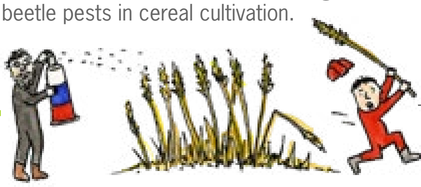
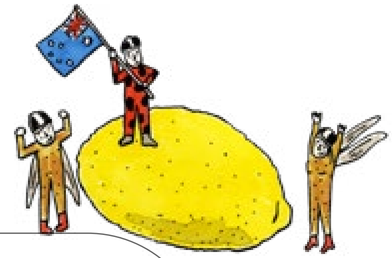
1884

Russian microbiologist and Nobel Prize winner Ilya Mechnikov becomes the first to use a fungus to attack beetle pests in cereal cultivation.

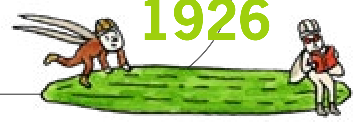


1888



Australian ladybirds and parasitic flies introduced in Californian citrus cultivation. The method is adopted around the world.

1926



British cucumber grower discovers parasitic wasps that infest damaging greenhouse whitefly. Mass production of parasitic wasps for application in Europe, Australia, Canada and New Zealand.

Late 1940s

Rise of synthetic insecticides that replace use of parasitic wasps.

1967

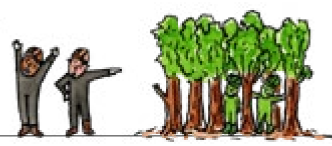
Cucumber grower Jan Koppert finds he is allergic to chemical insecticides and looks for alternatives. Founds the predecessor of Koppert Biological Systems.

1970

Both spider mite and whitefly have become resistant to insecticides. Call for alternatives.

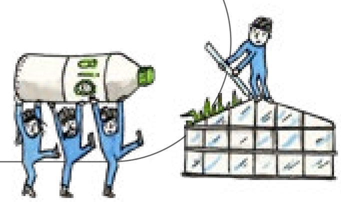
1976

Damaging leaf miner from the US turns up in Dutch tomato greenhouses. Leiden researchers Jaap Woets and Joop van Lenteren leave infected tomato plants in a wood. After a few days, there are natural enemies on them.



1980s

Greenhouse growers switch en masse to integrated biological pest control.



1990s

Introduction of predatory mites and assassin bugs to tackle thrips and of predatory wasps to tackle aphids.

2018

Around the world, 230 species of natural enemies are used commercially. The global leader is Koppert Biological Systems, producing millions of natural enemies every week, in addition to enzymes, bacteria and fungal preparations.

INSECTS AS ALLIES

Back-up troops for a healthy harvest

A growing army of insects, fungi and bacteria is helping crop farmers fight diseases and pests. 'The demand for non-chemical pest control is bigger than ever.'

TEXT MARION DE BOO **ILLUSTRATION** TJARKO VAN DER POL **INFOGRAPHIC** WUR / PETRA SIEBELINK

'Lovely big creatures, aren't they?' says Gerben Messelink of Wageningen Plant Research with enthusiasm. 'They are impressive pillagers!' He displays a petri dish on which dozens of assassin bugs are running round in circles. Wriggling with their long feelers, they check out the Indian meal moth larvae that their menu consists of as long as they are in the incubator. 'Soon they'll be transferred to our gerbera greenhouse to attack the destructive whitefly,' says Messelink.

The assassin bugs prick the young larvae with their proboscis and suck them dry. But they are not choosy and they also like plant juices. So *Verbascum* plants, which the bugs love, are placed next to the brightly coloured gerberas in the greenhouse. This helps these natural allies of the gerbera grower get off to a flying start. Once released, they survive on the crop for weeks and reproduce, keeping the system going. The gerberas stay healthy, and the grower does not have to use chemical sprays against whitefly.

Messelink and colleagues at the WUR Greenhouse Horticulture business unit in Bleiswijk have collected many species of assassin bugs in southern Europe, some of them knocked out of the vegetation in the wild, and some from collections at sister institutes. They are now studying which species performs best in which crop. Some species have a preference for whitefly, and others for leaf mites or thrips.

LESS TOXIC SPRAYING

Such research is sorely needed. Worldwide, farmers and horticulturalists have increased their use of chemical pesticides by a factor of 15 to 20 in the past 40 years. Without crop protection, 85 percent of the harvest can be lost, but the current situation is anything but sustainable. A European directive of 2009 demands that the use of chemical pesticides be cut down drastically. Supermarket chains are even imposing criteria on their producers that go beyond the legal requirements, partly under pressure from environmental organizations that publish annual rankings of the 'cleanest' suppliers of fruit and vegetables.

