitable candidates for new crop protection products – see graph on page 71.

Considering the difficulty in bringing any pesticide to the market today, discovering and successfully developing a new insecticide that is easy on bees but tough on pests is a particularly significant accomplishment. Yet what first drew Nauen to Sivanto prime was not its inherent bee safety but its potential in insect resistance management programs. As the first product from a novel class of chemistry known as the butenolides, Sivanto prime has become critically important to modern pest management. "Having a new product with a distinct chemical nature gives farmers a much-needed tool in their fight against destructive insect pests," notes Nauen. "This new butenolide will be a key component of Iintegrated Pest Management (IPM) practices, which depend in part on alternating different modes of action to help delay insect resistance development."

Dr Maria Teresa Almanza, the head of the Bee Testing and Risk Assessment Team in Bayer's Environmental Safety Department, is well-acquainted with the new bee testing requirements in Europe and in other regions around the world. "One of our main challenges is to align these different requirements and set up a global strategy for bee testing and risk assessment," she notes. "There has been a huge shift in evaluating risks to bees, which includes increasing the number of species to be assessed, covering all possible routes of exposure (e.g. sprays, systemic residues in nectar and pollen, dust from seed treatment), different life stage responses (adults and larval developmental stages) and whole colony impact, such as overwintering success or other complex, chronic (long-term) endpoints. Creating new testing procedures for these factors is much easier said than done."

Knowing this makes the discovery and development of Sivanto prime all the more satisfying: It has a complete range of uses (e.g. foliar, soil, drip irrigation) and can even be sprayed during full bloom in a wide range of crops according the product instructions.

"One of our main challenges is to align the different requirements and set up a global strategy for bee testing and risk assessment."

Dr Maria Teresa Almanza
Head of Bee Testing and Risk Assessment Team of Environmental Safety, Bayer

[2] Philipps McDougall (2016). The Cost of New Agrochemical Product Discovery, Development and Registration in 1995, 2000, 2005-8 and 2010 to 2014.

"We'd like to engage in joint sessions with all parties when we meet with the authorities, as this will help establish the transparent process we need to create meaningful new environmental safety testing protocols."

Dr David Fischer
Director of Pollinator Safety at Bayer in the USA

Trying to harmonize bee safety testing methods among different regions is quite difficult when the area of research is rapidly evolving. Thirty years ago, most research focused on answering the question whether or not spray applications would kill bees. While this understanding is still important, today's emphasis is on bee reproduction, colony-level effects and potential long-term impact. To be truly meaningful, new testing protocols must deliver reproducible results. A good example of this involves how scientists validate new studies on honey bee larvae: "Working with other scientists of regulatory agencies, research institutes, industry and contract research organizations, Bayer is participating in a 'ring test' on bee larvae in 17 testing facilities across the world to validate a protocol and make sure that the methodology will yield consistent and reproducible results," notes Almanza.

Some countries are considering requesting studies on pollinators other than honey bees, which presents an entirely different set of challenges for new product development and registration.

With more than 20,000 bee species in the world, it is impractical to develop testing protocols on all of them, so new research is addressing those which are of economic importance and which can readily be reared in sufficient quantities for testing, including bumble bee (*Bombus* spp.) and certain solitary bee (e.g. *Osmia* spp.) species.

Once again, Sivanto prime passes the test: Laboratory studies show that bumblebees are not more susceptible to flupyradifurone than honey bees and field trials found no effect on pollination efficiency of bumblebees when flupyradifurone was applied according to the use directions. Nonetheless, honey bees will remain the prime target of research for the foreseeable future. As Schmuck is quick to observe, "There is no other individual organism in the ecotoxicological arena for which so many tests are conducted as for the honey bee."

"While the goalposts do change, there is rationality behind some of the new testing requirements," notes Dr David Fischer, Director of Pollinator Safety at Bayer's Research Triangle Park facility in the USA. "New application technologies and novel compound properties may require different testing approaches, but in the end we must strike the right balance between agricultural production and the protection of bees." Finding the right balance requires communication, collaboration and a little common sense. The number of bee studies conducted can be immense. "There are more than ten studies per compound, as well as additional studies for each of its major metabolites," says Fischer. "But the number can be much greater, adding up to 100 studies or more, as in the case of the neonicotinoid, imidacloprid. Conducting these studies is important, but it is also important that regulators receive input from all stakeholders regarding the practical aspects or value of new research before coming to a decision – not just from manufacturers, but from the growers who depend on these products, as well," notes Fischer. "We'd like to engage in joint sessions with all parties when we meet with the authorities, as this will help establish the transparent process we need to create meaningful new environmental safety testing protocols."

Looking ahead: challenges and opportunities

While it may be impossible to discover and develop an insecticide which perfectly meets all of our demands for effective pest control and all of our desires for safeguarding non-target species, that doesn't mean effective solutions can't be found. Carefully designed product label instructions and best management are just two common practices that have been shown to effectively reduce the exposure of bees to insecticides. As field research continues to increase our understanding of the interactions between crop protection and pollination, scientists are finding new ways to improve bee safety and minimize potential environmental impacts of many products, both new and old.

