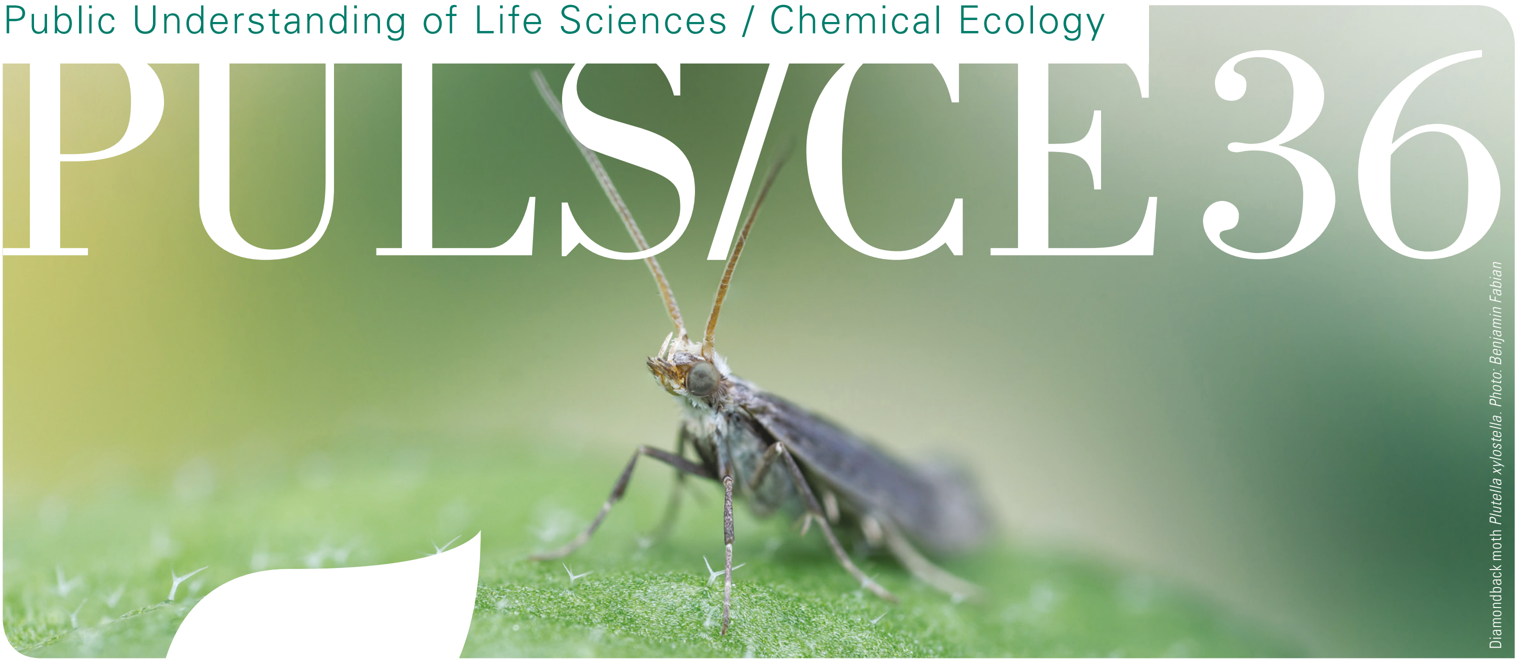
Public Understanding of Life Sciences / Chemical Ecology

PULS/CE 36



Max Planck Institute for Chemical Ecology

Newsletter November 2020

High ozone levels compromise pollination

Tobacco hawkmoths are not attracted to the scent of their otherwise preferred flowers once the scent has been altered by ozone. The toxic oxidant thus disrupts the interaction between plant and pollinator, a relationship that has evolved over millions of years ... **p. 3**

Switching between tolerance and defense

In wild tobacco, plant hormones of the strigolactone group are responsible for fine-tuning the production of plant defensive substances in the stem. Tobacco plants that can no longer produce strigolactones are impaired in their defense against stem-boring weevil larvae ... **p. 4**

Fungal pathogen disables plant defense

The detrimental fungus *Sclerotinia sclerotiorum* is able to detoxify the defense used by cabbage, a mustard oil bomb. Although the defense mechanism is active against the widespread pathogen, the fungus uses at least two detoxification mechanisms to invade cabbage and related species successfully ... **p. 5**