A further reason for sharpening up the criteria for pesticides was related to the effect on drinking water. At the beginning of this year, the European Food Authority (EFSA) assessed a number of insecticides (known as the neonicotinoids) as a danger to bees, which are indispensable as pollinators in agriculture and >

horticulture. Of the roughly 1000 chemical substances permitted in the European Union, more than half will disappear from the market within a few years, mainly because of sharpened-up environmental regulations. And some chemicals have become dysfunctional because pests have become resistant to them. So biological pest control offers a welcome alternative.

ASSASSIN BUGS AT WORK

In the Bleijswijk experiments, dozens of tomato plants stand in their individual gauze tents. A different species of assassin bug, sourced from Italy, Spain or Portugal, is at work in each of the tents. White granules have been scattered on the leaves. They are meal moth eggs, which the assassin bugs can feed on to start with. But then they are supposed to attack whitefly. Messelink: 'They need to be suited to the crop, the climate in Dutch greenhouses, and the prey they attack and suck dry. We look at the extent of the damage and their growth rate before the pest arrives. And we research whether the assassin bugs themselves damage the crops if they are present in great numbers. Pest damage to the leaves is not such a problem in gerbera and vegetables that are actually fruits, because the grower only harvests the flowers and fruit.'
The assassin bug is not alone. Ichneumon wasps, parasitic mites and numerous other natural enemies of pests and diseases are hard at work in greenhouses too. All growers of fruit vegetables such as tomatoes, sweet peppers, cucumbers and aubergines use biological pest control nowadays. Bumble bees have been released in greenhouses to take care of natural pollination ever since 1988, and bumble bees do not tolerate toxins.
The ornamental plant sector is slower on the uptake because ornamental plants have to look flawless, but

PHOTO ERIK VAN 'T WOUD / HH

A fruit farmer hangs bags of predatory mites among the berry bushes so they can attack spider mites and harmful insects.

even these growers are on the move.
Messelink: 'Our work as researchers is to collect and test suitable natural enemies and find out the optimal conditions for making use of them. What do they need in the way of food and shelter? What is the best way for them to settle and reproduce on a plant? We are working on this together with Koppert Biological Systems and other companies that are focusing on growing and trading in useful insects.'
In total, the Wageningen researchers have identified about 60 species of natural enemy for possible use for pest control in greenhouses. Besides the greenhouse whitefly, pests that have been studied include the tobacco whitefly, the red spider mite, the thrips, and the notorious tomato leafminer moth, originally from South America.

STANDING ARMY

Smart measures are making biological pest control in greenhouses more and more effective. To help them get a head start on their prey, the natural enemies are first given a 'starter package' of alternative foods such as *Verbascum* plants, pollen, bee pollen or whatever else they like, so that they reproduce fast. Messelink: 'We want to work towards a "standing army": you shouldn't wait until you notice a pest to put the natural enemies to work. They need to be at the ready in large numbers in advance. But meanwhile they shouldn't starve, of course. Many people think a modern greenhouse is very sterile, but we actually building a whole ecosystem. We call that functional biodiversity. If, for instance, you want to have a small army of ichneumon wasps at the ready to attack the sweet pepper mite, you can feed them on grain mites for the time being. They don't damage the sweet pepper plant, but you do then have to put grain plants in your greenhouse. Some assassin bugs will feed on brine shrimp cysts, while others like cattail pollen.'
New natural enemies are continuously being introduced into the greenhouses, and the always highly innovation-minded horticulturalists are quick on the uptake. But with globalization, new diseases and pests are arriving all the time too. 'And then you have to look for new natural enemies to combat them,' says Messelink. 'Now, for instance, the tomato russet mite is suddenly becoming a huge problem, and the arrival of the sweet pepper beetle and the brown marmorated stink bug is only a matter of time. It also seems as though pests are settling more easily because crops are grown in the greenhouses all year round these days. The greenhouses are never empty.' >

GLOBAL PEST CONTROL MARKET

The global market for biological pest control (invertebrates and microorganisms) in 2015 was less than 3% of the total pest control market.

Growth in market in next five years

GERBEN MESSELINK
Senior researcher, entomology for biological pest control

'We want to work towards a standing army of natural enemies'

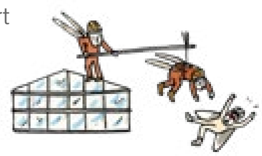
DECADES OF RESEARCH IN WAGENINGEN

1953 Jan de Wilde, professor of Entomology at Wageningen, starts basic research on insect-plant relations, laying foundation for environmentally friendly pest control.