Achieving test perfection may never be possible but Bayer's efforts to do so will continue unabated. "We've been at the forefront of developing bee safety testing protocols over the past 25 years and we expect that to continue," notes Schmuck. "Our focus remains the same: understanding the true risks and benefits associated with any new product under development, which we believe will help to better inform our policy makers and enable our partners to continue their pursuit of agricultural sustainability."

Wild bees
Red mason bee (*Osmia bicornis*), Bumblebee (*Bombus terrestris,* below)

CONCLUSION

The challenge of feeding a rapidly growing world population requires the use of innovative crop protection technologies and the preservation of natural resources, including insect pollinators.

Recognizing the need for both, Bayer scientists are conducting bee safety studies already in an early phase of a new product's development and are participating in developing new testing protocols to better assess potential risks to pollinators. One product that exemplifies Bayer's new development approach is Sivanto prime, a bee-friendly insecticide from a novel chemical class, which is critically important to integrated pest management programs in many crops.

Increasing costs and less new compounds are the reality throughout the industry

Since 1995, the number of potential candidates screened by manufacturers has tripled but the number of candidates in full development has declined by more than 60 percent.

Source: ECPA 2013, R&D Trends for Chemical Crop Protection Products and the Position of the European Market

TARGETED RESEARCH FOR BEES IN THE USA

Healthy Hives 2020 USA, a multi-year, million-dollar research initiative, is well on its way to finding measurable and tangible solutions for improving the health of honey bee colonies in the USA by the end of 2020. A diverse group of researchers and scientists is focused on studying critical bee health topics affecting beekeeping, such as bee nutrition, the parasitic Varroa *mite, disease management and enhanced colony management techniques through "smart hive" technology.*

Today's beekeepers are coping with a broad array of challenges, making management of their hives more difficult than ever before, while the need for bees in agriculture continues to increase. Healthy Hives 2020 USA is looking at areas that will improve honey bee health over the next four years and counter the continued reduction of colony losses.

The Healthy Hives 2020 USA initiative was launched in 2015 at the Bayer North American Bee Care Center in Raleigh, North Carolina. The two-day workshop brought together some of the nation's leading bee health experts and stakeholders from a variety of backgrounds, including academia, government, agriculture, business and the beekeeping community.

"Research projects conducted through the Healthy Hives 2020 USA initiative are helping identify and develop solutions for improving honey bee colony health and performance. It is increasingly important to highlight the advancements made through research."

Dr Daniel Schmehl
Pollinator Safety Scientist at Bayer, USA

The 17 summit workshop attendees identified the areas of research with the highest probability of finding measurable and tangible ways to improve honey bee colony health in the USA. These were later reviewed and prioritized by the Healthy Hives 2020 USA Steering Committee.

The program is focused on four major research objectives:
- Conducting an economic assessment of commercial beekeeping operations to help beekeepers maximize efficiency and production;
- Creating a set of "Best Management Practices" for commercial beekeeping based on definitive colony health performance data;
- Evaluating the use of "smart hive" technology to monitor honey bee colony health during commercial migratory operations; and
- Assessing honey bee genetics for traits which are relevant for colony resistance to pests and diseases, as well as pollination efficiency and honey production in the USA.

Leveraging Bayer-funded research grants, the nonprofit pollinator research organization Project Apis m. leads the administration of the program, including issuing requests for proposals, managing accountability and allocating funding. Project Apis m. and the Healthy Hives 2020 USA Steering Committee have allocated $ 794,713 of the 1 million US dollars provided by Bayer to date.

STEERING COMMITTEE / REVIEW PANEL

A review panel assesses the Healthy Hives 2020 USA project proposals and provides the funding decisions. The panel includes:

Steve Sheppard, Washington State University (Chair)

Don Parker, National Cotton Council

Dick Rogers, Bayer Bee Care Center

Dave Westervelt, Florida Department of Agriculture and Consumer Services

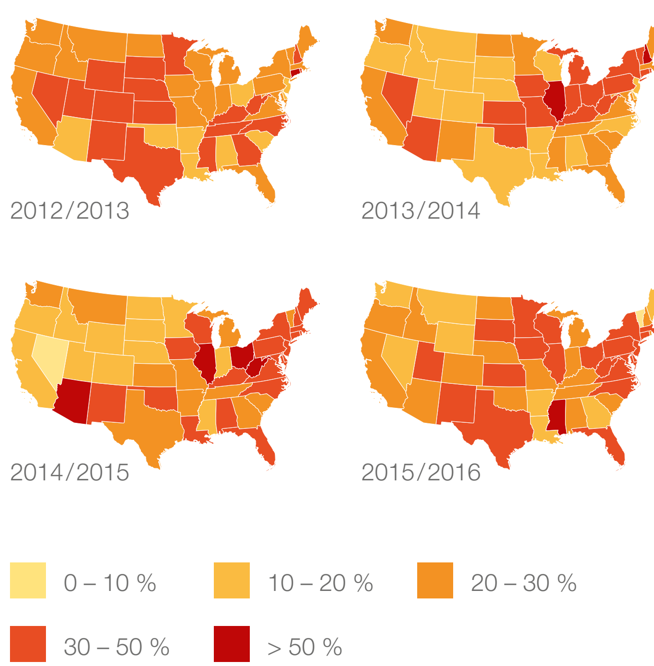
Gloria Degrandi-Hoffman, USDA ARS Tucson Bee Lab

Randy Verhoek, Harvest Honey Inc.