MAX PLANCK
GESELLSCHAFT

Studying insects in the period of human impact

The co-directors and group leaders of the new Max Planck Center (from left to right): Silke Sachse (MPI-CE), Martin Andersson (Lund Univ.), Christer Löfstedt (Lund Univ.), Rickard Ignell (SLU Alnarp), Mats Sandgren (SLU Uppsala), Peter Anderson (SLU Alnarp), Bill Hansson (MPI-CE), Markus Knaden (MPI-CE), Sharon Hill (SLU Alnarp), Susanne Erland (coordinator).
Photo: Mårten Svensson

nGICE

The partners of the Max Planck Center are - apart from the MPI-CE - Lund University and the Swedish University of Agricultural Sciences (SLU).

Insects are largely odor-driven creatures. Therefore, it is crucial to investigate how their olfactory-driven behaviors are impacted by the challenges posed in the Anthropocene.

Climatic changes and atmospheric pollution caused by humans affect natural environmental odors, and thus the odor-mediated behaviors of insects. Altered behavior may change ecological interactions, such as pollination, influence biodiversity and affect natural communities. How insects spread geographically and adapt to new niches is likewise affected by ongoing global and regional changes.

Changes in insect behavior present new challenges not only for agriculture and forestry but also for human health, as diseases transmitted by insect vectors, including malaria and dengue, continue to spread. Each of these aspects depend on insect olfaction and are therefore sensitive to variations in the natural odor space.

In the coming decades, we will face rising temperatures with increasingly frequent weather extremes, e.g. droughts and floods, as well as increasing levels of pollutants. Recent findings suggest that pollutants, such as ozone and nitric oxides, can oxidize odors emitted from plants, and in so doing, drastically reduce effective pollination levels (see Research Highlight, page 3). Intraspecific insect communication via sex- and aggregation pheromones may also be negatively affected by air pollutants, diminishing insects' reproductive success, as well as the ability of natural enemies to locate their prey. Moreover, ozone directly affects the production and emission of volatiles from plants through oxidative stress. However, how these anthropogenic factors affect odor landscapes and the extent to which insects are able to locate them remain unknown.

The three partners of the new Max Planck Center next Generation Insect Chemical Ecology (nGICE) will rely on complementary knowledge, skills and equipment to address this challenge through a novel approach. They have expertise in different insect models: herbivores (bark beetles and moths), insect vectors (mosquitoes) and the best-established insect model, the vinegar fly *Drosophila melanogaster*. Individual insect interactions, as well as the evolutionary and ecological aspects of these species will be the focus. These model systems will be used to elucidate the effects of global change on all levels of insect chemical ecology.

Bill Hansson

www.ngice.mpg.de

High ozone levels compromise pollination

For the last 20 years or so, the term "Anthropocene" has been used in the scientific community to refer to the geological epoch in which humans are responsible for many changes in biological and atmospheric processes.

A team of researchers from the Max Planck Institute for Chemical Ecology and the University of Virginia has investigated whether human-driven ozone pollution in the air influences the attraction of a pollinating moth to the scent of a flower known to be one of its favorites. Using wind tunnel experiments, scientists investigated how *Manduca sexta* tobacco hawkmoths responded to the scent of their otherwise preferred flowers after ozone had altered it. The behavior of the moths in a choice assay between the original floral scent and the ozone-modified odor – an assay that simulated current conditions on hot days in the moths' natural habitat – was alarming: the ozonated flower odors had lost their attractiveness to the moths completely. The question now was whether hungry moths could learn to interpret an initially unattractive scent as a food cue.

The researchers asked whether the moths can learn to associate the ozonated odors with the nectar reward. They used the fact that over short distances moths become attracted to a flower also by using visual cues, even in the absence of attractive odors. When feeding at a visually attractive artificial flower that emitted the ozonated odors, the moths immediately learned the modified flower blend and later became attracted to these ozonated odors also in the absence of visual cues. The observations showed that tobacco hawkmoths quickly learned new stimuli to cope with their rapidly changing environment. What is particularly noteworthy about this responsiveness to a changing environment is that it occurs in real time and not over evolutionary timescales.