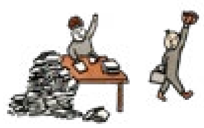
1960 Leen Bravenboer obtains PhD in Wageningen on using predatory mites to combat spider mites in greenhouses.

1970s Naaldwijk Research Station and the universities of Leiden and Wageningen collaborate with Koppert on the biological control of the main greenhouse pests.

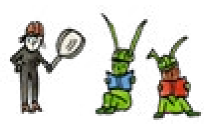
First practical trial with parasitic wasps to combat whitefly.



1983 Joop van Lenteren becomes professor of Entomology at Wageningen and does research on biological pest control.

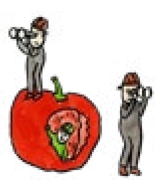


1997 Louise Vet, professor at the Wageningen Entomology lab, studies insect learning behaviour and helps to optimize pest control.



2002 Marcel Dicke, professor of Entomology at Wageningen, studies the interaction between plants and insects, and receives a Spinoza Prize in 2007.

2010 Wageningen collaborates with the university of Lavras in Brazil to find new natural enemies of the tomato leaf miner, an invasive species in Europe since 2006.



2016 Wageningen presents research on earwigs for the biological control of the pear psylla in orchards.

In the BINGO project funded by the EU Horizon programme, Wageningen researchers are looking at genetic variation in useful natural enemies. The aim is to select the most suitable candidates and to 'improve' them by cross-breeding them in a kind of breeding programme.
Abiotic factors such as the greenhouse climate, humidity and lighting are being studied too. For many natural enemies, the dark winter months are a difficult period, while the pest just goes on developing. 'Hyperparasitism' can be a big problem in the spring and summer. Hyperparasites are insects that attack parasites. For example, ichneumon wasps that feed on leaf mites are themselves attacked by other, parasitic ichneumon wasps, which turn up in the greenhouse spontaneously. In the worst case, there is no new generation of wasps and biological pest control fails.
'We are also doing a lot of research on ways of combining biological control with better plant resilience and selective use of pesticides, which you can spray in emergencies,' says Messelink. 'You can make plants resilient against pests and diseases using fungi

'Companies are lobbying in Brussels to speed up the registration procedure, but it's going very slowly'

that grow into the plant and promote its growth. The use of all sorts of bacteria and microbiological communities in the root environment can be effective too.'

HORMONE-LIKE SUBSTANCES

In practice, there are already dozens of such 'bio-stimulators' on the market. Microbes such as *Trichoderma harzianum*, which excrete hormone-like substances, can strengthen roots and thus increase the crop's resilience. In nature, fungi, bacteria, unicellular organisms and nematodes that cause plant diseases are continuously fought by other species. This is known as

MARCEL DICKE
Professor of Entomology

'Plants are highly capable of fending for themselves'

'antagonism', and it limits the damage done by plant diseases. But that natural equilibrium is disturbed when the plants are sprayed with chemicals.
Of course, breeding resistant plant varieties remains another important line of attack. And this is helped by greater insight into insect-plant relations. Wageningen professor of Entomology Marcel Dicke discovered in the late 1980s that some plants 'call for help' when they are being devoured, by emitting signal substances which attract natural enemies such as assassin bugs. 'We are now working with breeders, who are very interested in characteristics such as the production of "cry for help" odours and their molecular markers,' says Dicke. His group will also soon be starting a research project on the effects of coloured light on biological pest control insects.

ESCAPE

Compared with greenhouse horticulture, with its well-controlled conditions and high yields per hectare, the introduction of biological pest control in outdoor cultivation on fields and in orchards is a lot trickier. The conditions are less predictable. If you release a natural enemy into a field of onions, you run the risk that it will make its escape. What is more, the margins in this kind of cultivation are much lower than in greenhouse horticulture.
Dicke: 'We are doing a lot of research in open-air situations on cabbage and mustard. It has become clear that plants are highly capable of "fending for themselves": mustard seed plants on which we let butterflies lay eggs produce just as much seed as control plants that were not exposed to the butterflies.' The plants react to the eggs with faster growth, flowering and seed dispersal. They attract ichneumon wasps and lemonade wasps, among other insects.
Outside the greenhouse, current biological pest control consists primarily of distributing helpful microorganisms. Biological growers work a lot with compost to spread those organisms over their land, and there are special mixtures for sale for boosting 'soil resilience'. More and more growers also make use of flowery field edges in which useful natural enemies can take shelter and survive. Meanwhile they – like the greenhouse horticulturalists – are seeing their 'medicine cupboard' getting steadily emptier due to changing regulations and under pressure from their customers. In 2017, five new biological pest control methods were approved, and only one new chemical pesticide.