"Today's beekeepers are in urgent need of practical solutions to improve the health of their colonies. The projects funded by Bayer through Healthy Hives 2020 USA are critical to helping enhance the vitality of honey bee colonies, while also improving crop productivity."

Danielle Downey
Executive Director of Project Apis m.
and Healthy Hives 2020 Program Manager

Variations in winter losses of honey bee colonies in the USA



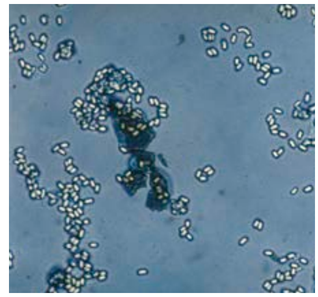
Source: The Bee Informed Partnership, USA
https://bip2.beeinformed.org/geo/

Research projects conducted through the Healthy Hives 2020 USA initiative are helping identify and develop solutions for improving honey bee colony health and performance.

OUTLOOK

Bayer is a sponsor of multiple research efforts to identify and develop solutions for improving honey bee colony health and performance in the USA. To date, Bayer has committed millions of dollars to honey bee health projects, including those through the Healthy Hives 2020 USA initiative.

Nearly all of the Healthy Hives 2020 USA projects funded in 2016 and 2017 are still in progress, and initial results look promising. More research projects will be funded as the Healthy Hives 2020 USA initiative moves forward, striving to ensure honey bees remain healthy for generations to come.



Funded research projects include those on *Nosema* (above left) and queen breeding (above right).

Since its launch, the program has funded ten innovative research efforts that either support one of the program's priority objectives or was felt by the Steering Committee to have the potential to make an immediate impact on honey bee colony health. Grant recipients include*:

Professor Arathi Seshadri, Assistant Professor, Colorado State University, who is studying phytochemicals as a management tool for sustainable honey bee colony health and productivity.

Dr Brandon Hopkins, CEO, Advanced Beekeeping Solutions, who is conducting an evaluation and comparison of management strategies and economics of apicultural practices in commercial beekeeping operations.

Dr Edmund Stark, Michigan State University, who aims to develop a commercially viable, cost-effective product to control the *Varroa* mite, generally considered to be the major cause of honey bee colony losses in many regions of the world.

Dr Jody Johnson, Cullaborate, LLC, who is leading an efficacy study for potential novel miticides to control the *Varroa* mite.

Dr Olav Rueppell, University of North Carolina at Greensboro, who is determining whether different commercially available honey bee genetic lines provide resistance to virus infection.

Professor Quinn McFrederick, Assistant Professor, University of California, Riverside, who is determining how *Nosema ceranae* infection alters the honey bee midgut microbiome.

Dr Steve Sheppard, Washington State University, who is comparing U.S. honey bee genetic lines for queen production and pollination efficiency under field conditions.

And the work of **Dr Stephen Martin**, **Julie Shapiro** and **Dr James Wilkes**, depicted in more detail on the next page.

These researchers and their colleagues are helping to enhance the health and vitality of U.S. honey bee colonies. In their efforts to seek solutions for sustainable beekeeping, they are also helping to understand and combat honey bee colonies' most significant threats.

* Note: Only the lead researcher is listed.

Dr James Wilkes, of the Computer Science Department, Appalachian State University

He and his team, including Dr Joseph Cazier and Dr Ed Hassler of the Center for Analytics Research and Education, Appalachian State University, are helping beekeepers make wise hive management decisions by advancing technology-assisted data collection at the honey bee colony level. See http://www.HiveTracks.com.

"Our 'smart hive' project is aimed at building a data platform that identifies and improves Best Management Practices through tailoring them to specific apiary or hive locations. Additionally, the improved monitoring of hive conditions aims to reduce costs, increase efficiency in honey bee colony management and provide a measurable reduction in annual colony losses within both commercial and hobbyist operations."

Dr Stephen Martin is a professor at the School of Environmental & Life Sciences at the University of Salford in Manchester, UK.

He investigates how the viral landscape is changing and how these changes are affecting honey bees in the USA.

"The Varroa *mite is providing a new viral transmission route for a previously rare and largely benign virus called Deformed Wing Virus (DWV). The mite's main role in causing the death of honey bee colonies is by acting as a transmitter of this virus. DWV is now one of the most wide-spread insect viruses in the world with most colonies in the U.S. infected – healthy-looking bees are also potentially infected, not just the deformed ones, as people often think.*

DWV is made up of several distinct viral strains, and each viral strain may have a different effect on the honey bees. Our project seeks to determine if non-virulent strains can be linked to increased colony survival to develop a long-term solution to the problem of Varroa-*transmitted viruses."*

Julie Shapiro is the Honey Bee Health Coalition (HBHC) facilitator at the Keystone Policy Center.