Unfortunately, the learning ability of moths demonstrated in the study does not mean the problem has been solved, as air pollution still poses a serious risk to pollination and pollinators. Although learning may be key to insects recognizing their host plants in polluted environments, one of the major questions remaining from our study is whether pollinators will be able to find their flowers in the first place in order to learn pollution-altered floral scents. Another important aspect to consider is that other pollinators may not learn new smells as easily as *M. sexta* has. This study is therefore only a starting point for further investigation. Field studies are going to be critical to understanding which flowers and insects are most affected by which pollutants, and why.

Air pollution and climate change have far-reaching consequences for our ecosystem. So far, little is known about the impact of atmospheric changes on the chemical communication between plants and insects. Not only are plant odors altered but also the sex pheromone female insects use to attract males; the result could lead to mating failure. Insect mortality has risen dramatically in recent years, and researchers worldwide are searching for the causes, including the new Max Planck Center next Generation Insect Chemical Ecology, where two co-authors of this study, Bill Hansson and Markus Knaden, will play a major role in that effort. [AO/KG]

A tobacco hawkmoth (*Manduca sexta*) drinking nectar from a flower of the tobacco species *Nicotiana alata*. The nocturnal moth locates its food source both by smelling the odor and by seeing the strikingly bright flowers. The visual signals of the plant to be pollinated, paired with *M. sexta*'s ability to associate new smells with nectar rewards, may help the insect to compensate for the interference in chemical communication caused by high ozone levels in the air. A highly reactive chemical and pollutant known to cause respiratory diseases in humans, ozone also changes the floral scents that flowers emit to attract their pollinators. *Photo: Anna Schroll*

Original Publication:

Cook, B., Haverkamp, A., Hansson, B.S., Roulston, T., Lerdau, M., Knaden, M. (2020). Pollination in the anthropocene: a moth can learn ozone-altered floral blends, **Journal of Chemical Ecology**, 46, 987–996.

Switching between tolerance and defense

Suhua Li, first author on the study, examines the stem of a tobacco plant in which a larva of the weevil *Trichobaris mucorea* has burrowed. The study shows that strigolactones, which constitute a class of novel plant hormones, do not directly regulate defenses against the weevil but, instead, indirectly use the existing hormonal regulatory networks - here, via jasmonates and auxins - to produce defensive substances that enable the plant to tolerate this herbivore inside its stem. *Photo: Anna Schroll*

Original Publication:

Li, S., Joo, Y. Cao, D., Li, R., Lee, G., Halitschke, R., Baldwin, G., Baldwin, I. T., Wang, M. (2020). Strigolactone signaling regulates specialized metabolism in tobacco stems and interactions with stem-feeding herbivores. **PLOS Biology**, 18(8): e3000830.

Hormones control various processes in organisms. One class of these signaling substances that were only recognized as hormones quite recently are referred to as strigolactones. In plants, strigolactones are involved in shoot formation and inhibit further branching of the stem. As scientists from the Department of Molecular Ecology discovered, a change in the signaling pathway of strigolactones influences processes regulated by other plant hormones, and, as a consequence, a plant's defense against herbivores.

In the field, the scientists noticed that when the pith-feeding larvae of the weevil *Trichobaris mucorea* attacked tobacco plants, the stems turned red because anthocyanin pigments accumulated. In the greenhouse, the stems of transgenic lines impaired in strigolactone biosynthesis and signaling turned red too. Since strigolactones influence branching in plants, and the root-shoot junction of a plant is the initial entry place for the weevil larva on its way into the pith of stem, the team of researchers wanted to know if and how these hormones affect weevil resistance in tobacco.

Studying genetically modified plants that no longer produced strigolactones revealed that these plants were significantly less resistant to *T. mucorea* than controls although an increased formation of jasmonic acid was found. This result surprised reasearchers, because most experts agree that jasmonates have a positive effect on plants' resistance to pests. The absence of strigolactones also affected the production of nicotine, another important defense substance in tobacco. This work breaks new ground by studying how strigolactones interact with the signals of other plant hormones to lead to particular changes in plant metabolites. The special mixture of these metabolites determine - like cocktail drug therapies developed to fight various diseases - resistance to the attacking herbivore.