USEFUL FUNGI

'The demand for non-chemical disease control is bigger than ever,' says Wageningen plant disease expert Jürgen Köhl of Wageningen Plant Research. Köhl leads the large 12 million-euro collaborative programme Biocomes, in which 14 European institutes and 13 manufacturers have worked closely for four years in a public-private partnership on developing biological pest control for outdoor cultivation. 'In Biocomes, we have mainly looked for useful fungi, bacteria and viruses as natural enemies of their pathogenic relatives,' says Köhl. 'Four years down the line at least 11 biological pest control products for use in open fields are set to come on the market.' Swiss researchers are going to register a highly selective virus as a means of controlling the extremely damaging tomato leaf-mining moth, which has become resistant to a lot of insecticides. An Italian partner wants to register a microbiological treatment for wheat and maize seed. The seed gets a coating which curbs the growth of harmful Fusarium fungi. In Belgium there is interest in new biological pest control organisms >

(parasitoids) for leaf mite in peaches and cherries. Together with the industry, Wageningen researchers are developing a biological spray against true mildew in grains. And German researchers are getting good results with crossbreeding nematodes that combat harmful pine weevils in forestry.

FOUND IN NATURE

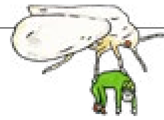
Promising candidates are being found in nature. Köhl himself did years of research on biological control of the Botrytis fungus, economically the most significant pest in a wide range of crops from grapes to cyclamens. After 15 years of field and laboratory research, he had selected the most successful microorganism: a species of fungus that was found in a field of onions. This fungus naturally flourishes on plants without causing any harm, and due to its competitiveness, it curbs the development of Botrytis. Full of pride, the researcher presented his find to the business world. Problem solved? 'The companies were not impressed,' says Köhl with a wry laugh. 'They thought the fungal spores were far too big. To spread

PHOTO TIBOR BUKOVINSZKY

An ichneumon wasp lays its eggs in a cabbage white caterpillar.

THE SAFETY OF BIOLOGICAL PEST CONTROL

In the 1960s, an Asian ladybird was introduced to the Netherlands to combat leaf mites. However, the little insect turned out to eat the larvae of indigenous ladybirds too, and to spread fungi that are deadly for the indigenous ladybirds. Since then the safety protocols have been thoroughly overhauled. Insects for biological pest control are only allowed to be released after a risk assessment that looks at the possible health risks for humans, animals, crops, and nature and the environment.
In theory, the Nature Conservation Law does not allow for the release of animals or their eggs outdoors or in greenhouses. To be allowed to make use of new organisms, suppliers and researchers have to apply for an exemption from the ban. An application of this sort comes with a dossier full of information about the ecology of the species, its 'preferred' prey, the chances of it spreading, and its effects on nature and biodiversity. The Netherlands Food and Consumer Product Safety Authority assesses these dossiers. On the basis of its advice, the Netherlands Enterprise Agency decides whether or not to allow for or against an exemption. Fungi, bacteria and viruses come under a different law, for which the risk assessments are carried out by the Board for the Authorization of Plant Protection Products and Biocides.



enough fungal spores on the fields or in the orchards, you would have to produce a vast amount of valuable biomass. It was a no-go.'

According to Köhl, researchers in the lab focus mainly on effectiveness. 'But there are many other factors involved in making biological control successful.' The researchers brought these criteria together in Select Biocontrol, a successful programme for the systematic screening of useful microorganisms. Köhl: 'The candidate must be safe for humans and the environment. It must be genetically stable and production must be feasible and affordable. There has to be enough of a market for it, you've got to be able to protect it as intellectual property, and there mustn't be an existing patent application by other parties. Of the many microorganisms that demonstrate a promising antagonistic effect, very few candidates make it to the commercial finishing line.'

Köhl applied Select Biocontrol successfully in his research on the biological control of apple scab, economically the biggest pest in the apple orchard. Common varieties such as Elstar and Golden Delicious get sprayed for this 20 to 30 times in the growing season. After some years of research, a new fungus was selected that combats apple scab while fulfilling the criteria, and now a company is working on production and registration.

CUMBERSOME ADMISSION PROCESS

In most countries, the registration process for admitting biological control microorganisms to the market is comparable to that used for chemical pesticides. Köhl: 'It takes about four years and hundreds of thousands of euros, or even millions. In February last year, the European Parliament passed a motion proposing a faster procedure for admitting biological pest control methods to the market. Of course the organisms should be tested to see whether they cause any harm. But you sometimes have to fill in pointless, superfluous details, such as their persistence in the environment, for instance. Companies are now lobbying in Brussels to speed up the registration process, but that is going very, very slowly.' ■

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JÜRGEN KÖHL
Senior researcher, phytopathology

'The demand for non-chemical pest control is bigger than ever'