Through the Bee Integrated Demonstration Project she helps showcase the best management practices that help to reduce honey bee colony loss through a coordinated and collaborative effort.

"The Bee Integrated Demonstration Project, lead by HBHC and supported by a broad variety of stakeholders, will utilize a suite of tools, guides and techniques developed by diverse partners in beekeeping and crop production. These can effectively address the primary risk factors influencing bee health, including honey bee forage and nutrition, hive management, crop pest management and education/cooperation.

Our demonstration project will measure colony losses throughout the season and use the gathered data to enhance beekeeping Best Management Practices with the goal of minimizing colony losses."

BEE RESEARCH IN BRAZIL

BOOSTING PRODUCTIVITY THROUGH FRUITFUL PARTNERSHIPS

Agriculture plays an important role in Brazil. The different biospheres and climates that characterize the country's farming landscape provide a wealth of resources. Whilst the South has a moderate climate and produces most of the country's grains and oilseeds, the Northeast experiences far less rainfall, yet still supports some essential crops for export such as cocoa, tropical fruits and the majority of melons, over 90 percent, produced in Brazil.

The melon crop is highly dependent on insects for pollination and bees are the main pollinators. Therefore, Bayer is collaborating with bee researchers and growers in this region to evaluate the health of honey bees used for managed pollination and look for ways to improve this with respect to increasing pollination effectiveness and ultimately improving crop yield. In two further separate collaboration projects, information is being collected with the aim to produce a pollen online catalog and a practical handbook on pollinators and crop pollination for farmers, beekeepers and other interested parties.

AT A GLANCE

- // Melons are an economically important crop in Brazil and the Northeast region is the hub for melon growing in the country.
- // Melon production is highly dependent on insect pollination, mainly by bees, so researchers investigated if pollination is already fully efficient or if it could be improved upon.
- // With many more Brazilian crops dependent on insect pollination, information is being collected in a separate collaboration project with the aim to produce a practical handbook on crop pollinators, to lead towards crop-specific, pollinator-friendly farming practices.
- // Additionally, a pollen catalog is being prepared which identifies the floral resources, namely pollen and nectar, which are important for the diet of different bee species.
- // These projects will provide practical, hands-on information for beekeepers, growers and other interested parties.

Melons are an economically important crop in Brazil with a large global market generating substantial export revenues. In 2014, for example, Brazilian farmers produced around 590,000 tons of melons.

“Melons are an extremely resilient crop,” says Professor Breno Magalhães Freitas, pollinator expert and agronomist at the Federal University of Ceará (UFC) in Brazil. “They are grown mainly in the poorest region of the country where people do not have many job opportunities in the countryside and may go hungry or leave the area, if crops could not be grown.” The production is, however, only possible due to the use of high technology and advanced agronomic practices regarding soil preparation, seedling preparation, irrigation and pest and disease control.

Professor Breno Magalhães Freitas, agronomist and pollinator scientist at the Federal University of Ceará in Brazil, analyzes why the productivity of melon plants in Brazilian agriculture can vary significantly.

FACTS & FIGURES

Brazilian melons in numbers

Harvesting time: In 2014, Brazilian farmers produced around **590,000 tons of melons** – 93 percent of them were harvested in the tropical northeastern regions. On average, each plant produces only one melon, resulting in an average yield of **25.3 tons per hectare**. Only Spain and Guatemala export more melons globally than Brazil.

Melon crops are pollinated by honey bees and other pollinators. Some varieties are totally dependent on insects to pollinate them.

Why melons need bees

Brazil's most cultivated melons are varieties such as Yellow, Honeydew, Piel de Sapo (Santa Claus melon), Charentais, Cantaloupe and Galia. They each have their own characteristics and they differ in many ways. Professor Freitas wants to understand why the productivity of these melon plants also varies significantly. With this information, he aims to help farmers to stabilize and improve their harvested yields.

Some melon varieties are totally dependent on insect pollination – primarily by bees.

To find answers, Freitas' research has focused on looking at whether a difference in pollination efficiency could be an important underlying factor. "Melon crops are highly dependent on insects to pollinate their stigma, which is the part of the pistil catching the pollen," he explains. "This is because melon pollen grains are sticky and too heavy to be transported by the wind." Some melon varieties are totally dependent on insect pollination – primarily by honey bees, as these can be used for large-scale managed pollination, but stingless bees *(Meliponini)*, carpenter bees *(Xylocopa)* and others can also help to pollinate the plants.

"Whereas European honey bee colonies have long been used for managed melon pollination around the world in Brazil, Africanized honey bees have more recently been used as well," notes Freitas. The melon producing states of Rio Grande do Norte and Ceará introduced the use of Africanized honey bees for managed pollination in 2000, with the counties of Petrolina/ Juazeiro (Pernambuco/Bahia states) following in 2008.