Studies of plant-insect interactions have so far mainly focused on free-living folivores. The weevil *T. mucorea*, however, spends most of its four-month life cycle inside the stem of a tobacco plant where it feeds on the pith. Apart from the red coloring of the stem, there are few visible signs of attack by this herbivore from the outside. However, the weevil's relatively long life inside the plant means that the insect must be tolerated rather than defended against (unlike a leaf-feeding insect, for example, which would be fended off with defensive substances).

The researchers propose that strigolactones in the plant represent a means of switching between defense against and tolerance of herbivores, a hypothesis that, if confirmed, would also offer interesting strategies for plant breeders. [KG/AO]

A larva of the weevil *Trichobaris mucorea* inside the stem of a *Nicotiana attenuata* plant. *Photo: Anna Schroll*

Fungal pathogen disables plant defense

Scientists in the Department of Biochemistry have long studied glucosinolates and isothiocyanates, special defense mechanisms of plants in the cabbage family. A new study focuses on how plant pathogens overcome these defenses in order to colonize plants successfully.

Researchers were able to show experimentally that the defense based on glucosinolates is actually effective against fungal attacks. However, they also discovered two different strategies used by the white mold fungus to detoxify the defensive substances: The first is a general detoxification pathway that binds glutathione to the isothiocyanate toxins. The second, and far more effective, way to render the isothiocyanates harmless is to hydrolyze them, i.e., to cleave them enzymatically with a water molecule. The aim of the scientists was to identify the enzymes and corresponding genes underlying this detoxification mechanism. Genes that enable the successful detoxification of these substances have been described in bacteria. They are called Sax genes after experiments with the model plant *Arabidopsis thaliana*: Survival in Arabidopsis eXtracts.

The researchers based their search on the known bacterial SaxA proteins to select candidate genes for further investigation. They tested whether these genes are expressed in greater quantities in fungi exposed to the toxins compared to in control fungi, and determined whether the resulting protein can render the toxins harmless. Using high-resolution analytical methods, the scientists were able to identify and quantify the metabolites produced by the fungus during detoxification. They used mutants of the fungus in which the SaxA-encoding gene had been knocked out for comparison. Results showed that the Sax protein of the white mold fungus is active against a range of isothiocyanates, allowing it to colonize different plants of the cabbage family.

Mutants lacking the gene for this detoxification pathway were dramatically reduced in their capacity to tolerate isothiocyanates. The mutants up-regulated the general pathway of detoxification, the glutathione conjugation, although this defense strategy could not detoxify isothiocyanates nearly as effectively as hydrolysis can. It is possible that this general pathway protects the fungus initially, while the machinery required for the more specialized pathway is assembled after initial exposure to the toxin and can take over later in the infection.

In further experiments, the researchers want to investigate how other fungal pathogens successfully detoxify isothiocyanates. They want to find out whether this widespread detoxification is due to repeated evolutionary events in fungi colonizing cabbage, or whether it is a feature that has been conserved over time and is therefore found in many fungal lines. [AO/KG]

The scientist Jingyuan Chen studies the growth of the fungus *Sclerotinia sclerotiorum* on an *Arabidopsis* plant (see also photo below). The fungal pathogen is a devastating pest that infects more than 400 different plant species, causing a disease called Sclerotinia wilt or white mold. White, cotton-like fungal spores cover plant leaves and stalks, causing plants to finally buckle and die. In agriculture, rapeseed is particularly at risk; however, the disease also affects other members of the cabbage family, as well as potatoes, legumes and strawberries. *Photos: Anna Schroll*

Original Publication:

Chen, J., Ullah, C., Reichelt, M., Beran, F., Yang, Z.-L., Gershenzon, J., Hammerbacher, A., Vassão, D. G. (2020). The phytopathogenic fungus *Sclerotinia sclerotiorum* detoxifies plant glucosinolate hydrolysis products via an isothiocyanate hydrolase. **Nature Communication** 11: 3090

The first human footprint discovered at Alathar. *Credit: Stewart et al., 2020*

Ancient human footprints in Saudi Arabia provide snapshot of ecology in Arabia 120,000 years ago

Using high resolution paleo-ecological information obtained from fossilized footprints, a team of researchers led by Mathew Stewart of the Max Planck Research Group Extreme Events was able to demonstrate that human and animal footprints found in an ancient lake bed in northern Arabia are approximately 120,000 years old. The findings, which represent the earliest evidence of humans in this part of the world, show that human and animal movements and the use of the landscape were closely linked. [MPI-SHH]