Although most Brazilian melon farmers are aware that their crops are reliant on bees, less is known about the efficiency of these pollination services and whether further improvements could be made. The question for the researchers was whether farmers could produce even more fruit and of a higher quality if honey bees had optimal conditions to thrive. Productivity does not just rely on pollination services alone but also on protecting the crop from destructive pests and diseases so, at the same time, farmers also need to consider the use of crop protection products in a pollinator-safe manner. For this, beekeepers and farmers need to work closely together. "To secure and even increase fruit production, we need to find a sustainable way for both sides to benefit, so that there are both healthy pollinators and strong crops," says Freitas. He adds: "In Brazil, we are still lacking information on how to best manage honey bees in order to achieve the best possible pollination results."

A field study, supported by Bayer, monitored honey bee colonies on eight melon farms – a total area of 12,000 hectares – in northeastern Brazil. The aim was to find out if and how pollination services by honey bees and other pollinators could be improved.

"Our main goal was to find out whether the melon crop in the study region is 'under-pollinated,' limiting fruit productivity. If so, we wanted to know why many of the melon flowers were not being pollinated and how to increase the level of insect pollination."

Claudia Quaglierini
Agronomist and Bee Care Manager at Bayer in Brazil

Monitoring bee health and pollination services

To change this situation and fill in knowledge gaps, Bayer supported a collaborative study with the UFC. In 2016, bee researchers began monitoring a representative sample from around 24,000 honey bee colonies on eight melon farms – a total area of 12,000 hectares – in northeastern Brazil. This is a region characterized by large cultivated plots, dry conditions and with seemingly few other flowering plants in the proximity to the fields. A baseline survey was performed on colony health, apicultural and pollination practices and pollination efficacy for each participating agricultural operation. In addition, an analysis of foraging sources for bees in the vicinity of the melon-growing areas was undertaken. "Our main goal was to find out whether the melon crop in Brazil is 'under-pollinated', limiting fruit productivity. If so, we wanted to know why not all the melon flowers are being pollinated and how to increase the level of insect pollination," explains Claudia Quaglierini, agronomist and Bee Care Manager at Bayer in Brazil.

The bee researchers took stock of the colony conditions and looked into the way the colonies were managed. Throughout the day, they monitored colony activity, including the honey bees' visits to melon flowers and the number of visiting wild bees.

Additionally, the experts analyzed environmental conditions such as the temperature and air humidity as well as the amount of nectar in melon blossoms. Fruit setting of the crops was also evaluated. "We realized that there really are pollination deficits in the areas that were being studied," summarizes Quaglierini. Freitas adds: "In checking the state of the honey bee colonies, the bee researchers found that the main reason for this was that many colonies were weak and quite a number of hives were in bad condition. This meant there was frequent robbery between colonies, and colonies were absconding (the whole colony abandoning the hive to look for a new home), due to predator and pest pressure, suboptimal positioning of the hives (lack of shade, leading to high temperatures in the hive, and hive positions that increased the risk of insecticide exposure), for instance. The colonies used were basically in such a poor condition that it was jeopardizing their effectiveness as melon pollinators."

From the observations around flower visits it became apparent that the melon crop was in competition for pollinators with wild plants, especially *Piptadenia moniliformis*, known as 'Angico de Bezerro' or 'Catanduva'.

Story continues on page 83.

POLLINATOR-PLANT RELATIONS MADE **SIMPLE**

In addition to the melon project in Brazil, information is being collected and made accessible to interested stakeholders in two further collaborations. With many more Brazilian crops dependent on insect pollination, one project aims to produce a practical handbook on the pollinators of Brazilian crops. The other project gathers data to produce a pollen catalog which identifies the floral resources, especially the pollen of the relevant plants, which are important for the bees' diet. It is hoped these will aid beekeepers, growers and other interested parties. For Bayer, generating data and sharing knowledge is paramount for enhancing bee research and developing best practices in agriculture.

The online pollen catalog

Since 2015, Bayer has been sponsoring and supporting the compilation of an online pollen catalog developed by the University of São Paulo (USP), Brazil. In the catalog, named 'Rede de Catálogo Polínico online' (RCPol), researchers are including data from various pollen collections around the world. "For the first two years, we focused on generating data related to 542 plant species and identified the floral resources, mainly pollen and nectar, which are important for a bees' diet," says Dr Cláudia Inês da Silva, ecologist at the bee laboratory of the USP. To generate the data, the researchers have been sampling pollen in agricultural areas and around apiaries, quantifying the composition and spatial-temporal distribution of floral resources, and documenting them in the pollen libraries of the partnering palynology laboratories. To facilitate identification and make the information easy to access, the team digitizes the plant and pollen images. The project is planned to continue until 2019 in order to enlarge the amount of available data, expanding the pollen libraries of the palynology laboratories of the partnering institutions.

Dr da Silva passionately highlights the power of the generated data: "The pollen libraries can serve as tools for the management of bee pastures and the surroundings of cultivated areas. Making RCPol publicly available will provide information to beekeepers and farmers about the management of plants that are preferentially visited by bees collecting pollen and nectar, which is relevant for honey and pollen production, and for pollination of cultivated plants," she further explains.

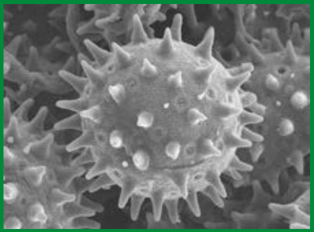
Many research teams are participating and contributing to this joint approach, within Brazil, but also in other parts of Latin America (Argentina and Colombia) and Europe (Germany, France, Spain). "In this project, we see intensive exchange and collaboration within the scientific bee community worldwide," says Quaglierini. "By disclosing our project results at national and international events, we hope this community involvement will increase even further."

Dr Cláudia Inês da Silva, ecologist at the bee laboratory at the University of São Paulo, Brazil.

Her research team is heading a large collaborative effort to develop an online pollen catalog.

"The pollen libraries can serve as tools for the management of bee pastures and the surroundings of cultivated areas."

Dr Cláudia Inês da Silva



Hibiscus pollen under the microscope.

At Germany's University of Freiburg, Professor Alexandra-Maria Klein is in charge of the pollinator manual project, together with her postdoc, Dr Virginie Boreux.

"The only way we can work out how to protect specific groups or species of bees is to know which ones rely on which plants and vice versa and understand their nesting requirements."

Professor Alexandra-Maria Klein

Practical handbook in the field

Another tool that will provide practical, hands-on information to farmers, growers, applicators, advisors and scientists alike is the Pollinator Manual, a handbook currently being developed by Professor Freitas and his colleagues at the UFC in collaboration with the University of Freiburg in Germany, Bayer and Syngenta. "Our Pollinator Handbook will inform farmers, growers and other interested stakeholders about whether a specific crop depends on insect pollination or not. If it does, the user will find information about specific pollinator species which are relevant for their crops."

The manual will also provide important information for the conservation of pollinators. "The only way we can work out how to protect specific groups or species of bees is to know which ones rely on which plants and vice versa and understand their nesting requirements," says Professor Alexandra-Maria Klein, heading the Faculty on Nature Conservation and Landscape Ecology at Freiburg University, Germany.

"It's time to generate important information for the conservation of pollinators in Brazil and, consequently, improve agricultural production," states Freitas. The project has recently started and the team has defined the relevant crops for Brazilian agriculture which will feature in the Pollinator Manual. "To make it easier to use, all crops and pollinator species in the handbook will be illustrated with photos," he concludes.

Bayer is convinced that by translating the scientific findings into easy-to-understand best practice recommendations, this manual will provide stakeholders with useful information. "In the near future, this new handbook may lead Brazilian farmers towards crop-specific, pollinator-friendly farming practices," notes Dr Christian Maus, Global Lead Scientist at the Bayer Bee Care Center in Germany. The Pollinator Manual is intended to be finalized by end of 2018.

Honey bee *(Apis mellifera)* visiting cashew *(Anacardium occidentale)* flowers. Honey bees are important cashew pollinators in Northeast Brazil.

Carpenter bee *(Xylocopa frontalis)* visiting a passion fruit *(Passiflora edulis)* flower. These flowers are pollinated only by large bulky bees like this species, one of its major pollinators.

Stingless bee (*Melipona seminigra)* visiting the Annato *(Bixa orellana)* flower. The bee species is an important pollinator of this crop which provides natural dye.

Melon study: causes of pollination deficits and their solutions

Honey bee colonies abandon their hives due to a lack of water, shade or nectar sources, pest infestation and other unfavorable conditions.

→ **Management measures, such as providing clean, fresh water, shade, moving colonies to and from the crop during and post flowering and protecting colonies from pests can significantly reduce colony losses caused by absconding.**

Weak and Wax Moth-infested colony due to a lack of proper hive management.

→ **Such hives must be removed from the crop, cleaned and replaced by strong, healthy colonies which are managed properly to avoid similar problems arising.**

Due to a lack of other clean water sources, bees were drinking water, for example, from leaking irrigation pipes which can be too hot or contaminated, for instance with bacteria, or contain fertilizers.

→ **A clean, fresh and cool source of water must be provided close to the hives to prevent bees drinking irrigation pipe water.**

Incorrect use of crop protection products and lack of good beekeeping practices (spraying of bee-toxic products during crop blooming, failure in removing hives after the pollination period) led to bee mortalities.

→ **In this case, the advice was to coordinate application with the time bees are placed in the crop in a way that prevents exposure.**

Weeds blooming nearby at the same time as the crop, which relies heavily on insects for pollination, may compete for pollinators.

→ **In this case, recommendation is to mow or cut down weed flowers at this crop stage to avoid competition.**

Student, Victor Monteiro (left) and Kamyla Tavares, Market Development at Bayer, prepare the artificial bee diet, based on locally accessible and affordable ingredients.