Original Publication: Stewart, M., et al. (2020) Human footprints provide snapshot of last interglacial ecology in the Arabian interior. **Science Advances** 6: eaba8940

The African cotton leafworm Spodoptera is a food generalist and feeds on many different plants. Extensive analyses demonstrated that the chemical defense of tobacco plants is a directed response to herbivore attack. *Photo: Danny Kessler*

Statistical analyses of plant metabolites allow solid testing of plant defense theories for the first time

Do plants attacked by herbivores produce substances that are effective against attackers in a targeted manner, or are herbivore-induced changes in a plant's metabolism, which could thwart the performance of herbivores, random? Scientists from the Department of Molecular and University of Strasbourg tested these hypotheses using the coyote tobacco *Nicotiana attenuata*. They combined extensive measurements of known and unknown plant metabolites using mass spectrometry with statistical measures derived from information theory. The results show that plants regulate their metabolism directionally to produce effective defenses. A comparative approach using different populations and closely related species demonstrated that the amount of certain plant hormones is crucial for the directionality of the plant's response to its enemy. [KG]

Original Publication: Li, D., et al (2020). Information theory tests critical predictions of plant defense theory for specialized metabolism. **Science Advances** 6: eaaz0381

Section of a wild tobacco leaf infected with the fungal pathogen *Fusarium brachygibbosum*. *Photo: Maitree Pradhan*

How an argonaute protein controls tobacco's defense against fungi

An argonaute protein (AGO4) is responsible for how tobacco plants adapt their defense to fungi of the genus *Fusarium*. This was revealed by researchers from the Department of Molecular Ecology. During a fungal infection, small pieces of RNA (smRNA) are reprogrammed, dependant on AGO4, and thus they influence the network of plant genes involved in the formation of jasmonic acid and other metabolic processes. Jasmonic acid is an important signaling substance for activating defense mechanisms. Plants lacking the AGO4 protein are therefore more susceptible to the fungal pathogen. [AO]

Original Publication: Pradhan, M. et al. (2020). Argonaute 4 modulates resistance to *Fusarium brachygibbosum* infection by regulating jasmonic acid signaling. **Plant Physiology**. 184, 1128–115

A changing mating signal may initiate speciation

When choosing a mate, females of different subspecies of *Drosophila mojavensis* recognize the right mating partners either by their song or by their smell. This connection was discovered by researchers from the Department of Evolutionary Neuroethology and their collaboration partners. A specific male sex pheromone, which is produced only by males from two of the four subspecies, is crucial for the mate choice of the corresponding females. Females from the subspecies in which the males no longer produce this pheromone are also able to perceive the chemical messenger, but for them the specific mating song is more important than the males' smell. New species apparently evolve when the chemical mating signal is altered and then when the signal is reinterpreted by the opposite sex in the context of other signals, such as the courtship song. [AO/KG]

Original Publication: Khallaf, M. A., et al. (2020). Mate discrimination among subspecies through a conserved olfactory pathway. **Science Advances**, 6: eaba5279

Mohammed Khallaf studies the evolutionary neurobiology of sexual communication in vinegar flies. *Photo: Anna Schroll*

Diamondback moth uses plant defense substances as oviposition cues

A research team from the Nanjing Agricultural University in Nanjing and the Department of Evolutionary Neuroethology showed that isothiocyanates produced by cruciferous plants to fend off pests serve as oviposition cues. The plant defense substances are interpreted as odor signals by females of the diamondback moth, cueing them to lay their eggs on these plants. The scientists identified two olfactory receptors whose sole function is to detect these defense substances and to guide the moths to ideal oviposition sites. They uncovered the molecular mechanism that explains why some insects that specialize in feeding on certain host plants are attracted by substances that are supposed to keep pests away. [AO/KG]

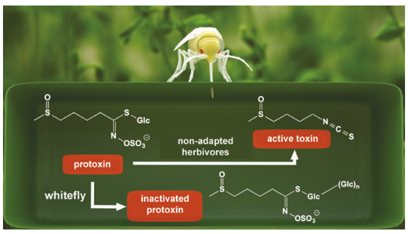
Original Publication: Liu, X.-L., et al. (2020). The molecular basis of host selection in a crucifer-specialized moth. **Current Biology**, doi: 10.1016/j.cub.2020.08.047