The developed food supplements positively influence colony growth and health, serving well as an artificial diet for honey bee colonies in the melon project.

BEE NUTRITION: DEVELOPMENT OF ARTIFICIAL DIETS FOR BEE COLONIES

Linked to the study on pollination efficacy and honey bee colony health in managed melon pollination in northeastern Brazil, Bayer collaborated with the University of São Paulo to look into the development of a food supplement for honey bee colonies being used for managed pollination under challenging conditions.

In melon growing regions of Brazil, honey bees are brought in to help pollinate the crop but melon flowers only provide some of the nutritional elements they require to stay healthy. Better nutrition may be provided by the wild flowers which sometimes border the melon fields. However, these may not always be available in sufficient quantity to provide nutrition for all. Moreover, in some cases, the surrounding flowering vegetation may have to be removed in order not to distract the honey bees from the crop. Offering additional nutrients to honey bees, as a dietary supplement, can help to keep the bee colonies healthy and in the crop fields, resulting in increased pollination efficiency for melon crops. To achieve this goal, researchers identified suitable ingredients – which are locally accessible and affordable – and preparation methods for an artificial bee diet. Furthermore, the project team set up directives for optimal storage and feeding instructions to be used by beekeepers.

The adequacy of the developed recipes was verified in honey bee colony trials, showing that the food supplements positively influence colony growth and health and serve well as an artificial diet for bee colonies. As such, colony losses due to food scarcity in managed melon pollination could be reduced. Further work is ongoing to optimize the diet to specific Brazilian scenarios other than melon pollination, such as watermelon and apple.

Another interesting finding which can play into optimizing crop protection use with regard to pollinator safety is that the highest foraging activity was seen in the morning. Spraying of insecticides can, therefore, be planned for late afternoon or night when there will be fewer bees in the crop. Additionally, it was seen that the bees mainly foraged close to the hives. An important aspect when distributing the managed colonies in the field in order to maximize the bees' visits to the melon flowers and hence pollination.

A positive finding from the bee activity monitoring was that native wild bees could be providing some additional pollination services, too. For melons, this is mainly in areas away from the beehives and close to field borders. It is often seen that a broader spectrum of different bee species act in a complementary way so that some visit when the weather is too hot for other species, when the number of flowers is not high enough to attract others or when flowers are too far away from a beehive or nests of other species.

Next steps

Based on the findings of the study, Freitas was able to define some key measures, such as good hygienic conditions within the hives, their position in the field as well as the regular replacement of queen bees, that could help beekeepers to optimize the conditions for their honey bee colonies. In addition, he advised both the growers and beekeepers on a crop protection regime which ensures the safety of pollinators and brings benefits to the grower in terms of pollination efficiency. "There is a need to incorporate pollination services into the melon production system in the region and to develop pollination management plans specific to each cropping scenario," he summarizes. The measures are being implemented according to the needs on the different farms and further data about their impact on pollinator health and melon pollination is anticipated by the end of 2017.

CONCLUSION

Bayer is working to help growers optimize – and so to increase – melon yields in northeastern Brazil, the biggest melon growing area in the country. Additionally, connecting different stakeholders and filling in gaps in knowledge about bees and other pollinators' pollen and nectar dietary requirements, as well as information on pollination of agricultural crops, may lead to even more pollinator-friendly approaches, with regard to integrated farming solutions. After all, healthy honey bees and thriving wild bee pollinators are seen to boost the production of melons and may also be relevant for other important crops in Brazil.

OUTLOOK

Dear reader,

Thank you for your interest in our Bee Care Program and activities and for taking the time to read our latest BEENOW magazine.

It is now five years since the opening of the first Bayer Bee Care Center, as part of the Bee Care Program which was established in 2011. A good moment to look back and reflect on the journey that has brought us to where we are today and what lies ahead.

Pests and diseases are key factors affecting honey bee health, not least the *Varroa* mite which transmits viruses, causing diseases that can prove deadly to colonies. That is why we are actively searching for ways to support beekeepers in *Varroa* control. For instance with the new Varroa Gate technology, a plastic strip impregnated with a varroacide, affixed to the hive entrance.

In the area of pollinator safety, Bayer is advancing product application technologies that help to further reduce exposure of bees and other pollinators to crop protection products. We have also worked quickly and extensively on developing further bee safety testing protocols as part of our product development processes. Thanks to our research activities we know more and more about the in-crop pollinator communities in various key crops in different regions. We are also, for instance, bringing more insights as to the impact biodiversity enhancement measures can have in an agricultural setting.

Looking forward, Bayer will contribute further, with research into alternative pollinators for agricultural crops and optimization of crop pollination to improve crop quality and increase yields. We will also continue searching for ways to combat the *Varroa* mite, either by control measures or via breeding *Varroa*-resistant bees.

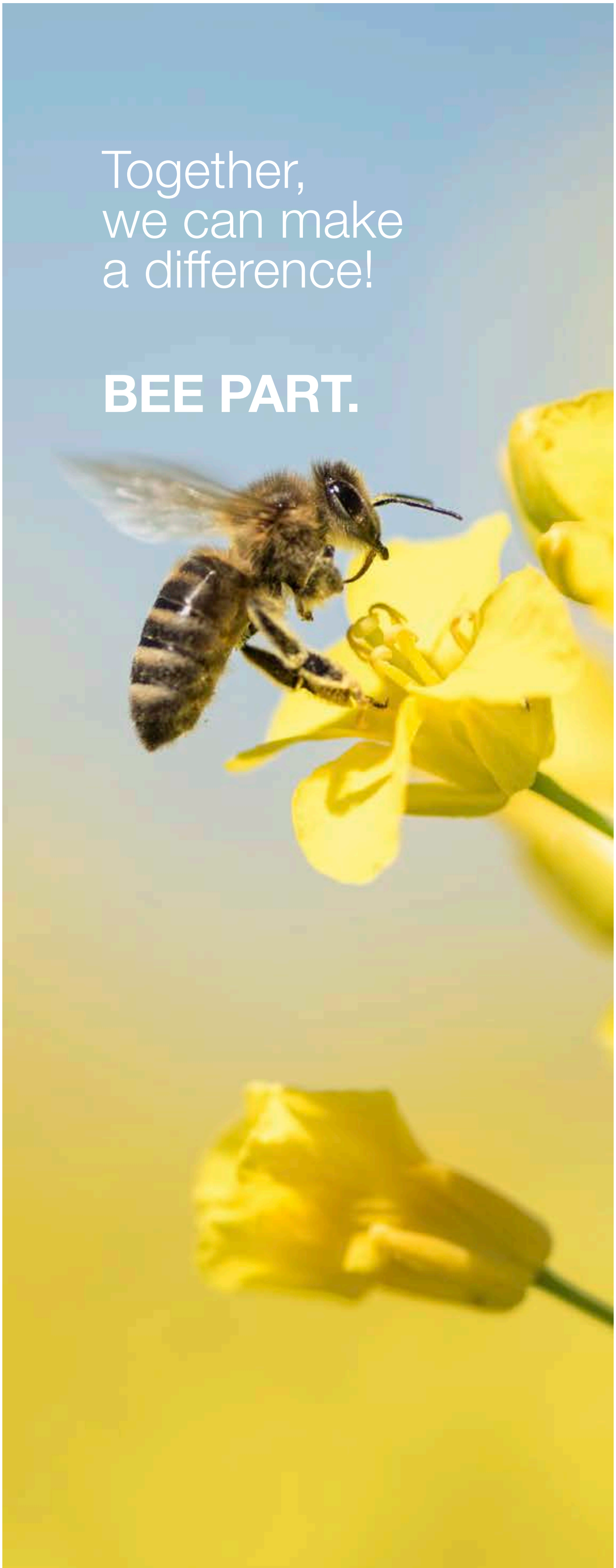
Also, we will be keeping an eye on upcoming threats for honey bees such as the Small Hive Beetle, Asian hornet and pathogens, such as *Nosema*.

Through this sustainable commitment to pollinator health and ongoing monitoring programs, we will continue to expand our knowledge of the different regional factors influencing pollinator health, raise awareness and act upon it.

We thank all those who are supporting and working with us to advance in the areas of pollination and pollinator health and look forward to sharing the results with stake-holders who have an interest in this topic.

Interested in learning more about our Bee Care Program activities? Please visit www.beecare.bayer.com to follow our work and contact us to share your ideas!

Coralie van Breukelen-Groeneveld
Head of Bayer Bee Care Center



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ILLUSTRATIONS
Bayer: pp 36, 73
ageko: pp 36, 24, 43, 47
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PHOTOS
Bayer, except:

Fotolia: pp 64 (above), 84/85

iStock: pp titel (above), 25, 51 (below)

Shutterstock: title (below), pp 2, 8, 9, 17 (below), 18 (2 left), 19 (left above), 30, 64 (left), 66, 71 (below)

Jenny Shanks, Plant Health Australia: p 14, 18 (below right), 19 (right)
Michael Holmes: p 17 (above), 18 (above)
Dr Mariano Higes: p 24 (below)
Benedicte Laborie: p 37 (above)
Rothamsted Research Ltd.: p 58 (below)
Willem Boot: p 60 (above)
USDA: p 50 (below)
Dr S. Yoshigaki: p 38
Dr Tomoyuki Yokoi: p 41
Dr Reinhold Siede: pp 22, 27, 28
Werner Mühlen: p 45 (below)
Professor Breno Magalhães Freitas: pp 77, 78, 82 (left below)
Felix Fornoff: p 81 (above)
Courtesy of The PR Company, Wellington, New Zealand: pp 20/21
Centro Apícola de Castilla-La Mancha, Spain: pp 33 (below), 32, 34, 35 (left)
Dr Joel González-Cabrera: pp 33 (above), 36 (right)
Prof. Dr Bernd Grünewald: p 37 (2 pictures, left below)

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