Diamondback moth *Plutella xylostella*: The pest insect, which is widespread throughout the world, is adapted to the defenses of cabbage and related crops. *Photo: Benjamin Fabian, MPI-CE*

Surplus sugar helps whiteflies detoxify plant defenses

An international team of researchers, including some from the Department of Biochemistry, has been able to prove that the sap-sucking whitefly *Bemisia tabaci* can activate the chemical defenses of crucifers. However, the pest is able to render many of the plant toxins harmless by binding surplus sugar to them, which has to be metabolized anyway. The whitefly thus deploys a completely new and until now undescribed detoxification mechanism to defuse the plants' defenses, which could explain the success of this major agricultural pest and its ability to cause crop losses in the billions of dollars. [AO/KG]

Original Publication: Malka, O., Easson, M. L. A. E., et al. (2020). Glucosylation prevents defense activation in phloem-feeding insects. **Nature Chemical Biology**, DOI 10.1038/s41589-020-00658-6



The detoxification process in the whitefly: The protoxin (glucosinolate) is inactivated when an additional glucose group is bound to it. *Graphic: Kimberly Falk, Moves like Nature*

Background photo: Karsten Zunk

New online seminar series "Scientists explain!"

Because of the Covid-19 pandemic, many institute activities are being held online, including our MPI-CE seminar series. On October 22, 2020, a new online format was launched: "Scientists explain!". In this series, young researchers from the Max Planck Institute for Chemical Ecology present entertaining talks on current research projects. The talks – a mixture of German and English presentations – are broadcast live in our YouTube channel and will continue to be available for viewing after the live broadcast.

Martin Kaltenpoth becomes new director at the MPI-CE. He will succeed David Heckel, who will become emeritus in March 2021. *Photo: Norbert Michalke*

Martin Kaltenpoth to become new director

The Max Planck Institute for Chemical Ecology is happy to welcome a new director: Martin Kaltenpoth was appointed Scientific Member by the Max Planck Society in March. The current Chair of Evolutionary Ecology at Johannes Gutenberg University in Mainz will initially perform his new duties as a secondary appointee and plans to establish his new Department of Insect Symbiosis in Jena starting in February 2021. An evolutionary biologist who headed a Max Planck Research Group at the MPI-CE from 2009 to 2015, Kaltenpoth investigates symbioses between insects and microorganisms. These are ubiquitous in nature and play an extremely important role in the ecology and evolution of their hosts. For example, bacteria are important for opening up new habitats, digesting food and providing defenses against enemies. Martin Kaltenpoth wants to understand symbiotic partnerships from single molecules to the fitness consequences of the interacting partners under laboratory and field conditions. The goal of his research is to characterize the diversity of bacterial symbionts in insects and their importance for the ecology of the hosts, and to understand the evolutionary origin of these relationships.

Aleš Svatoš. *Photo: Norbert Michalke*

Aleš Svatoš receives the Silverstein-Simeone Award of the International Society of Chemical Ecology

Aleš Svatoš was selected to receive the Silverstein-Simeone Award of the International Society of Chemical Ecology (ISCE). The Society honored the organic chemist and head of the Mass Spectrometry/Proteomics Research Group for his outstanding achievements in developing new chemical and spectrometric methods for cutting-edge research in chemical ecology. Svatoš has developed techniques for the structural characterization of olefinic compounds, such as pheromones and terpenes. His services to the ISCE, which he has been a member of since 1993, are also recognized. He has organized mass spectrometry courses and an "omics" symposium for junior scientists as part of the Society's annual conferences.

www.chemecol.org

www.ice.mpg.de

MAX PLANCK GESELLSCHAFT

Impressum: PULS/CE is published semi-annually and can be downloaded free of charge on the homepage of the MPI for Chemical Ecology and is distributed electronically as PDF to subscribers. A print version will be sent on request.
Editor: MPI-CE, Jena • Managing Director: Prof. Dr. David G. Heckel (viSdP). Editorial Staff: Dr. Karin Groten, Research Coordination • Angela Overmeyer, M.A., Information and Communication • Emily Wheeler, Editing
ISSN: 2191-7507 (Print), 2191-7639 (Online)